A Taxonomy for the EO Services Market:

enhancing the perception and performance of the EO service industry

Rationale

EARSC's extensive engagement with Earth observation user communities has highlighted the need for a common language to help service providers and users arrive at a mutual understanding of the types of services that can be offered and the benefits that can be delivered. We have developed an Earth observation taxonomy that is not only a process of naming and classifying the EO services but additionally a tool to improve the understanding between these communities.

Under this context, this document presents a reduced version of the Del 4.3. from the CopHub.AC H2020 project, which outlines the third update of the EARSC taxonomy. The EARSC taxonomy has been carefully reviewed and includes for the first time a generic definition of available products and how those form the basis for the delivery of the EO services (the combination of e.g. EO products, in-situ data, modelling etc. to deliver contextualized knowledge to a service user). This taxonomy update, from both the market and thematic perspectives, has been conducted in close collaboration with the research community through the CopHub.Ac project.
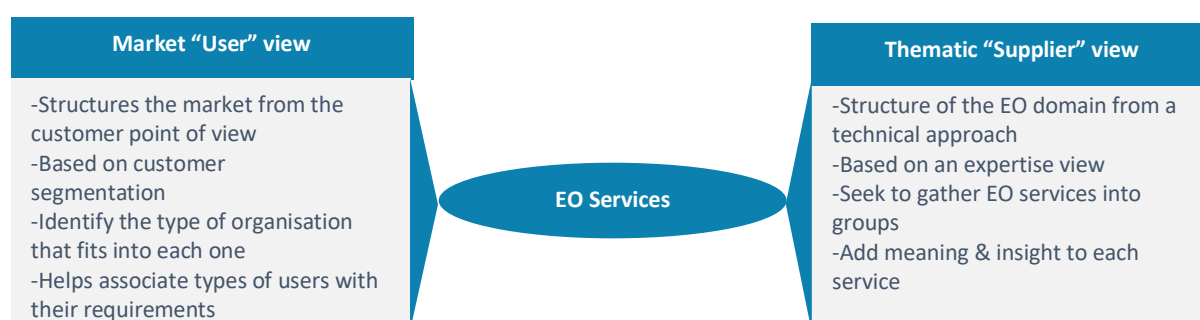
Inside this taxonomy, each catalogue of services contains specific services offered to citizens, business, government and other organisations. The taxonomy should be continuously updated to ensure its continued relevance in a fast-changing sector. We have made every effort to ensure that the structure is sufficiently robust to accommodate future market segments and thematic topics; as the market changes and grows, these changes will need to be incorporated in future taxonomy updates.

We look forward to receiving stakeholders' feedback and working with stakeholders in continuing this exciting evolution of the description and structuring of EO services.

Executive summary

For any sector providing services, reaching a community consensus on terminology is a prerequisite for ensuring a common understanding of the information exchanged among different stakeholders. Knowledge exchange among users of geo-information services presents many challenges and the development of a "knowledge-driven" approach is considered by the Earth Observation (EO) sector to be one of the milestones for embracing its diverse group of stakeholders. This update of a user-oriented taxonomy focuses on the translation between the world of the providers of EO services and the world(s) of their users. It provides a structured view of the uptake for EO services; it brings together the products and services which are offered by suppliers and maps those to the market sectors and needs to which those products apply.

Taxonomies[1], ontologies[2], inventories[3], different types of body of knowledges (BoK)[4] or controlled vocabularies[5] are the preferred means to achieve such a "common understanding" by identifying the terms of the domain and structuring the sector through semantic relationships, preferably with a focus on the end "user". Under this foundation, the European Association of Remote Sensing Companies (EARSC) recognised a need to structure the "offer" of the sector, its products and services for the actual use of the communities from whom these offers are intended, the "uptake". EARSC prepared and issued a first version of the Taxonomy for the EO Services Market in February 2012 and revisited the document in August 2015[6]. This taxonomy provided guidelines of clear and common descriptions of products and services helping suppliers and users arrive at a common understanding of what can be offered.

Market "User" view		Thematic "Supplier" view
-Structures the market from the customer point of view -Based on customer segmentation -Identify the type of organisation that fits into each one -Helps associate types of users with their requirements	EO Services	-Structure of the EO domain from a technical approach -Based on an expertise view -Seek to gather EO services into groups -Add meaning & insight to each service

EARSC representation of "User" and "Supplier" view

This report presents and explains the rationale for the proposed EO taxonomy update and to address the common products and services from two perspectives: the market view and the supplier view.

The **market view** provides a tool to help classify and understand the markets for EO services as well as to define the type of customer. The representation of market stakeholders in the use of value-added services and applications is the core of this section. It focuses on user needs and the use of Earth observation from the users' point of view.

The "market taxonomy" has been upgraded reflecting the evolution of the sector and how the user groups are structured. One of the developments is the split of the market "public and international bodies" into other sectors. Within these organizations, their employees provide or make use of the

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[1] Taxonomy formalizes the hierarchical relationships among concepts and specifies the terms to be used to refer to each; prescribes structure and terminology (ref Medium article by S. Garfield, 2019)

[2] Ontology identifies & distinguishes concepts and their relationships; (ref Medium article by S. Garfield, 2019)

[3] Inventory is the listing of items; it requires some form of classification unit or individual entities to count (https://bit.ly/2HA4lGq)

[4] Body of Knowledge (BoK) is the complete set of concepts, terms and activities that make up a professional domain, as defined by the relevant learned society or professional association. Type of knowledge representation by any knowledge organization (ref link Wikipedia).

[5] Controlled vocabulary is an organized arrangement of words and phrases used to index content and/or to retrieve content through browsing or searching (ref link). More info on the Glossary section

[6] EARSC taxonomy for EO services market V1 and V2 (http://earsc.org/file_download/489/A+Taxonomy+for+the+EO+Services+Market+issue+2+%282%29.pdf)

EO services for sector-specific applications such as public administration activities assisting "environmental, climate change or health security" policy making decisions or actions in the "defence & security" sector, especially under emergency and social protection. Our latest findings on the "survey into the state & health of the sector"[7] revealed a significant increase in the activities specific for different groups of users. Such was the growth in the "defence and security" segment, that even if we consider it explained by the weight of big contracts from big players in this sector, we decided to consider it in this revision as an independent sector. Other new independent market segments recently incorporated include "urban planning", supporting the activities of many service providers in the public sector, and "citizens & society" with so many people now carrying a mobile application in their pockets able to visualise applications based on EO data. The latter has not been reflected in the previous taxonomy but gained relevance being a direct "user" of special EO services available through Apps. The Figure below represents the upgraded taxonomy with the Market (User) perspective.

EARSC Taxonomy (Market /User) perspective (2020)

[7] EARSC EO Industry Survey Report (2019) (http://earsc.org/file_download/568/Industry+survey+2019+final+version+07_11_2019.pdf)

The **thematic view** provides a tool to help describe and classify the services and products that are offered by the service providers. The "thematic perspective" deals unambiguously with a thematic application area[8] (i.e. agriculture), which is not linked *per se* to the processing or acquisition of EO (or indeed, other kinds of) data or, quite naturally, to activities further upstream (i.e. satellite and sensor design or manufacture), instead the source focuses on concepts, challenges and applications in a specific domain (e.g. agriculture) or thematic segment (agriculture monitoring).

During the upgrade of the taxonomy, the structure of the thematic perspective was reviewed. The updated structure of the taxonomy thematic viewpoint allows for 4 levels/tiers in the description of EO services from the supplier side point of view. The Table below presents the EO services structure.

<div align="center">EO services structure</div>

Level 1	**Thematic classes (DOMAIN)**	Single block of knowledge (big category of objects)	Largest conceptual category (typically nouns) covering all known areas of EO services from the supplier's point of view. The EARSC taxonomy contains 6 classes.
Level 2	**Thematic segment (AREA)**	Set of EO services (greater detail of objects)	Classifies concepts in greater detail, i.e. different segments. The upgrade proposes 31 areas compared with the 25 in the previous taxonomy. Description is tackled in the <u>thematic section</u>.
Level 3	**EO Service (SERVICE)**	Purpose of the information	EO services (sometimes considered applications by service providers) propose an action or a sequence of actions (specific events appropriate in a given situation, e.g., "assess the environmental impact of farming". For example, it unifies major entities such as environment, agriculture or deeper in granularity such as crops. The range today covers more than 80 services (see the section "<u>Structuring the EO services</u>" and the thematic taxonomy at the EARSC portal[9])
Level 4	EO Application	Specific for a geographical area, timeline, etc.	This level presents set **keywords** which in effect define the **products** which make up a service (key words are also considered in our taxonomy to represent **products, parameters** or **essential variables**).
	Products	Describe tangible satellite-based data products	
	Parameters & Essential Variables for the land, atmosphere and ocean	Information elements derived from EO data key *parameters* of the *Earth* and the environment	

While the major classes of the thematic taxonomy have not been adapted (**Level 1**: Six major thematic classes: atmosphere & climate, built environment, disasters & geohazards, land, marine & ocean, security & safety), the thematic areas in the **Level 2** have been slightly adapted through the addition of "climate change" under atmospheric a climate section, the specification of "biodiversity and ecosystems" for both marine and land segments, "food production" under defence and security, and adding, under the built environment thematic classes, dedicated segments on "networks" and "waste". **Level 3** includes a revision in the thematic areas adding a description of EO Services, based on the feedback from thematic experts who have been consulted. For example, under "climate change" we have integrated elements related to "climate change monitoring, mitigation and adaptation". In "built environment" domain we added a dedicated item on "urban settlements assessment". The area dedicated to "multi-hazard assessment" was included as an EO service at the request of experts in the "disasters & geohazards" domain. Better descriptions and additions complement the **Level 4** descriptions; provision of keywords such as "monitoring risk factors, fire weather index, flood map exposure" and inclusion of "early warning", in the "disaster & geohazards" domain. Concerning the land domain, we have incorporated a shift in the meaning of the concepts such as "measure land use statistics" in the sector, replacing "land accounting" or minor details such as replacement of "water level" with "surface water dynamics". The Figure below provides the main structure of the taxonomy from the thematic perspective.

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[8] Exploring sectoral uptake of Sentinel data within academic publications (http://earsc.org/Sebs/wp-content/uploads/2020/03/SEBS-A-Task-1.1_2020_v01_submission.pdf)
[9] EARSC portal (<u>https://earsc-portal.eu/pages/viewpage.action?pageId=15794378</u>)

EARSC Taxonomy (Thematic / Provider) Perspective (2020)

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1. Introduction

> *"If you don't know the name of the things, the knowledge of them is lost"*
> *Carl Linnaeus*

The Earth Observation (EO) sector is rapidly evolving. The increase in a number of satellite constellations, platforms and the impact of a range of relevant emerging technologies creates a vibrant space for the development of new services and capabilities. Bringing these new services to their relevant markets requires a common understanding of the problems addressed and the solutions proposed between the solution provider and the market user. Mutually acknowledged taxonomies or other types of controlled vocabularies, specifying the terms of the domain and structuring it via relationships, can achieve such a common understanding. Table 1 summarises the importance of a sector taxonomy.

Table 1- Why a taxonomy?

WHY A TAXONOMY? ©EARSC taxonomy	- tool to improve the **understanding between communities** - process of **naming, classifying, categorizing** and **structuring** EO services and products - clear and **common description** of the knowledge landscape (ontologies, taxonomies, associations of concepts/terms, classifications, keywords) - add **meaning** and **insight** to each service and helps associate various types of content - taxonomy is **evolving** based on sector developments, market needs. It is never a "finished document" - accepted, comprehensible, useful, repeatable

It is important to note that many activities have been conducted for the improvement of the EO and Geoinformation Systems (GI) semantics and data interoperability such as the work is done by DiBiase et al. (2006)[10] in developing the Body of Knowledge (BoK) hierarchical structure with concepts and methods, by Nagai et al. (2012)[11] on an ontology registry and the semantic interoperability, and by Ahearn et al. (2013)[12] who proposed an extension of DiBiase's BoK. The evolution on this type of work continued and Gruber et al. (1993)[13] suggested ontology specifications which would help the community of service providers to harmonise catalogues of services in the context of knowledge sharing or the specification of a conceptualization of ontologies. Arvor et al. (2019)[14] advised on ontologies to interpret remote sensing images so the work on ontologies made a step in the Earth Observation sector. Many pieces of work in the "taxonomy" and "ontology" domains, in addition to the ones mentioned above, have informed and guided EO ontological development. Recent work made under the context of the EO4GEO[15] project is revolutionising the BoK providing the links with business processes and innovative skills development in both the EO and GI sectors. This work is reflected in the paper from Stelmaszczuk-Górska et al. (2020)[16] which is closely connecting the development of the BoK, integrating EO concepts and the EO uptake. One commonality across all

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[10] DiBiase et al. (2006) https://www.ucgis.org/assets/docs/gist_body_of_knowledge.pdf
[11] M. Nagai et al. (2012) https://www.isprs-ann-photogramm-remote-sens-spatial-inf-sci.net/I-2/235/2012/isprsannals-I-2-235-2012.pdf
[12] Ahearn, S. et al. (2013) https://www.tandfonline.com/doi/abs/10.1080/13658816.2013.802324
[13] Gruber et al. (2013) https://tomgruber.org/writing/ontolingua-kaj-1993.pdf
[14] Arvor et al. (2019) https://www.tandfonline.com/doi/full/10.1080/15481603.2019.1587890
[15] EO4GEO project aims to help to bridge the skills gap between supply and demand of education and training in the EO/GI sector
[16] Stelmaszczuk-Górska, et al. (2020) Body of Knowledge for the Earth observation and geoinformation sector - a basis for innovative skills development, ISPRS 2020 issue.

approaches is that ontologies include essential vocabulary together with a specification of the meanings from the vocabulary representational form Robert et al. (2020)[17].

The EARSC taxonomy includes an identification of the fundamental EO categories considered independently of the market/user or thematic/application approaches but also the relationship between categories. The taxonomy effort is a process of naming and classifying the EO services and products as a tool to improve the understanding between communities while the specific ontology analysis is a process of defining vocabulary, representation of knowledge and making relationships. This update of the taxonomy will further improve the accessibility of the EO services, ensuring shareability and reusability among the different taxonomy approaches in the geoinformation sector and facilitating a common description of the knowledge landscape and the relevant EO products and services.

2. Terminology & Methodology

Service providers and potential end users can better access and use EO services when information about these services is organized into categories and subcategories within a hierarchical taxonomy. A quick review shows that there are many, different taxonomies in use and no standard exists in the EO market today. Of the various taxonomies that exist some are organised around customers and markets and some products and services. Our goal is to provide an update of the EARSC taxonomy, a single unified structure with mapping across both market and thematic perspectives (hybrid approach), to ensure the most complete representation possible. Hierarchical taxonomies require a lot of consultation, research and testing to design well. That is why we highlight the exchange, discussion, and the contribution of the experts to consolidate the outcomes presented herein. This chapter is about the importance to use the same terminology and the way to approach the users.

2.1. Using a common language

Changing something requires understanding it first. For the user uptake, it is necessary to understand why users engage (or do not engage) with the EO services. A particularity of the EARSC taxonomy is the existence of "verbs to define the object" but also the "use of verbs to communicate the actions" that the final users need to understand in the elaboration of the services.

2.1.1. Common language: Approaching the users

Building on a common understanding of the user needs will undoubtedly increase the uptake of EO applications in a wide range of market sectors. Two common gaps are identified that can significantly limit the exploitation of the taxonomy by external users: **the lack of awareness** and the **lack of collaboration between stakeholders**. Taking the first point, this exercise exposes the taxonomy to other communities and provides somehow the definition of the "EO service" and its structure which is commonly applied into the EO terminology and their usage within different market sectors but also with different groups such as the academia and research communities. Consequently, we could progress with the second gap solution engaging these stakeholders in the process.

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[17] J. Robert et al. (2020) https://bit.ly/2P4rzc2: Representational vocabulary is expressed as "essential vocabulary"

Based on Bloom et al. (1956)[18] and the recent revision made by EO4GEO partners Hofer et al., (2020b)[19], the assimilation by end users follows the levels of behaviour in learning which classified six levels of cognitive performance. Thus, every process engaging another community should follow a "learning approach" and the six levels of iteration as presented in Figure 1.

Figure 1: Bloom taxonomy and the engagement with communities.

So, the process will go from "remembering & understanding" to "evaluating & creating". The exchange with the users allows them to reflect on their particular challenges and fully understand why EO services may be a solution for their needs. In the same line of discussion, Schutzberg et al. (2012)[20] evaluates the actions and the skills as the ability to apply knowledge and use know-how to complete tasks and solve problems.

Concerning this common language, in activities where EO data is used there are three main action verbs which collaborate to deliver the "information" as a result; "understanding" the basic parts of a map, and "analysing" the relations with spatial criteria (or "creating" or "applying" EO intelligence in another domain). In this type of discussion, the focus is on the output (from Data to Information towards Knowledge to Wisdom (**DIKW**)). Table 2 reflects on the transition from "data to information" some action verbs are "collect, store, process, display" in line with the verbs used to formulate skills needed to deploy different tasks. The section "knowledge to wisdom" corresponds to other action verbs such as "analyse, evaluate, create, apply" developing a shared understating from "the needs to the solution".

Table 2- Data Information Knowledge Wisdom

DIKW	Question	Description
Data & Information	**What** data?	Refers to geospatial data content, including its quality and usability. How the data is consistently (temporally/geographically) collected and how it is "made" with a certain the level of accuracy and confidence (spatial, temporal and spectral resolution). The validation and uncertainty assessment is a crucial requirement from the end-user perspective of a satellite data product (Otto et al., 2016)[21]. For the "land" domain Justice et al., (2000)[22] defined the validation of data as "the process of evaluating (by independent means) the accuracy of satellite-derived land products and quantifying their uncertainties by analytical comparison with reference data".
Knowledge	**How** and what type of access?	Final or intermediate users request the information be structured in some meaningful way so as to convey facilitate decision making. The data are represented in such a way, e.g. accessing and integrating the defined data layers to produce geospatial information, developing data models as to allow a justifiable belief in the user, through which decisions can be made.
Wisdom	**Why** the user needs that information?	It is related to the user of the information products derived from the data (as well as data models) across vertical markets but also amongst key user communities. The wisdom generated through the EO data service provision is the justifiable belief in the state of the world, based on the knowledge generated from the data, from which sound decisions can be made.

[18] Bloom, B. (ed.) et.al. 1956. Taxonomy of Educational Objectives. The Classification of Educational Goals: Handbook 1 Cognitive Domain. Longmans, New York

[19] Hofer, B., Casteleyn, S., Missoni-Steinbacher, E.M., Aguilar- Moreno, E., Albrecht, F., Lemmens, R., Lang, S., Albrecht, J., Stelmaszczuk-Górska, M.A., Vancauwenberghe, G., Monfort- Muriach, A., 2020b: From Tasks to Concepts and Skills - Complementing the Body of Knowledge with a Business- oriented Perspective. Transactions in GIS. (accepted)

[20] Schutzberg et al. (2012) http://blog.abs-cg.com/2012/06/flipping-blooms-taxonomy-in.html

[21] Otto et al., (2016) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017RG000562#rog20135-bib-0090

[22] Justice et al., (2000) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017RG000562#rog20135-bib-0055

	What type of EO user?	

Ideally, verbs indicating concrete actions should be used to describe the tasks to be performed during the process of producing the EO service from the "processing" to the "distribution". Users will be capable of exploiting such verbs facilitating the identification of service steps and its structure. The section on "actionable verbs" below introduces the most commonly used verbs when defining the EO services.

2.1.2. Common language: Building EO services (data and products)

Following Hartman et al. (2016)[23], we found key definitions to improve the descriptions and manipulation of the data and its use to produce value-added products from the raw data involving the typical workflow for any EO data user (data collection, processing, analysis, distribution and use). The EO services consist of a portfolio of different products that are derivatives of the data provided by the space component, modelling, or in-situ data. Herein the EO services (defined here as delivering a specific type of analysis) and applications (defined herein as delivering that analysis applied specifically to one region/user or time) are defined as being built by products and parameters or essential variables (see Section: 2.1.4: Taxonomy definitions). To better understand the EO products, the following sub-sections will outline the (pre-)`processing stages and the language adopted in this report to describe EO services.

2.1.2.1.   Data collection

Handling the acquisition planning from sensors with the direct downlink and reception of data from the satellites to the data collection and discovery of the dataset. It is about the understanding the data and the content, its downloading or working on the cloud with the corresponding imagery which is normally done on demand through planning with the suppliers which are matching different acquisition scenarios with data acquisition approaches. These processes also cover the ingestion of meta data and browse products, for some sensors augmented by cloud masks, into other catalogue system (data pool enlarged by the inclusion of other sensor data acquired by some different ground stations). The data collection catalogues permit fast data availability analyses and in-depth data searches for small and large areas of interest worldwide.

2.1.2.2.   Data processing

To turn data into knowledge (data into EO service), first the observational data need to be acquired by satellite instruments and downloaded to ground stations in a raw format. These pre-processing levels are described in Table 3 (drawn from the ESA[24], WMO [25], NASA[26] USA data center[27] definitions. For example, "pre-processing" strictly speaking refers to data preparation on L0-L1, while L2-L4 corresponds to "processing". Overall data processing[28] includes pre- and post-processing of imagery into usable products (creating a spectral and/or spatial subset), registering the data to a geographic projection and removing atmospheric distortions.

Table 3- Definition of processing levels (pre-processing & processing)

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[23] https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2017RG000562
[24] https://business.esa.int/newcomers-earth-observation-guide
[25] http://www.wmo.int
[26] https://science.nasa.gov/earth-science/earth-science-data/data-processing-levels-for-eosdis-data-products
[27] https://nsidc.org/the-drift/2013/08/is-it-1b-2-or-3-definitions-of-data-processing-levels/
[28] data processing services include: orthorectification, atmospheric and radiometric correction, cloud free image mosaic generation, datacube productions, ancillary data formatting and fusion, multiscale, multi-source image analysis, quality validation procedures, geographic analysis, modelling procedures, automated dissemination mechanisms

Category			Level	Definition		Description
pre-processing			0	**Data preparation levels**[29] **(L0-L2)** Transforming data into a form suitable for analysis, including operations such as atmospheric correction, cloud detection and radiometric calibration	**Raw** telemetered data	Unprocessed instrument (raw) data (removed communication artefacts)
			1		Instrument data extracted, **geolocated and calibrated**	**1A)** prepared for geolocation and radiometric calibration. Product resampled onto a cartographic grid. Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters **1B)** geolocation and calibration. Data processed to sensor units *(e.g. brightness temperatures // data corrected for instrumental and geometrical effects)* **1C)** instrument specific *(e.g. brightness temperature (IR) or Reflectance factor (VIS)...)*
processing	value added		2		Data corrected for **geophysical** (cartographic) effects	Derived geophysical parameters at the same resolution and location of the source data (referenced & calibrated) *(e.g. sea ice concentration, land and sea surface temperature (SST), precision images and mosaics, humidity, radiative flux, ocean colour, quality index)*
		big data analytic	3	**Composite products** based on **space-time grid**		Ortho-rectified data acquired during a certain period of time. Quantity retrieved from single instrument data. Variables mapped on uniform space-time grid scales, usually with some completeness and consistency. *(e.g. mosaic, maps (temporal & spatial interpolation)*
		information products	4	**Composite multi-sensor** and/or **multi-satellite product**		Model output, results or variables derived from multiple measurements or from analyses of lower-level data (e.g., variables derived from multiple measurements or model analysis) *(e.g. ocean primary productivity, or the production of a flood map which depends on land surface imaging, various wind speed measurements)*

The ESA ground segment[30] website describes "**pre and processing data information**" as the **data** that includes the imagery transmitted from the satellite to the ground receiving Earth station, plus the effort associated with conditions (cloud cover, snow, look-angle), or the products such as stereo imaging and basic corrections (radiometric, geometric). The pre-processing products result from calibration, geolocation, remapping and dynamics adjustment of Levels 0-1 data and the imagery products are used for further processing. Some processing is nowadays automated involving different processing steps, such as orthorectification, bundle block adjustment, radiometric adjustment and topographic normalisation. Those are data streams right through to the extraction of ready-to-use geo-information products.

2.1.2.3.   Data analysis

Data analysis and interpretation are often considered under processing, covering the full range of activities on analytical work, aggregation where the combination with other information such as environmental data layers, model outputs or in situ data is done, the visualisation or distribution of data. In the previous Table3, the generic term of **value adding products** corresponds to the Levels (L2-L4) where processing and applications transform raw data into information. **Big data analytics** includes the processing and application-specific analysis of multiple images and a wide variety of datasets to extract information not apparent in the base data input (L3). These products often include an analysis of a given area over a period of time permitting the extraction of trends, or an indication of changes and developments and (L4) is represented by **information products** include processing and applications-specific analysis that add (typically) domain-specific value to the information. At these levels, imagery cost represents an essential, but not major, a portion of the final product and /or service (integration of datasets) (L4) price. Table 4 represents the data analysis section focus only on the analytical component.

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[29] https://www.e-education.psu.edu/geog480/node/497
[30] Commercial Ground Segment at ESA

Table 4- Data analysis categories

	Category	Description
Processing	**Analytics - Descriptive**	Providing analytical results which describe the past and present situation by actual measurement (what happened?) *[e.g. generic maps, derivation of NDVI, derived elevation (terrain information, topographic), deformation & displacement (near surface geology, change detection, continuous monitoring), detected features (land use, land cover), …]*
	Analytics - Predictive	Providing analytical (modelling, insight, what will happen?) results which estimate missing values by interpolation techniques or predict the future situation *[e.g. forecast (air quality/pollution), estimate fluxes, climate forecasting…]*
	Analytics - Prescriptive	Providing analytical results which (foresight, how can we make it happen?), it is about decision support and automation, stipulate a guide to an action *[e.g. actionable as construction sites leading to sales opportunities (impact assessment, route planning, optimization, …]*

Data providers produce accurate geometrically and radiometrically optimised data products in the required formats and specifications ready for the analysis. The actual analysis is done by service providers or experienced users with the relevant expertise and technical skills.

2.1.2.4. Data use

The resulting geo-information products may consist of a combination of reports, statistics or maps with actionably purposes, reflected in the thematic domains, consequently the thematic taxonomy is bridging the experience form the service provider for a particular need or challenge directly to the user "integrate data easily, geographically enhance information, increasing the power of information by merging data and publishing the enhanced data for its final use".

The data use under specific usage and license agreements often depends on aspects such as data aggregation, visualization and distribution showed in Table 5.

Table 5- Data use categories

Category	Description
Aggregation	Combining the satellite data with other information sources *[e.g. integrating information, GI, parameter model, thematic compilations…]*
Visualisation	Creating visual representations (online tools) that helps to see and understand what data represent. These correspond to the Platform-as-a-Service (PAAS) business model[31] and provide users with an environment (incl. tools and software providing a ready-to-use toolkit that gives the user all the necessary software for the handling, exploratory analysis and visualization of large volumes of time series data within a single framework) where they can discover, visualise and process Earth Observation data (platforms) *[e.g. models (web visualization (2D,3D), urban block models, …]*
Distribution	Providing access to data, via direct download, application programming interfaces *[e.g. API or web services, hubs, thematic platforms, DIAS…]*

2.1.3. EO services descriptions – standardised verbs

In a former version of the EARSC taxonomy[32], we have introduced a standard set of five verbs to describe the needs of the user (and eventually the service on offer): **assess, detect, forecast, map, and monitor**. Based on interactions with NextGEOSS project, in this revision we have added the sixth verb "analyse". Table 6 below represents the correspondence of these actionable verbs with the Bloom taxonomy providing definitions by which those were adapted to the EO domain and the market

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sectors. Note how value-added services are increasing in complexity from the detection and mapping to analyse and assessment.

Table 6- EARSC taxonomy Standard verbs & comparison with Bloom & DIWK

Value added	Bloom taxonomy	DIWK	EARSC Taxonomy Verbs	Alternatives / Equivalents / Synonyms	Definition
+	Create & Evaluate	Wisdom	Assess	evaluate, create, understand, review, quantify, report	to watch and check a situation carefully for a period of time (not a one-time event) to discover something about it (evaluate and create is a selective exercise that attempts to systematically and objectively assess progress towards, evaluate knowledge and learning during the effort to achieve an outcome.
	Analyse & Apply	Knowledge	Forecast	predict, plan, model, estimate, project	to provide statements covering a range of different outcomes, to say what you expect to happen in the future (predict future events based on specified assumptions)
			Analyse[33]	apply, process, parse, detail	to study or examine something in detail to discover more about it (apply knowledge by detailing the elements and critically examine and relate these parts separately and/or concerning all the process)
		Information	Monitor	understand, track, observe, record, follow	to watch and check a situation carefully for a period of time in order to discover something about it (keeping track and understand how the natural and manmade environment change (status of) over time, it is continuing function that aims primarily to provide the management)
	Understand	Data	Detect	recognize, identify, warn, highlight, spot, measure	to notice something that is partly hidden or not clear, or to discover something, especially using a special method
-	Remember		Map	understand, locate, classify, trace	to represent an area of land in the form of a map (a feature the way it is arranged or organized)

2.1.4. Taxonomy definitions

This section provides definitions of the various terms used in the EARSC taxonomy structure. The structure is based on two main approaches: *market* and *thematic*. The **thematic approach** reflects the technician/expert view on the services, while the **market approach** reflects the customer view. This perspective bridges both communities **"Markets" (users)** & **"Thematic" (providers)** around the same complete set of EO services. These two communities naturally use different terminologies to describe the same services. In generating the taxonomy, we have tried to recognise the difference between a **client-side** a description of the service and a **supplier-side** description. The terminology used to describe this approach is presented below and summarised in Table 7.

EO services sector revenues can be broken down into value-chain segments. In our exercise, the "market" oriented approach focuses on the markets the company serves instead of the products and services they make. We use the term **"markets" to describe the first level** of distinction of customer types, e.g. between public authorities and industrial users. These markets are then broken into economic industry groups with activities sufficiently similar in their economic behaviour for economic monitoring and analysis[34], e.g. the Industrial market is broken into "communications", "transportation", "marine & maritime", "utilities" and "construction". **This second-tier groups in the market view are termed "Sectors"** (see a full list of all markets and sectors for the updated market view on the taxonomy in Table 11).

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[33] Analyse has been inserted in this revision of the taxonomy
[34] OECD, Guidelines for Collecting and reporting data on research and experimental development © OECD 2015(https://bit.ly/2SYSgzU)

The semantic dimensions to be embedded in the **thematic view** include structure and representational granularity. We also had some pragmatic reasoning, identifying whether the taxonomy is descriptive[35] (providing information and responding to the question 'what?') or prescriptive[36] (affecting the structure and responding to the question 'how?'). The thematic taxonomy view also follows a hierarchical classification scheme and it will be a building block to be integrated into more advanced ontologies, such the case for the EO4GEO Body of Knowledge (BoK).

The Thematic approach focuses on the application areas in which EO service providers consider their service to reside. The differentiation between these **first order Thematic classification, termed "Domains" (or "Themes")** can be thought of in terms of how the developer sees their expertise being applied. For example, while applications to identify ships at sea and ground motion both exploit SAR technology, or climate scientists and air pollution specialists both use data on the atmosphere, the individuals doing these tasks would consider their expertise and area of applications to be very different. Within these domains too, experts' knowledge is grouped according to more precise areas of expertise. **Under the thematic view on the taxonomy, these second order groupings are described as "Areas" (or "Segments")**, e.g. within the Atmosphere & Climate Domain, expertise is classified under the Areas of climate, atmosphere and meteorology (see a full list of all Themes and Areas in the 2015-2019 version of the taxonomy, and the updated 2020 Thematic taxonomy Domains and Areas in Table 14).

These two viewpoints converge on the EO services, as shown in Table 7 below. These services form the 'bottom layer' where the Market and Thematic views on the taxonomy converge. They must therefore only be described once (See Section 3.4: Structuring the EO services for detail on the keywords for each service defined within the taxonomy). Within this work, the EO services will be presented in relation to the thematic view as major discussions have been conducted with the Academia and Research communities which are more oriented towards the expert view perspective.

EO services are described presenting a set **keywords** which define the **services**. Services are defined here as being comprised of the following elements:

- **Parameters** or **essential variables:** the information elements derived from EO data, the key *parameters* of the *Earth* and the environment, e.g. Chl_a and water temperature
- **Products**: The output of a service, e.g. a map or a report that is of direct use to the user, e.g. a map of harmful algae distributions
- **Application**: The application of a service to the specific needs of one (community of) user(s), e.g. a service that can detect harmful algae is trained and run on the Eastern Mediterranean, forming the Eastern Mediterranean harmful algae detection application.

These elements of the taxonomy fit together as shown in the following Tables: Table 7 shows the hierarchy of the terminology used while Table 8 shows how the EO services form the bridge between the market and thematic views on the taxonomy – both views ultimately describe this same range of services.

Table 7: Descriptive levels used in the EARSC taxonomy

Level 1	DOMAIN (Theme)	Markets	describes the first level of distinction of customer type or broad market

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[35] (details/describing/classifying) an organizational scheme for classifying the structure of conditions for learning describing the approaches, methods, and goals of instruction (ref https://www.igi-global.com)
[36] (imposition /enforcement) organizational scheme for specifying the optimal and appropriate approaches and sequence of instruction to achieve corresponding specific learning objectives and desired performance outcomes (ref https://www.igi-global.com)

Level 2	AREA (Segment)	Sectors	Describes the customer type or market in more detail
Level 3	EO Service (SERVICE)		Merge of EO and model or in-situ data that provides an
Level 4	EO Application		Specific for a geographical area, timeline, etc.
	Products		Describe tangible satellite-based data products
	Parameters & Essential Variables for the land, atmosphere and ocean		Information elements derived from EO data key *parameters* of the *Earth* and the environment

Table 8- One taxonomy, two perspectives, one communality (EO services)

EARSC TAXONOMY							
MARKET (User) perspective			EO SERVICES (3rd level)	**THEMATIC** (Provider) perspective			
Customer and User (view)				Technician and Expert (view)			
-Structures the market from the customer point of view -Based on customer segmentation -Identify the type of organisation that fits into each one -Helps associate types of users with their requirements			The special nature of **EO services** is their composing ability. The EO services gather the information and data for a particular object. This characteristic allows the composition of service chains that tackle the necessity of solving complex business procedures supported by technological platforms. The EO services propose an action or a sequence of actions, specific events appropriate in a given situation geographically or temporal (**an application**) for example, "assess the environmental impact of farming in the region of Murcia". For example, it unifies major entities such as environment, agriculture or deeper on granularity such crops. The description of the EO services include the **products** which make up a service but also key words representing the **parameters** or **essential variables**.	-Structure of the EO domain from a technical approach -Based on an expertise view -Seek to gather EO services into groups -Add meaning & insight to each service			
1st level		2nd level		2nd level		1st level	
MARKET	Responds to the highest rank in the market perspective, describes a part of the economic activity, it is a group or groups of customers who require the products and services provided by industry. Understand the major markets in which EO services are doing business. These major markets structure prove sufficiently robust to accommodate future sector segments. We can cite as an example the market super-category "managed living resources".	SECTOR	It provides some granularity introducing a group of business activities (industry activities) that have similar characteristics. For example (agriculture, forestry and fisheries) all in the primary sector and helping to define the type of customers.	AREA	It is the set of EO services (greater detail of objects) with similar characteristics and associated patterns. There corresponds to thematic segments in each of the domain. For example, objects to be monitored in built environment such as urban areas, infrastructure, transport, or waste. It may be also named as a segment.	DOMAIN	Responds to the highest rank in the thematic perspective, categorises by type of activity for which the observations are being made i.e., risk assessment, forecasting, responding, monitoring, detecting etc. for a particular domain. We propose 6 domains (atmosphere & climate, build environment, disasters & geohazards, land, marine, security & safety). It may be also named as thematic.

2.2. Methodology

2.2.1. EARSC Taxonomy approach

As indicated in the Introduction, there are many types of taxonomies described in the literature, including hierarchies, classification schemas, controlled vocabularies, etc. The existing EARSC taxonomy, developed in the period 2015-2019, could be best described as a hierarchical classification approach. Such a list of a hierarchically ordered number of categories and provides a range of benefits such as:

- Categorisation of content
- A process of naming and classifying EO services and products
- A tool to improve the understanding between communities
- Helping to associate various types of content to influence the potential customers
- Adding meaning and insight to each service
- Assisting future content knowledge strategy

The first and second level groupings (markets/sectors and domain/areas) for the two viewpoints on the EARSC taxonomy from which we begin this study, i.e. the taxonomy developed from 2015 – 2019 are shown in Table 9 and contrasted with updated versions in Table 11 (market) and Table 14 (thematic).

Table 9- Taxonomy overview levels (2015-2019). EO services as communality

MARKET		EO SERVICES (3rd level)	THEMATIC	
MARKET (1st level)	SECTOR (2nd level)		AREA (2nd level)	DOMAIN (1st level)
Managing Living Resources	Agriculture fishing forestry	EO services from both the markets they serve and the thematic areas they represent. EO services will help suppliers and customers arrive at a common understanding of what can be offered. services defined each of which offers several products.	climate atmosphere meteorology	Atmosphere & Climate
Energy & Natural Resources	alternative energy oil& gas minerals & mining		floods landslides volcanos fires earthquakes	Disaster & Geohazards
Industrial	communications transportation marine & maritime utilities construction		agriculture inland water snow & ice topography geology land forests land use	Land
Services	real estate management insurance & finance retail & geo-marketing travel, tourism & leisure news & media		urban areas infrastructure	Built Environment
Policy Authorities	local & regional planers education, training & research security, defence & military emergency		metocean coastal marine ecosystem fisheries sea-ice ships	Marine & Maritime
International Bodies	environmental pollution & climate humanitarian operations & health		security	Security

2.2.2. EARSC Taxonomy update: Steps and sections

The goal of using a taxonomy is to improve the ability for interested parties to identify relevant content in a large collection of content, so the first levels should embrace a collection of other levels, providing the structure for more granular classifications, i.e. a hierarchical approach. Each taxonomy must, however, balance the need to be specific and also not overwhelming when choosing the number of level areas. The challenge in a taxonomy is to help users find and use the right information efficiently and effectively. So, the methodology for creating and updating a taxonomy should respond to the questions: **what this taxonomy is and how we ensure it remains relevant; how was the taxonomy upgraded and what it looks like now; how does the upgraded taxonomy align with the needs of external communities.** These questions are addressed through three specific steps in the methodology as shown in the Table below.

Table 10- Methodology steps and sections

STEPS	Methodology	Description	Questions
1	DEFINITION	Review bibliography of the existing taxonomies oriented towards user uptake (literature search, documents based on legacy of taxonomy including correlations and correspondences)	What is "the taxonomy" and how do we ensure it remains up to date?
2	RESULTS	Exchange & discussion with stakeholders to; a) Define and refine the high-level areas in the EARSC taxonomy concerning market (user) and thematic (application) perspectives and growing the level of detail and granularity with subgroups for better EO service classification. b) Reflect on the state and health of the sector to reflect changes on the levels of granularity using the market observatory. c) Provide findings on the EO services structure complemented with key information on the scope of thematic areas and the relation between them.	How was the taxonomy upgraded? and What does it look like now?
3	UPTAKE	External communication. Uptake and replication from users.	What is the applicability to other communities?

The first step in defining a successful taxonomy is ensuring that sector stakeholders understand what it is and what it is used for. The **DEFINITION** phase shows the general approach of the EARSC taxonomy and gives a rationale for the two-sided view that defines it through i) a discussion on the complexity of aligning the viewpoints of users and suppliers in one approach and ii) by comparison to a range of other, existing taxonomies (Copernicus, H2020 projects, commercial services…). This step also presents how we will ensure that the taxonomy remains continually updated and relevant (living document), through incorporation of user feedback and planning or regular review cycles. It addresses the question "what is the taxonomy?".

The next step in upgrading the taxonomy is to discuss with relevant stakeholders, in this case the EO service providers, to ensure that we i) include all services on offer in the market, and ii) have accurate descriptions for each service. The **RESULTS** of these discussions with sector experts and the resulting relationships between the EO services are presented as **the updated taxonomy**. These results are presented for the **Market**, and **Thematic** viewpoints, with a dedicated section on the structuring of the third level, the **EO services**, as part of the Thematic viewpoint.

The third step in defining an EO taxonomy is to ensure that the results are applicable for the full range of stakeholders in the ecosystem. To this end, the **UPTAKE** section presents the applicability of the updated EARSC taxonomy to other communities.

3. Results: Taxonomy Evolution

The Results chapter presents the structural elements and the specific updates of the taxonomy, responding to the question of 'How was the taxonomy upgraded?' and presenting what it looks like now. Section 3.1 covers the "users" and their definition while Section 3.2 will analyse the composition of the "thematic" (suppliers) perspective. Section 3.3 discusses the structure of the EO services which form the bridge between these two views.

3.1. Market (user) view on the Taxonomy

3.1.1. Market: Taxonomy classification

The updated Market view on the taxonomy is presented in Table 11 with the major markets & sectors. Evolution changes are presented in "bold". Ending December 2019, EARSC has upgraded the "Market taxonomy" reflecting on the evolution of the sector. We prefer to focus here on functions developed in the different market levels. Therefore, we have included the public sector functions in several market areas. The user groups related to "policy authorities" and "international bodies" were embedded in other market sectors fulfilling such activities as defence and security or environmental, climate & health market areas. The new group "citizens & society" has been defined to account for the citizen as a client, as serviced by EO services delivered directly to citizens through Apps.

The latest EARSC "Survey into the state & health of the sector"[37] revealed a significant increase in the activities specific for different groups of users. Such was the growth in the "defence and security" segment that we decided to consider it now as an independent Market in our taxonomy. We also added a sector on "urban planning", supporting the activities of many service providers in the public sector such as "smart cities" or "local and regional planning". The customer was always a local planner but due to the increase in revenues of these type of services deserve their own independent category. Another evolution is the one regarding the "industrial" and "services" segments which were considered to be too generic, so they have been replaced by more focused activities on the "infrastructure and transport" and "financial" activities where "ICT and digital interfaces" were integrated. These modifications respond to more adjusted classification on the type of users of the EO services. Table 11 shows these evolutions in bold.

Table 11- Evolution of the market taxonomy

EARSC market taxonomy (2015-2019)		Updated (2020) taxonomy (major Markets & sectors)	
managed living resources	agriculture fishing forestry	managed living resources	agriculture fishing forestry
energy and natural resources	alternative energy oil& gas minerals & mining	energy and mineral resources	**renewable** energy oil& gas **raw materials**
industrial	communications transportation maritime utilities construction	**infrastructure & transport**	construction utilities & supplies communications & connectivity transport & logistics marine travel & tourism
services	real estate management insurance & finance	**financial & digital services**	insurance & real estate retail & geo-marketing

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[37] EARSC Survey into the State & Health of the European EO Services Industry 2019
(http://earsc.org/file_download/568/Industry+survey+2019+final+version+07_11_2019.pdf)

	retail & geo-marketing travel, tourism & leisure news & media		news & media **ICT & digital interfaces**
policy authorities	local & regional planers education, training & research security, defence & military emergency	**urban development**	**smart cities** local & regional planning
international bodies	environmental pollution & climate humanitarian operations & health	**defence & security**	emergency & **social protection** security, defence & military humanitarian operations
		environmental, climate & health	environmental ecosystems & pollution health care meteo & climate
		citizens & society	**consumer solutions** leisure education, training & research

The figure 2 represents the update of taxonomy from the market/user perspective.

Figure 2: EARSC Taxonomy (Market perspective)

3.1.2. Market: User terminology

Major user groups have been identified and a description is provided in Table 12, which shows a structured view of the "offer" of the sector, its services for the actual use of the communities from whom it is intended, i.e. the "uptake". The "EO services" are the common point bridging the "market" and the "thematic" taxonomy, serving the needs of the users (adding key targets and terminology) and providing the knowledge and expertise of the services providers. The EO services are largely

analysed and most benefit from the understanding of the "action verbs" which categorize its description (verb + object).

The needs and challenges are closely expressed by services providers as "EO services" and in some cases as products using EO data dedicated to meeting the needs (challenges) of the Markets which are expanded in the table below.

Table 12- Definition of EO users[38]

MARKET TAXONOMY				
Market	**Description**	**Sector**	**Users**	**"Needs" relevant to "EO services"[39]**
Managed living resources	Users in managed living resources refer to human activities exploiting natural organic resources. Knowledge and information products to forge a viable strategy for the user's operations such as the assessment of the status of the resource due to natural or human activities for effective commercial exploitation and conservation. This includes **agriculture, fishing and forestry** sectors.	**Agriculture**	Agricultural commodities/trading, agricultural production / horticulture, agricultural services, agriculture machinery, agriculture and rural development policy, agri chemicals / plants & fertilizers, animal production / livestock/ Stock traders on commodity price like wheat, coffee. The EO/GI users also include agriculture and rural policy makers and insurers.	- forecast production yield and monitor variability in crop development; - support usual farm management / operations providing highly accurate customized consultation to any farmer and for any kind of crop, from the smallest to the largest scale; - calculate the correct amount (savings) of fertiliser, water or pesticides; - more informed decision-making on crop type and land use, savings on seed through optimising seed density during planting (vegetation-Index Crop-Insurance); - implement a crop production index to build an insurance product; - evaluate farm solvency & trade on commodities stock exchange; - monitor farming deforestation impact and delineate field boundaries; - assess losses based on actual damage extent in the field overall monitor several stages in the value chain to make better-informed decisions in planning, planting and growing the new crops; …
		Fishing	Fish stock management, fishing fleets, fishery distribution logistics, aquaculture / fish farms, coastal management agencies. Besides, the users include fisheries authorities / policy makers.	- improve fisheries economic activity boosting their income, making the fishing experience easier, safer, and more sustainable, assessing fish shoals, catch optimisation & understanding the impact, overfishing, livestock monitoring/management, etc; - detect patterns of illegal behaviour at sea (illegal fishing, narco-traffic, immigration, maritime pollution, piracy); …
		Forestry	Forest management, forest services, commodities, logging industry, wood, paper and pulp industry, forest policy, forest machinery. They also include forest policy makers.	- establish historical forest area changes and implement forest monitoring solutions; - verify the impact of and compliance with no-deforestation policies and transform the industry towards sustainable practices (sustainable management of forest); - set-up reducing emissions from deforestation and forest degradation (REDD+ national strategy and support final users in obtaining

38 Descriptions have been contrasted with the conceptual activities undergoing at the Body of Knowledge (BoK) under the EO4GEO project (www.eo4geo.eu)
39 Needs have been extracted from EARSC services providers activities at EARSC membership (www.earsc.org/members), Copernicus market report 2019 (https://www.copernicus.eu/sites/default/files/2019-02/PwC_Copernicus_Market_Report_2019_PDF_version.pdf)

				certificates and carbon credits) (REDD+ MRV (monitoring, reporting and verification));
				• perform cost-effective and accurate forest inventory, at national or local scales;
				• conservation and enhancement of forest carbon stocks, baseline mapping and stock change;
				• damage assessment;
				• …
Energy and mineral resources	Users in energy and mineral resources deal with the harvesting of energy from **renewable resources** and **extractive industries** including **oil and gas and raw materials**. EO information helps them in exploring potential locations to build new mines or power plants, in identifying risks from infrastructure and in managing the environmental impact of their operations. Uses that apply to the extractive industries: a study of landforms, structures, and the subsurface, to understand physical processes creating and modifying the Earth's crust.	**Renewable energy**	Solar energy providers, wind energy providers, tidal energy providers, energy and carbon traders, local and regional planners, and national policy makers.	• successful management of renewable resources as the selection and development of exploration areas;
				• detection and quantification of renewable energy potentials;
				• solar radiance data for renewable energy project planning, and nowcasting for extreme weather events;
				• assess environmental impact assessment for industrial permitting and monitoring purposes;
				• aspects of energy planning, production, and distribution within bioenergy and thermal power, wind, solar, renewable energy and energy-efficient heating and cooling solutions;
				• …
		Oil & gas	Offshore and onshore exploration and production, drilling and support services, oil and gas commodities trading, and energy planners.	• assessments and monitoring of environmental impacts related to energy exploration, extraction, transportation and consumption;
				• establishment of an environmental baseline, or snapshot, for planning and design;
				• monitoring conditions over time (via change detection, feature mapping or geophysical parameter measurement) to understand environmental impacts and trends;
				• hazard assessment (risk assessment and post-event analysis, including operational and situational awareness);
				• oil spill and pollution monitoring;
				• assess pack ice and icebergs, and internal wave/soliton mapping to help mitigate potential risks posed to offshore activities;
				• improved representation of the subsurface, optimize field development and achieve more efficient oil and gas production;
				• …
		Raw materials	Mining and quarrying companies, exploration and survey specialists, commodities traders, exploration and extraction equipment suppliers, drilling, excavation and support services, and regional planners / policy makers.	• challenges focus on lifecycle phases of the mineral extraction: areas of poor coupling, baseline historic mapping of environment and ecosystems, continuous monitoring of changes throughout the lifecycle, engineering geological evaluation, facility siting, pipeline routing and roads, identification of adverse terrain for trafficability, infrastructure monitoring, land motion relating to fault lines or other causes, lithological discrimination, mapping geological features,

				monitoring of assets, natural hazard risk analysis, reservoir management, risk assessment, structural interpretation, support to surveying crews for planning surveys and H&S, terrain evaluation and geo-morphology characterisation; • on-site field data and calibration information; • change detection and time series analysis; • risk management and environmental impact analysis; • geological mapping, mining management; • selection and development of exploration areas, detection and mapping of illegal mining activities, or monitoring assets; • …
Infrastructure & transport	Users in transport and infrastructure apply to all manufacturing and physical supply in **land** but also **marine** domains including **transport & logistics, utilities, construction, communication & connectivity**, and **tourism.** They oversee assets, monitor competition, build competitive advantage and source ground-truthing data.	**Construction**	Construction companies, civil engineering consultancies, architect and design companies, planning authorities, and national land agencies dealing with structures, tunnels, etc.	• assessments of key infrastructure changes and construction developments; • continuous mapping and monitoring of critical infrastructures across multi-site projects; • continuous monitoring to detect encroachment events, including intentional damage to infrastructure or a threat to staff safety; • engineering development, planning, monitoring and controlling of infrastructure solutions at all levels of scale and complexity to optimize the processes and results; • demand and suitability analysis; • assess the environmental impact of human activities (detect land movement, subsidence, heave, and monitor land-use statistics); • intelligence on the location, extent, magnitude and evolution of deformation; • …
		Utilities & supplies	Operators of utilities such as water, electricity, waste, power stations (including hydroelectric), water plants, landfill and waste, a well as survey companies, regulatory bodies, distribution companies, regional planners / policy makers.	• monitoring electrification planning, renewable energy resource assessment, distributed generation, grid operation and reliability, and disaster risk reduction and recovery efforts; • identify risk hotspots on and around the rights-of-way and mitigate risk by monitoring vegetation around power lines; • improve the safety and reliability of their network; • understand and plan tree trimming cycles and verify vegetation maintenance completion. Reduce the risks of power outages, asset damage, and other economic losses, as well as environmental and safety hazards from storms or wildfires; • improve access to reliable electricity and resilience infrastructure, incorporate renewable energy into the electric sector, and improve energy governance; • dynamic water availability and change monitoring, water demand and usage assessments; • …

		Communications & connectivity	Construction companies, civil engineering consultancies, architect and design companies, planning authorities, and national land agencies.	• support operations of communications networks through information to set up infrastructure settlement networks and coverage; • assessing changes to urban/rural areas, and mapping line of sight visibility; • …
		Transport & logistics	Road transport operators, haulage, road infrastructure operators, tolls, airport operators, rail operators, airlines and airline services, and transport engineers.	• corridor assessments and route / network planning; • reliable maps for transportation management systems to guide decision-making, determine how/where to engage across large supply chains in transport and logistics (rail, roads, highways); • assess and monitor high-risk areas by providing more information on geological hazards along with rail and road networks; • …
		Marine & maritime	Ports & Harbours administration, bulk cargo carriers, cruise liners operators, ferry operators, naval operations, and rescue and safety at sea.	• contribute to more efficient marine operations and further development of the Blue economy[40] comprising all the activities related to oceans, seas and coasts, that cover established sectors (e.g. exploitation and preservation; aquaculture, fisheries, water quality, coastal tourism, maritime transport, etc.) and new ones, e.g. blue bioeconomy and biotechnology, coastal and environmental protection, etc; • weather monitoring for vessel detection and identification; • policy objectives such (bath water quality, integrated coastal marine directive, marine strategy framework directive, UNEP regional seas; • …
		Travel & tourism	Tour operators, leisure service providers, hotels, parks etc., offices of tourism, travel agencies, ski and coastal resorts, surfers & sailors.	• forecast of weather conditions over a particular environment such as coastlines (safety of tourists and holidaymakers through operational weather observations and providing a picture of changing circumstances, natural features and their characteristics; • validate the assessment of resorts, evaluation of conditions for safety for outside activities (biological reserves areas (canopying), improved mapping for tourists with classification and other advanced automated processing technologies; • cultural heritage, displacement monitoring (detection of slow movements and structural failures of historical buildings and structures and of terrain in the surrounding areas); • assessment of land use change (e.g. pollution in rivers and lakes); • …

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[40] 2018 Annual Economic Report on EU Blue Economy (https://ec.europa.eu/maritimeaffairs/sites/maritimeaffairs/files/2018-annual-economic-report-on-blue-economy_en.pdf)

Financial & digital services	Users in financial and digital services cover a broad area of activity that touches on many other market sectors such as **insurance & real estate, retail, news & media and digital interfaces**. They look to better understand risks, accelerate claims, and detect fraud. The categories included are identifiable as a "service" for the tertiary sector which provides advice, access, experience activities and knowledge and there are not part of the physical supply of goods.	**Insurance & real estate**	Primary insurance companies, re-insurance sector, insurance brokers, insurance service suppliers, commercial banks, major projects, and international financial institutions).	- detection and monitoring of hazard-prone locations, including vulnerability assessment; - better management of risk exposure, assessment (capital/risk) to natural disasters such as hurricanes, earthquakes, and floods; - key analytics reports and alerts of risks (such identification of risk); - assess situations for predictive analysis or risks on a property basis; ...
		Retail & geo-marketing	Retail centres and advertising and marketing agencies. They use EO/GI data in the field of navigation and Location Based Services (LBS), shopping chains or logistics.	- leverage geospatial intelligence to take management decisions leading to reduced costs on, e.g. new location selection, practices or processes through e.g. implementing dashboards to integrate and visualize spatial variables & information such as reliable NRT data, stores and localized areas, identification of public segments of interest, location of establishments, billboards and their influence on online advertising, customer dynamics, study of competitors, price strategy design etc; ...
		News & media	Television companies, broadcasting providers, news and information agencies, web service providers, and entertainment software providers.	- bringing together images, videos, and visualisations from the Earth onto known platforms (digital, print, radio, television) to inform society on the ecosystems, environments, emergency, risk and safety of people or socioeconomical impact; ...
		ICT, knowledge & digital interfaces	Fixed and mobile telecommunications providers.	- assist with data processing and enhancements, and provide a range of specialist analysis ready data solutions to help final users maximize intelligence from imagery; - baseman data for radio network analysis; ...
Urban development	Users in urban development and users involved in the development of rural settlements perform tasks at local and regional scales (to the scale of nations) on mapping land use and monitoring urbanization. These users benefit from EO information to manage the use of land & its impacts. Users include experts in e.g. urban planners, architects, spatial planning offices, urban policy makers in public/private sectors in **smart cities** or **generic urban** local/regional **planning** belong to this category.	**Smart cities**	Urban planners, architects, spatial planning offices, urban policy makers.	- baseline inventories for site suitability studies, city infrastructure monitoring, information on green urban areas and peri-urban ecosystems; - estimate distribution of the population, economic activity, property ownership and valuation, land use/ land cover inventories; - sustainable cities and communities creating places where the environments enhance liveability and quality of life; - classification tools using administrative vector data as reference for supervised image classification; - map and assess urban adaptation to climate change, environmental/socio-economical characterization and map green urban areas in and around cities; - map risk of land change and ground deformation and its temporal evolution;

				• water and sanitation planning to support water related infrastructure projects and waste management; • …
		Local & regional planning	Spatial planning departments of municipalities, spatial planning offices, and spatial planning policy makers	• inventories of informal settlements, integrating different data streams into the map-based products (cadastral maps for land administration and mapping); • mapping of building footprints and building blocks as well as classification of building/infrastructure types; • optimize planned routes for transport and infrastructure, and when combined with mapping solutions, can help mitigate the impact of natural hazards whilst minimizing project costs; • interactive analysis, simulation and visualisation tools for urban policy implementation; • socio-economic and demographic analysis and impact assessment, facility planning; • …
Defence & security	Users in **defence** and **security** work in the field of **military, emergency and social protection** and define, collect, analyse information to provide intelligence & safety (monitor events, improve response and drive resilience). Some examples are activities under **Humanitarian response** such as border control organisations, police and rescue forces, coast guards, civil protection, military services, and intelligence services which can use EO services to detect and monitor high risk areas produced naturally or by humans, monitor border incursions or maritime movements.	**Emergency & social protection**	Coast guards, ambulance services, fire services, police services, civil protection organisations, and rescue services. They benefit from increased efficiencies and effectiveness through monitoring, detecting and assessing natural risks/disasters.	• mapping disaster areas for situation awareness and detecting sensitive risk areas; • economic and social vulnerability assessment to natural hazards and climate change (monitoring, action and adaptation); • assess loss (€/m2) mostly for assets combined with in-situ data; • …
		Security, defence & military	Border control organisations, police and rescue forces, military services, and intelligence services.	• defence mission (naval forces): intelligence, support to troops, manoeuvres, support to aerial operations, interception of suspicions activities (assist with trapping/catching traffickers in the act); • support the detection of illegal or irregular activity and to make land /maritime operations safer and more efficient (situational awareness), overall citizens' security; • …
		Humanitarian operations	Humanitarian aid and support organisations such as; at European level (DG RELEX, DG ECHO, DG ENV/ MIC), at UN level (OCHA, UNHCR, UNDPKO, UNDP, UNOPS, UNITAR, UNICEF, UNESCO, WFP), International (IFRC, WHO, WB, donor organizations), and national level (Civil Protection Agencies, Ministries of Internal Affairs/ Civil Protection Department, Development and Aid agencies).	• improve emergency response and assessing pressures on populations and migration, monitor & tracking displacement population and humanitarian movement and camps; • assessment and support to aid actors dealing with hazard assessment (risk assessment and post-event analysis), including operational and situational awareness as well as those involved in recovery, disaster risk reduction and preparedness activities; • disaster resilience and assessing geo-hazard vulnerability of cities & critical infrastructures; • reach actionable information to send the right people and supplies to the most vulnerable sites;

				•	…
Environmental, climate & health	Users in the **public administrations** or **private organizations** using EO to increase the **environmental or climate change** impact on policy making decisions which are key to our safety and our economy i.e., assisting in developing monitoring to evaluate and deliver policy goals, provide an assessment of ecosystems, rapid response to major environmental risk events, or those associated with **health security** & care. These users are largely related to international treaties and hence a strong international collaboration.	**Environmental ecosystems & pollution**	Environmental ecosystems & pollution users include coast guards, ambulance services, fire services, police services, civil protection organisations and rescue services.	• • • •	assist with the preservation of the natural environment such as reservoirs, inland water monitoring, water management systems (hydrological, hydrogeological maps, water point); solutions that safeguard the environment such as environmental impact assessment, strategic environmental consultancy, sustainability, waste & resources); resilient & sustainable ecosystems including continuous monitoring of ecosystems such as wetlands; …
		Health care	Public administration personnel, civil servants, public health community, etc working on health issues such as air quality, forecasting sunlight exposure, forecasting epidemics, diseases.	• • •	site-specific field conditions as well as import phenological timing events, which helps to make predictions on air quality, which impacts on the health of citizens; pandemics highlight the need for a comprehensive and integrated approach to human health. Enhancing environmental health through better air quality, water and sanitation, waste management, along with efforts to safeguard biodiversity, will reduce the vulnerability of communities to pandemics and thus improve overall societal well-being and resilience; …
		Meteo & climate	Meteorologists in a range of downstream sectors.	• • • • • • •	disaster resilience and assessing extreme weather; monitor, understand, evaluate and assess the impact of the climate change; prediction of conditions of atmosphere reliable weather forecasts; mitigation actions preventing/reducing the emission of greenhouse gases into the atmosphere; climate change data modelling (aerosol, biomass, cloud, fire, greenhouse gases (GHG), glaciers, ice-sheets, land cover, land surface temperature, ocean colour, ozone, permafrost, salinity, sea ice, sea level, sea state, soil moisture, snow, sea surface temperature (SST), water vapour); renewable energy production prediction, all kinds of commodities market trading, inventory management; …
Citizens & society	Citizens and society in general use and engage with EO services through **mobile devices, social media platforms and apps**. We also categorize in this section	**Consumer solutions**	Mobile devices, social media platforms, apps developers.	•	adoption by society of mobile devices, social media platforms, internet connectivity, Internet of Things (IoT), machine learning, portable and low-cost sensors to interact and visualise scientific research for their interest;

		Leisure	People oriented to basic public understanding on EO services for their leisure activities	• citizen interest on particular environments and ecosystems such as beach area estimation, (understand and check protected areas where sports may be regulated), wind, water depth, water salinity, etc; • information on textures and landscapes for video games, such as flight simulators, augmented reality, 3D; • …
	the users in **education, research and training** providing knowledge and learning outcomes.	**Education, training & research**	Schools and education authorities, universities, research organisations, and professional training organisations	• through environmental research, academics make discoveries that impact on environmental and social outcomes; • enabling the education and research community to find and consume EO services, data access, processing tools, analytics, etc for their research field; • growing the awareness of EO services in researchers in disparate fields leading to new use cases; • promoting the use of EO in schools to foster innovative thinking and ideation of the applications and services of tomorrow; • …

3.2. Thematic (provider) view on the taxonomy

3.2.1. Thematic: Taxonomy classification

Earth Observation (EO) is nowadays considered as an operational tool to contribute to the detection or quantification of a phenomenon which fits users' needs in numerous markets or thematic areas. A "thematic-oriented approach" focuses on the products and services a company/organization offers and the thematic similarity of these. A service list provides a standard way of referring to each service when communicating within and between organisations.

Previous discussions revealed the need to define each of the levels used during the upgrade of the "**thematic taxonomy**". The structure presented in Table 13 allows four levels/tiers. This structure is firstly discussed at Section 2, Definitions Section. By composing the elements from level 1 (domain) while expressing the elements of level 2 (areas), 3 (EO services) and 4 (a generic description defining the products and parameters that make up the EO service), we can represent concepts without any conflicting interaction between them and independently in the knowledge base. The hierarchy represents different granularity and goes from:

Table 13- EO services structure

Level 1	**Thematic classes (DOMAIN)**	Single block of knowledge (big category of objects)	Largest conceptual category (typically nouns) covering all known areas of EO services from the supplier's point of view. The EARSC taxonomy contains 6 classes.
Level 2	**Thematic segment (AREA)**	Set of EO services (greater detail of objects)	Classifies concepts in greater detail, i.e. different segments. The upgrade proposes 31 areas compared with the 25 in the previous taxonomy. Description is tackled in the thematic section.
Level 3	**EO Service (SERVICE)**	Purpose of the information	EO services (sometimes considered applications by service providers) propose an action or a sequence of actions (specific events appropriate in a given situation, e.g., "assess the environmental impact of farming". For example, it unifies major entities such as environment, agriculture or deeper in granularity such as crops. The range today covers more than 80 services (see the section "Structuring the EO services" and the thematic taxonomy at the EARSC portal[41])
Level 4	EO Application	Specific for a geographical area, timeline, etc.	This level presents set **keywords** which in effect define the **products** which make up a service (key words are also considered in our taxonomy to represent **products, parameters** or **essential variables**).
	Products	Describe tangible satellite-based data products	
	Parameters & Essential Variables for the land, atmosphere and ocean	Information elements derived from EO data key *parameters* of the *Earth* and the environment	

It must be noted that within both the service provider and user communities the terms service and application tend to be used interchangeably. We seek here to apply some structure to their use. As shown in Section 2.1: Using a common language, we define a service as being a process incorporating e.g. sets of algorithms, EO data, model outputs etc. that are applied to give information or knowledge of the Earth, and an application as a specific implementation of that process, i.e. a service may offer to Assess and monitor water bodies, which could be applied (i.e. algorithms trained) to deliver water quality information on the Black sea, or another application to deliver water quality information on the Baltic Sea. In reality the line between "EO service" and "application" can sometimes be very narrow or inexistent in some cases. Below we present two examples of the complete structural definition of EO services. To illustrate the methodology and terminology described in Table 13 (above).

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[41] EARSC portal (https://earsc-portal.eu/pages/viewpage.action?pageId=15794378)

Figure 2, below, shows the structural levels for a jellyfish monitoring service. This service may be requested by local authorities, fishermen's organizations or tourism industry players which have the need to monitor coastal waters for the safety of tourists. Each of these potential users requires a picture of changing circumstances of these jellyfish blooms and their characteristics (coastal degradation, raise of sea surface temperature). In addition to EO-derived data this service needs in-situ data and numerical models to create a neural network that is trained and validated with real time oceanographic monitoring systems on one particular location. Concretely the structure for the example looks like:

- Domain: Marine
- Area: Coastal
- EO Service: Forecast jellyfish blooms
- Application: It could be applied for example in the "Mediterranean Sea" (Malaga coastal area)
- Product: it will describe maps with the information of the parameters but not relevant on this service
- Parameters: currents, salinity, SST, chlorophyll content

Figure 3 represents a service predicting and mapping the risks associated with potential diseases using environmental and climatic parameters which can be used to support surveillance, prevention and control activities. This is a service that may be of interest for healthcare professionals to better understand e.g. "health security events". For example, a pandemic highlights the need for a comprehensive and integrated approach to human health. Enhancing environmental health through better air quality, water and sanitation, waste management, along with efforts to safeguard biodiversity, will reduce the vulnerability of communities to pandemics and thus improve overall societal well-being and resilience. The use of EO can inform the estimation and monitoring of environmental and climatic determinants, and thus disease prediction and risk mapping. Hence a service detecting risk areas will inform about the geographical distribution of the risk of climate-related infectious diseases, providing an estimation of the population at risk, target areas of surveillance or the ones related to control and prevention, i.e.:

- Domain: Defence, security (inc. safety)
- Area: health security
- EO Service: monitor and detect sensitive risk areas
- Application: May be geographically or temporally indicated
- Product: overall risk maps (vector habitat maps, exposition to infected vector risk maps, disease transmission, etc)
- Parameters: precipitation, humidity, T, characterization of environmental and climate variables

Notice the examples described above and shown figuratively below are just to provide some examples of the structure of a service, not to analyse the service itself.
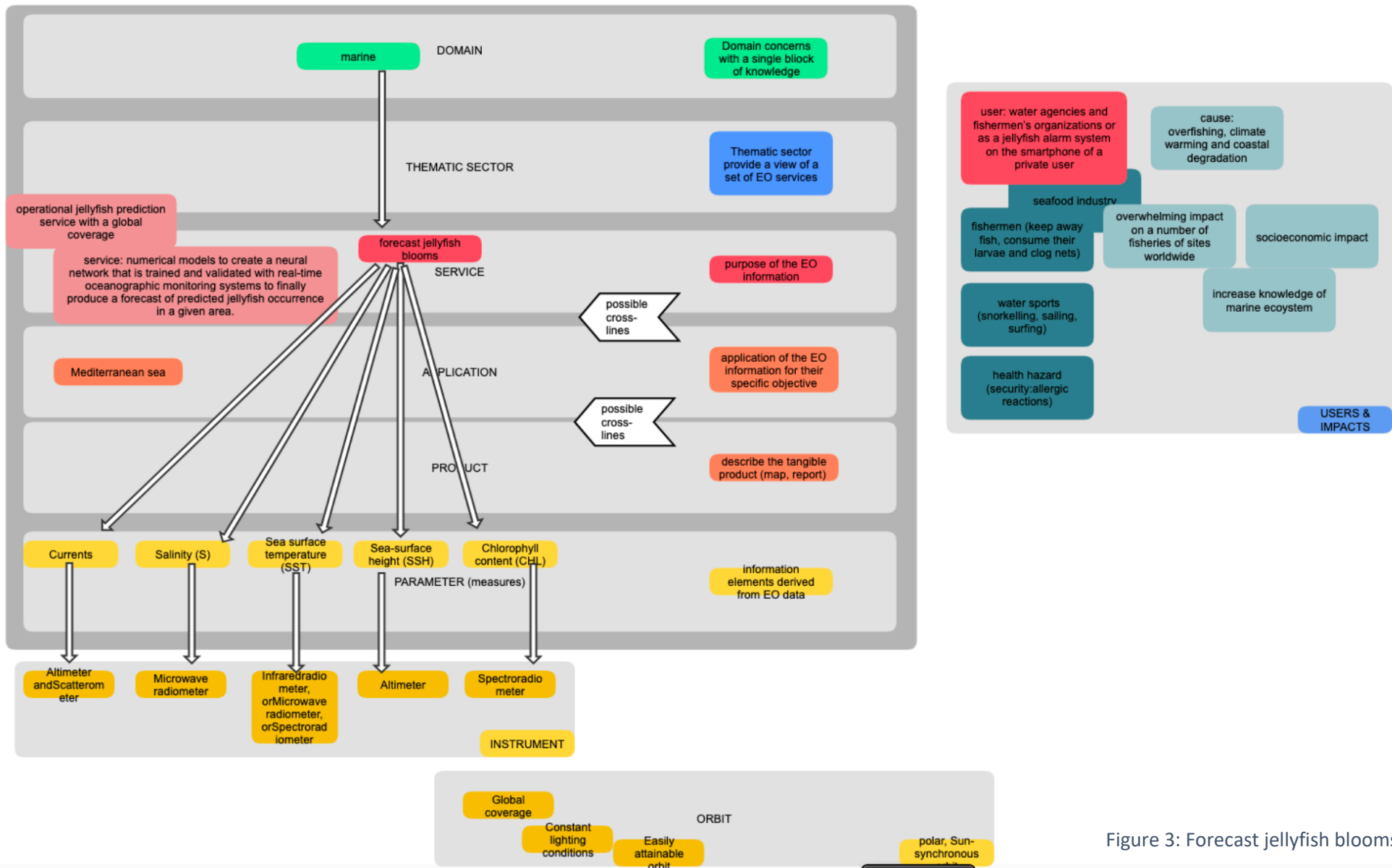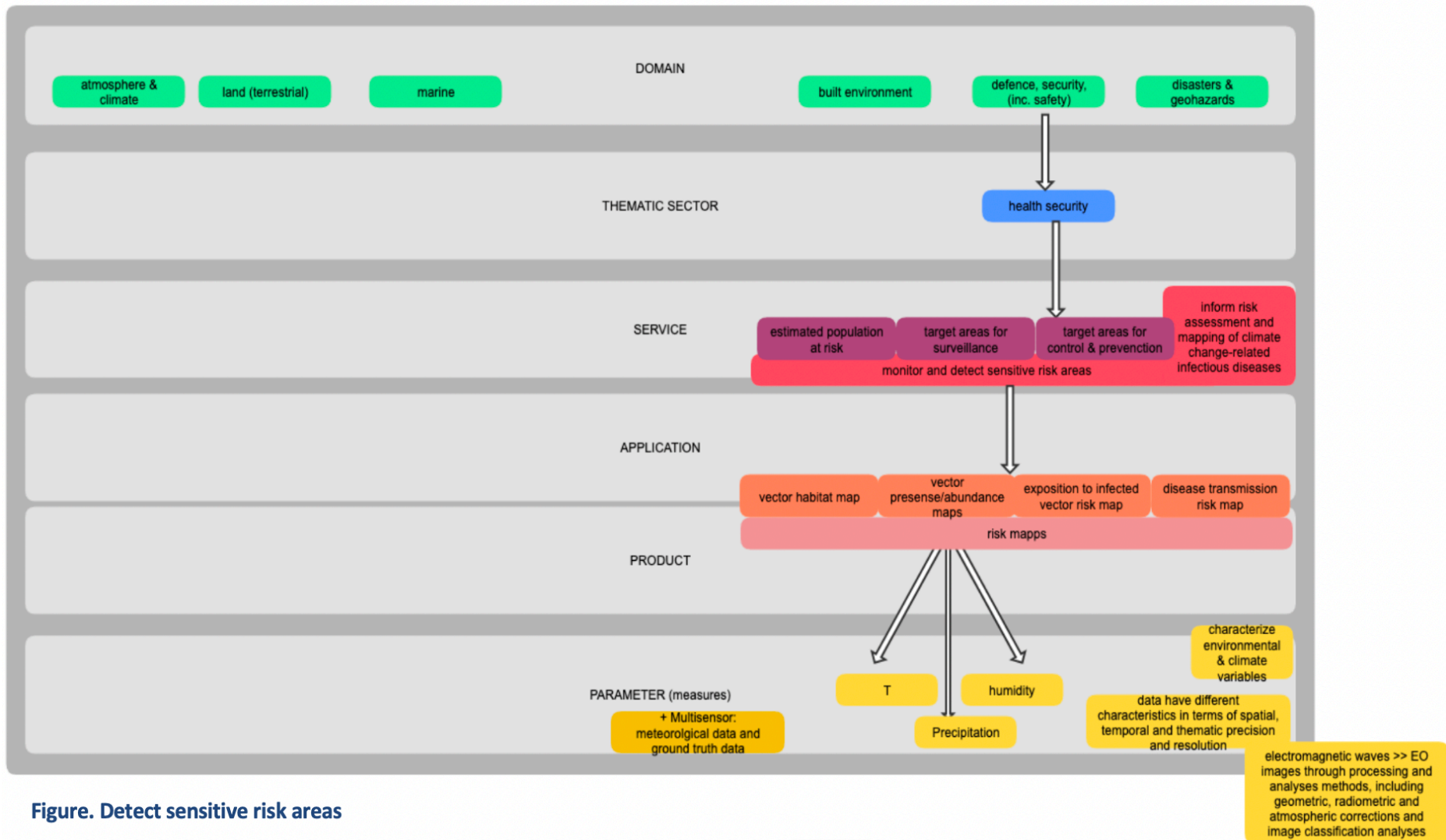
Figure 3: Forecast jellyfish blooms

Figure. Detect sensitive risk areas

Figure 4: Detect sensitive risk areas

Table 14 shows the evolution of the Areas (or segments) in this update of the taxonomy, adding more complementary segments in some domains such as the "security and safety". The main evolutions are marked in "bold".

Table 14- Evolution of the Thematic taxonomy

EARSC taxonomy (thematic) (2015-2019)		EARSC taxonomy (thematic) (2020)	
Thematic Classes (DOMAIN)	**Thematic Segment (AREA)**	**Thematic Classes (DOMAIN)**	**Thematic Segment (AREA)**
atmosphere & climate	climate atmosphere meteorology	atmosphere & climate	climate **change** atmosphere *(emissions & surface fluxes)* meteorology
built environment	urban areas infrastructure	built environment	urban areas infrastructure transport *networks* **waste**
disaster & geohazards	floods landslides volcanos fires earthquakes	disasters & geohazards *(emergency)*	floods landslides volcanos fires earthquakes **multihazard**
land	agriculture inland water snow & ice topography geology land forests land use	land	agriculture *(fields)* forests inland water snow & ice land use/land cover **biodiversity** & land ecosystem topography & **motion** geology
ocean & marine	metocean coastal marine ecosystem fisheries sea-ice ships	marine & maritime	metocean coastal **biodiversity** & marine ecosystem fisheries sea-ice & icebergs ships marine **pollution**
security	security	security & **safety**	**critical assets** **customs & border** *(migration)* **health** *(epidemics & diseases)* **food security & production**

The figure 5 represents the update of taxonomy from the market/user perspective.

Figure 5: EARSC Taxonomy (Thematic perspective)

3.2.2. Thematic: Domains terminology

The description for the domain terminology is enforced by action verbs which are describing the observed object. By definition, "Remote Sensing" is the acquisition of information about an object or phenomenon. The object of remote sensing may be a well-defined natural or anthropogenic target such as a bridge, or it may be a geographical area such as a defined landscape (farm, forest, sea…). Thematic services provide knowledge related to the production of information of relevance to different stakeholders. Table 15 presents a generic overview of the static geoinformation products and dynamic monitoring services on the six major domains (atmosphere & climate, built environment, disasters & geohazards, land, marine, security). The description highlights the use of verbs and its harmonization to the major group highlighted in the section related to actionable services.

Table 15- Definition of major thematic domains[42]

Domain (1st level)	Description	Thematic Areas (2nd level)	Key words thematic[43]
Atmosphere and climate change	The atmosphere and climate domain encompass all atmosphere and climate change focused services/applications which **assess, monitor, forecast** and provide timely, continuous and independent data (e.g. emissions, climate forcing, greenhouse gases, reactive gases, O3, solar UV radiation, aerosols…) which affect temperature, air quality and the transmission of solar radiation. These services/applications closely monitor each of the Earth's different subsystems and help to better **understand** and **evaluate** the impact of climate change and its impacts on the atmosphere, meteorology or hydrological cycles.	atmosphere	…quality-controlled information related to air composition, pollution and health, solar energy, greenhouse gases (GHG) emissions and climate forcing's.
		climate change	…long-term datasets (also linked to weather forecasts) on key indicators of climate change systematically generated and preserved to better understand climate change and associated adaptation and mitigation measures and risk management (i.e., large-scale ecological response to global climate change such greening of the Arctic). The assessment of climatic variations may persist over decades or more. This is measured through geophysical quantity/quantities associated with climate variations and change as well as the impact of climate change onto Earth (time series analysis, anomaly detection, missing data reconstruction, forecasting). Climate change is triggering factors on geohazards or direct effect for many land and ocean processes.
		meteorology	…seasonal preparedness, forecasting of meteorological variables e.g. air temperature, wind, humidity, cloud coverage, precipitation and evapotranspiration (related to numerical weather prediction models, in-situ observational data and machine learning techniques).
Built environment and human factors	The urban environment domain covers applications/services addressing all **planning, modelling, monitoring** and **understanding** of urban environments and infrastructure. These can include identification of new structures, ground movement, movement of structures, land cover/land use, and identification of urban water bodies and be applied to a range of applications such as transport networks or energy provision, or waste monitoring**.**	urban areas	…monitoring urban expansion (site development information and urban growth monitoring), sustainable urban development (highlighting urban 'hot spots', town planning, identification of urban risk management priorities, land management, insights into human settlement layers or green/smart spaces (tree canopy cover, urban forest diversity and air quality), community dependency assessments.
		infrastructure	… infrastructure health, asset optimisation and monitoring such construction of new buildings, energy, water supply (i.e., hydropower in snow reservoir), sewer systems or information networks susceptible to vulnerability due to engineering works, industrial activities or other effects which can develop land subsidence due to landslip, mining or other.
		transport networks	… monitor the stability of rail and road networks by analysing/predicting and assessing track/terrain settlement behaviour including the identification of possible 'hotspots' or high-risk areas (geological hazards, weather forecasts…) in the network that is under threat.
		waste	…monitor spatial and temporal changes in legal waste sites and detect illegal dumping sites providing a series of reports and/or alerts with evidence of the location and extent of the waste site identified.
Disasters & geohazards	The disasters & geohazards domain provides information for an emergency response concerning to different types of	floods	… assess the scale and/or extent of actual or potential flooding events (closely associated with modelled or measured rainfall and cascading geohazard models).

[42] Descriptions have been contrasted with the conceptual activities undergoing at the Body of Knowledge (BoK) under the EO4GEO project (www.eo4geo.eu)
[43] Key descriptions extracted from EARSC membership (www.earsc.org/members)

		landslides	… detection, monitoring and interpretation of different types of terrain motions such as ground displacement or landslide flows through e.g. characterization of scale, slope stability, surface/surface deformation, properties of the material (such as rock, soil, ice), meteorological (rainfall, temperature), hydrogeological parameters.
	disasters. It includes a wide array of EO services for the **mapping, monitoring** of geohazards and how cascading impacts of disasters can affect the security of every citizen. These tools can be applied to a range of disasters/hazards such as landslides, volcanoes, fires, earthquakes and cascading hazards. Other types of disasters such as ground subsidence, tsunamis, cyclones/hurricanes may be tackled under the land/marine/atmosphere domain respectively. Such EO services help on the improvement of crisis management, risk reduction including early warning systems for mitigation of disasters and emergency response, re-establishing services after such events and planning tools to help in understanding emerging problems that may be critical in the mid-term. Services in this domain typically consider the Sendai Framework for Disaster Risk Reduction[44] with the priorities for action; understanding, governance, reduction for resilience, preparedness for effective response, recovery, rehabilitation and reconstruction.	volcanos	… identifying volcanic hazards (data for detection, discrimination & distribution of volcanic ash) and assessing associated risks for human settlements and the environment, detecting and self-directing observations of an eruption arising from volcanic activity such as lava flow, ground fissures, earthquakes and mud slides, as well as the environmental effects of the gas and ashes released by an eruption, monitor precursors to volcanic eruptions (colour changes in crater lakes, damage to vegetation, and ice melting on ice-capped volcanoes) leading up to a possible eruption and assess their significance.
		fires	…observation and measurement capabilities for monitoring fire events (fire management, post-fire erosion monitoring, the basis for risk assessment, evaluation based on tree cover/type density maps), and estimating risks (areas that are dry and susceptible to wildfire outbreak, actively flaming and smouldering fires, burned area, and smoke and trace gas emissions), and extent of burnt areas for rapid damage estimation and recovery planning.
		earthquakes	…understanding, mapping and responding to active tectonics, surface ruptures and quantifying earthquake risks, estimating the distribution/depth of ground motion and slip on faults.
		multi-hazard	… early warning systems and multi-hazard disaster risk information and assessment (identify, analyse, evaluate, treat, monitor and review) in the different phases of multi-hazard risk management such as safety, the provision of a synoptic view of the region of interest, pre-event baseline mapping extending back several years and, in many cases, damage estimates.
Land	Land resources and its management form the basis of all societies. It includes all services/applications that are focused on **monitoring, assessing** quality & availability, **managing, planning** and improving the use of land areas and its ecosystems (land, soil and inland water). The key **track** on the evolution of the land surface (use, cover, seasonal and annual changes and monitors its variables) even if it involves human intervention (environmental challenges, impact evaluation or suitability analysis).	agriculture (fields)	… includes monitoring of information on the physical configuration of the surface and any change of that surface over time such as monitor fields, mange crops, farm management, tillage scheduling (soil treatment), irrigation scheduling (know when and how much), pest and disease alarm (early warning system for pest and disease infection risks), crop growth monitoring (define a different crop management zones or detect field problems such as pest infestation or soil nutrients deficiencies), improve crop yield estimation (estimate field productivity, make better financial decisions, improve income, insight of market opportunities and solve some modern agriculture problems), and comprehensive crop monitoring and modelling systems. Land variables which affect crops (along with a host of weather and climatic variables) include; land cover, surface soil moisture, dry matter productivity, surface temperature, a fraction of absorbed photosynthetically active radiation (FAPAR), normalised difference vegetation index (NDVI), leaf area index (LAI), a fraction of green vegetation cover (FCOVER), and weed or pest infestations.
		forests	…efficient use and management of forest resources (inventory & timber harvesting), providing intelligence & insights into forest composition like tree species, tree height and diameter (DBH), tree growth & productivity, tree cover density, wood inventory, harvest planning. Insights into forest health (biodiversity, protected areas) & threats, e.g. deforestation, drought, insect plagues, soil health, storm damage, and other forest disturbances.
		inland waters	…monitor the extent of reservoirs and lakes, observe seasonal activity, track resource utilization (reliable, repetitive, and low-cost information for water supply management) and environmental benefits, provision of temporal and spatial information on parameters which provide insight into the ecological status, dynamics and trends of inland waters. Key

[44] The Sendai Framework (https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030)

			parameters of water quality assessments include turbidity, suspended matter, chlorophyll-a, harmful algal blooms and trophic state classification.
		snow & ice	...verification of snow-related processes in land surface models, the impact of snow cover changes on ecosystems/biodiversity/human activities (e.g. road or mountain safety), analyse impacts of changes in the snow on water availability and permafrost, the role of snow in climate-related changes to the hydrological regime/cycle/ surface-atmosphere energy fluxes. Monitor snow cover (snowpack conditions such as depth, wetness), ice mass balance.
		biodiversity & land ecosystem	...data assimilation techniques to combine satellite observations of the land surface with radiative transfer and other physical models to provide best estimates of biophysical parameters, improving understanding of ecosystems and ecosystems and assessing vulnerability, etc.
		land use/land cover	...LU/LC - land use (biophysical coverage of land), land cover (socioeconomic use of land) - and land-use change (LUC) data are often used to detect ecosystem change risk factors.
		topography & motion	...topographic measurements deliver consistently digital elevation models (DEMs) for the mapping of large areas and in the monitoring of elevation changes in areas of land subsidence or uplift, ground subsidence, assets and infrastructures stability monitoring.
		geology	...multi-scale geological mapping and mineral exploration of any terrain and climatic environment, including services such elevation data sets which suit their study objectives in terms of scale, resolution and environment. Properties of soils, surface lithology can be detected.
Marine and ocean	The marine & ocean domain covers the **tracking, measuring, observing, modelling and assessment of** all maritime & marine focused activities across a broad range of applications such as marine safety, e.g. marine operations, oil spill combat, ship routing, defence, search & rescue; marine resources, e.g. fish stock management; marine and coastal environment, e.g. water quality, pollution, coastal activities; climate and seasonal forecasting, e.g. ice surveys, seasonal forecasting… Concerning the concept of "Digital Ocean" improving the monitoring of the Blue, Green, White and Brown Ocean, the classification may be linked as blue (metocean, marine pollution, water quality, ships & navigation...etc), green (fisheries, ecosystem and biodiversity) and white (sea ice & icebergs) while brown is related to coastal zones	metocean	...observations for quality meteorology over oceans (offshore weather and sea state monitoring) complemented with NRT data collection of variables such as wave height and frequency, wind speed and direction and ocean current velocity on global and regional scales.
		coastal	...coastal mapping (i.e. on land) represents an integrated approach in relation to environmental monitoring, incorporating such fields as urban development and coastal wetland loss, land-use cover and change, wetland mapping, coastal geomorphology (barometric pressure, on/off-shore wind, the slope of beach), maritime safety and security issues (hazard, disaster). The coastal zone (water ecosystem) may cover water depth-bathymetry and water optical properties, waterbody nutrients / productivity (chlorophyll-a concentration), littoral and subtidal habitat (mangroves, coral reefs, seagrass canopy density), erosion and sedimentation mapping, long time series of ocean colour products including uncertainties estimates or health issues such as algal bloom detection… Can be closely related to marine, land and inland water monitoring products.
		biodiversity & marine ecosystem	… monitoring and improving the understanding of the complexity of the global marine ecosystem (physical, chemical, biological and ecological processes) through critical observations in the health of and changes to marine biodiversity.
		fisheries	… improve understanding (through bio-geochemical analyses and forecasts for global and regional seas, topography, ocean colour, sea-surface temperature and ocean currents, key inputs for fish stock numerical modelling) of fish stock (including resilience and vulnerability) to natural and anthropogenic factors such as over-fishing effects (surveillance capabilities for the detection of illegal, unreported and undetected fishing activities).

		sea-ice & icebergs	…monitoring and forecasts of sea ice, including its extent, thickness, motion and ridges, hydrodynamic forecasts, ice monitoring and forecasting to allow for safe and efficient transportation route planning, improve the precision of ice thickness measurements.
		ships	…fleet tracking, provide real-time sea-ice data to ensure navigation safety in polar shipping routes, shipping route optimisation, marine reserves and protected area monitoring, illegal activity detection.
		marine pollution	…detection of marine oil spills through SAR, support research on marine litter with forecasts of sea currents and sea-surface heights (altimetry), sea-surface salinity, sea-surface temperature, ocean colour and sea-ice data.
Security & safety	It is the provision of EO services **defining, collecting, analysing** information to provide intelligence & safety (understand events, anticipated impacts and quick respond). It also includes political boundaries such as borders. Receive and share information quickly, understanding of complex operating environments such as border surveillance, maritime surveillance, support to EU External Action, ensuring security and sovereignty.	critical assets	… monitoring environmental and man-made risks to assets, such identify failure for dams, pipeline networks, roads, nuclear power stations by helping on decisions about assets through the analysis of remotely sensed imagery and data to reduce the cost of monitoring and predicting land use change and environmental risk. Needs assessments for response, recovery and reconstruction areas are also important.
		customs & border (migration)	…basic maps (digital, paper, using both EO and non-EO sources), crisis and damage mapping, situation maps, refugee/IDP support maps, thematic maps, communication reporting, alert services.
		health (epidemics & diseases)	…monitoring, identification and predict threats to human health. environmental and climate influences on appearance of unusual spreading of disease provoked through zoonosis (such Covid19), proximity to hazardous locations (such as toxic or nuclear waste sites), changes in biodiversity, land use, and land degradation, etc. can influence health outcomes. air quality, risk maps, etc combined with analytics and modelling are applied to improve health security.
		food security & production	…better monitoring and targeting of food aid and security issues through e.g. water monitoring (droughts), early warning system for pest and disease infection risks, crop losses associated with certain environmental conditions, e.g. temperature, rainfall, humidity.

3.3. Alignment with Copernicus services

The European Copernicus programme[45] is also an important element that will influence the future market for EO services. Copernicus is a key programme in Europe, and we should ensure that the Copernicus Services can be found a place within the taxonomy. The Copernicus services have already been defined each of which offers a number of products. Nevertheless, the Copernicus programme is dealing primarily with public sector information needs and hence a workable taxonomy must go beyond Copernicus since many other elements of the market are not addressed, more specifically those addressing built environment and links with other market sectors. Therefore, we propose this generic alignment at a high level, as shown in Table 16, which associates very well with the EARSC taxonomy, and often incorporate the Copernicus Services as it is shown in next chapter structuring the EO services.

Table 16- EARSC thematic perspective vs Copernicus services

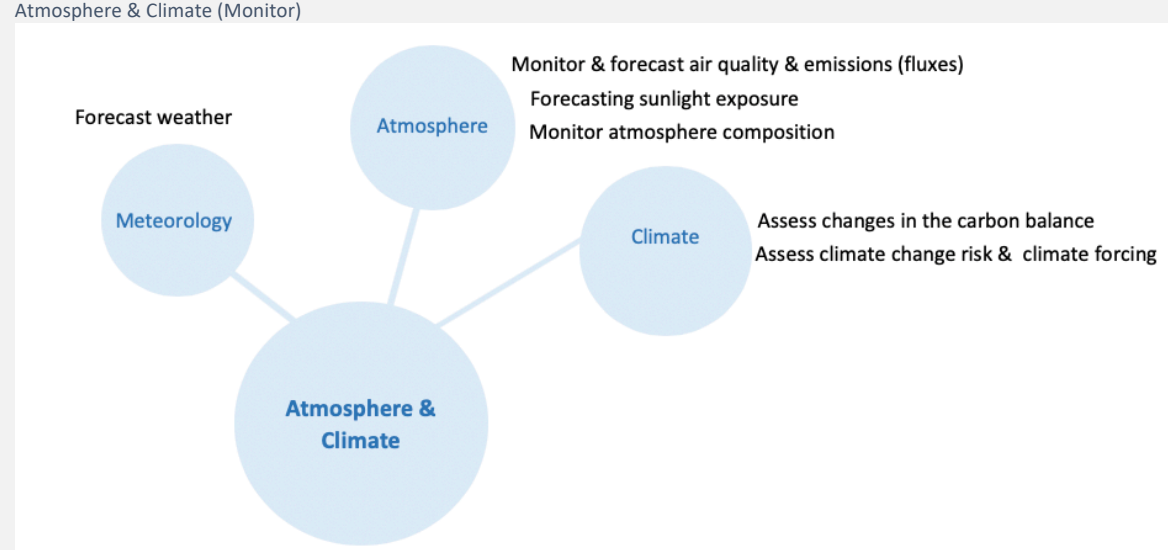| EARSC thematic perspective	Copernicus Services	Copernicus components/areas/applications
Atmosphere & climate EO services	Copernicus Atmosphere Monitoring Service (CAMS)	-air quality and atmospheric composition -ozone layer and ultra-violet radiation -emissions and surface fluxes -solar radiation -climate forcing …
	Copernicus Climate Change Service (C3S)	-support adaptation and mitigation policies by providing consistent and authoritative information about climate change (assessment of climate change impacts, risk management, sustainable human iterations within the environment…)
Built environment EO services	Services related to Copernicus Land Monitoring Service (CLMS) but specific for built environment	
Disasters & geohazards EO services	Copernicus Emergency Management Service (Copernicus EMS)	-a mapping component; (e.g. as digital or printed map outputs) -an early warning component (The European Flood Awareness System (EFAS), The European Forest Fire Information System (EFFIS), The European Drought Observatory (EDO), Global Flood Awareness System (GloFAS), Global Wildfire Information System (GWIS) and Global Drought Observatory (GDO) …
Land EO services	Copernicus Land Monitoring Service (CLMS)	-systematic monitoring of biophysical parameters -land cover and land use mapping -thematic hot-spot mapping -imagery and reference data …
Marine EO services	Copernicus Marine Environment Monitoring Service (CMEMS)	-Marine safety -Marine resources -Coastal and marine environment -Weather, seasonal forecasting and climate …
Safety & security EO services	[Copernicus security service(s)]	crisis prevention, preparedness and response -Border surveillance -Maritime surveillance -Support to EU External Action …

3.4. Structuring the EO services

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[45]www.copernicus.eu/en/about-copernicus

This section shows the layer where the Market view and the Thematic views meet – the level of EO services. We present these services aligned with the thematic perspective as we have had the most in-depth discussions with the thematic sector experts through the course of this update. Since our main goal is to classify and structure the market for EO services, we provide as much continuity from previous taxonomies but allowing flexibility to understand the change in the market and also provide a classification within which the Copernicus and other key programmes could fit. Tables 17 to 21 below show a range of keywords describing EO services in each of the Domains and Areas in more detail and show consistency with EO programmes.

3.4.1. Atmosphere & Climate (Monitor)

Table 17- Atmosphere and Climate EO services

Thematic area	EO services	Description & keywords
Monitor the atmosphere	Monitor and forecast air quality & emissions (fluxes)	Pollution and greenhouse gas emission monitoring. Measuring atmospheric concentrations and characterizing the micrometeorology or using atmospheric dispersion models to back-calculate the emission rates that gave the concentrations observed. Air quality/pollution source maps (CH4, CO2, NO2 & SO2, Particulate Matter, maps of average pollutant flux PM2.5, PM10).
	Monitor atmosphere composition	Monitoring present conditions and forecasting the distribution (transportation), for a few days ahead, of both anthropogenic and naturally occurring key greenhouse gases (GHG) like carbon dioxide (CO2), methane (CH4), or reactive gases such as nitrogen dioxide (NO2), sulphur dioxide (SO2), ozone (O3), etc.
	Forecasting sunlight exposure	While the solar radiation impacting the top of the atmosphere can be well modelled, the solar radiation arriving at the surface is dependent on the atmospheric transmission and turbidity and aerosol optical depth. Forecasting and risk assessment amount of solar (sunlight) radiation which reaches the surface of the planet (UV, radiation measures, models).
Monitor climate change	Assess changes in the carbon balance	Measuring carbon stocks, especially aboveground biomass and providing an overview of a range of approaches that have been developed and used to map biomass across a diverse set of conditions and geographic areas (quantifying stem volume and carbon stock changes). It also includes historical climate data.
	Assess climate change risk & climate forcing	Assess current and future vulnerability to climate change including variability caused by a perturbation of the climate system and associated atmospheric composition (aerosol, ozone and greenhouse gases) driven by human activities).

		The radiative forcing measures the imbalance in the surface solar irradiance and is a useful predictor of globally averaged temperature change.
Forecast the weather (meteo)	Forecast the weather	Monitor and forecast weather conditions such as temperature, storms, precipitation, heat waves and tropical cyclones – as well as other hazards influenced by weather, like floods or dispersion of atmospheric or marine pollution.

3.4.2. Built environment (Monitor)

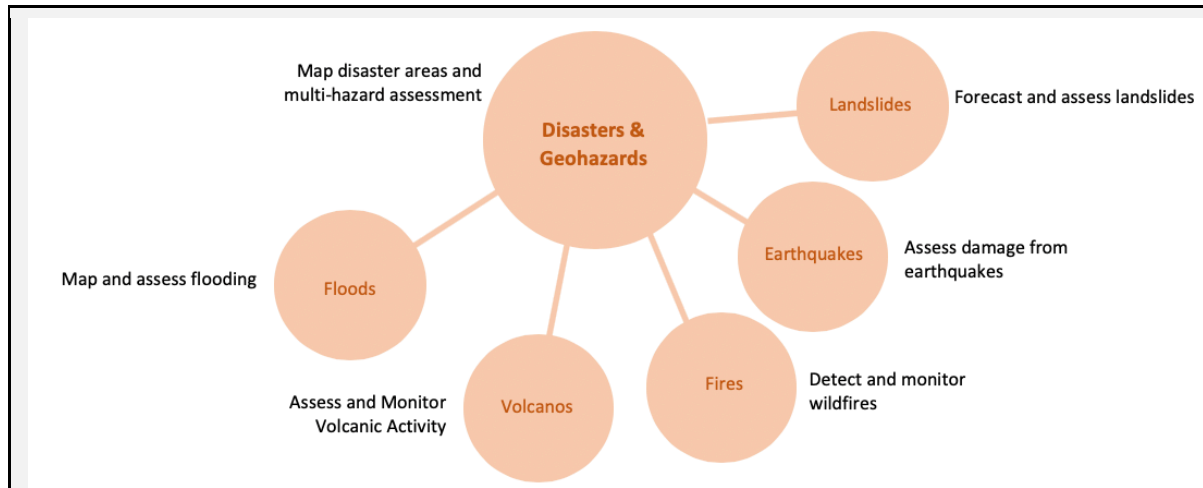Table 18- Built Environment EO services

Thematic area	EO services	Description & keywords
Monitor the built environment	Monitor urban areas	Observation, identification, mapping, assessment and monitoring of urban areas and their dynamics at a range of spatial and temporal resolutions. Digital imaging processing methods such basic thresholding, unsupervised classification or products such urban heat island, impervious surfaces, land use change (residential, commercial, other), building density (3D city modelling), high photovoltaic penetration at the urban scale.
	Monitor urban surroundings	Understanding human settlements on the outskirts and near rural areas. Mapping and evolution characterization of human interactions (environmental, population and habitat fragmentation, soil sealing and socio-economic) of rural areas and surroundings, urban sprawl, green urban areas.
	Monitor urban green and blue areas	Monitor green and blue urban areas (in relation to urban form, energy use and carbon emissions). It is about the estimation of urban energy fluxes at a neighbourhood scale (urban energy balance) using land cover, Digital Surface Models (DSM), surface roughness parameters (such as plan area index, frontal area index, roughness length and zero-displacement height), urban ecosystem restoration, urban heat island effect, green corridors, garden monitors.
	Monitor construction and buildings	Construction site surveying and progress mapping, comprising surrounding ground as well as displacements of key components of such structures. There is a need for Near Real Time (NRT) data delivery and measuring stress.

Monitor infrastructure & installations	Assess damage from industrial accidents	Assess structural integrity of the infrastructure, site suitability and vulnerability. Connection with disaster risk reduction (emergency response, recovery, rehabilitation and reconstruction).
	Asset infrastructure monitoring	Industrial activity assessment, monitoring of functional planning zones, exploit correlation with industrial activity to improve the model of subsurface, site suitability and vulnerability, land cover, infrastructure, dyke monitoring, emergency airport planning, etc.
	Map and monitor solar energy (solar farms)	Urban solar mapping and understanding the basic characteristics of solar radiation over specific monitoring locations including estimating the variability of solar radiation for site selection and grid data/operators. Solar monitoring services use time series, Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI), shadow mask.
	Map and monitor energy (wind farms)	Understand where wind farms can be sited most cost-effectively and monitor and map wind energy fields (design and operation), wind roses, wind speed & direction.
	Map and monitor hydroelectric energy	Hydrological network mapping (drainage navigation erosion) including hydropower grid monitoring and resource assessment. Water resource (reservoirs) monitoring, hydrological modelling and flood forecasting and mapping (dams).
Monitor transport networks	Map line of sight visibility (land surface)	Landscape visibility mapping and analysis, including spatial planning, terrain mapping (DTMs), land surface, map transmission and land routes.
	Map and monitor transport networks	Transportation systems, interdependencies and industrial progress planning including site, soft ground and network mapping, highway environmental monitoring and assessment, identification of road or track for logistics planning.
Monitor waste	Monitor land pollution and waste management	Identifying illegal dumping and waste management and disposal for law enforcement. Landfills and dump sites emit large quantities of methane, quantify the emissions from these large sites in a single snapshot (maps) and do it frequently, surface and subsurface soil contamination monitoring, Land use/Land cover (LU/LC) maps which depict the physical characteristics of the surface, dry matter productivity, migration of pollutants and imperviousness land surface are parameters needed for this service.

3.4.3. Disasters & Geohazards (Assess)

Table 19- Disasters & Geohazards services
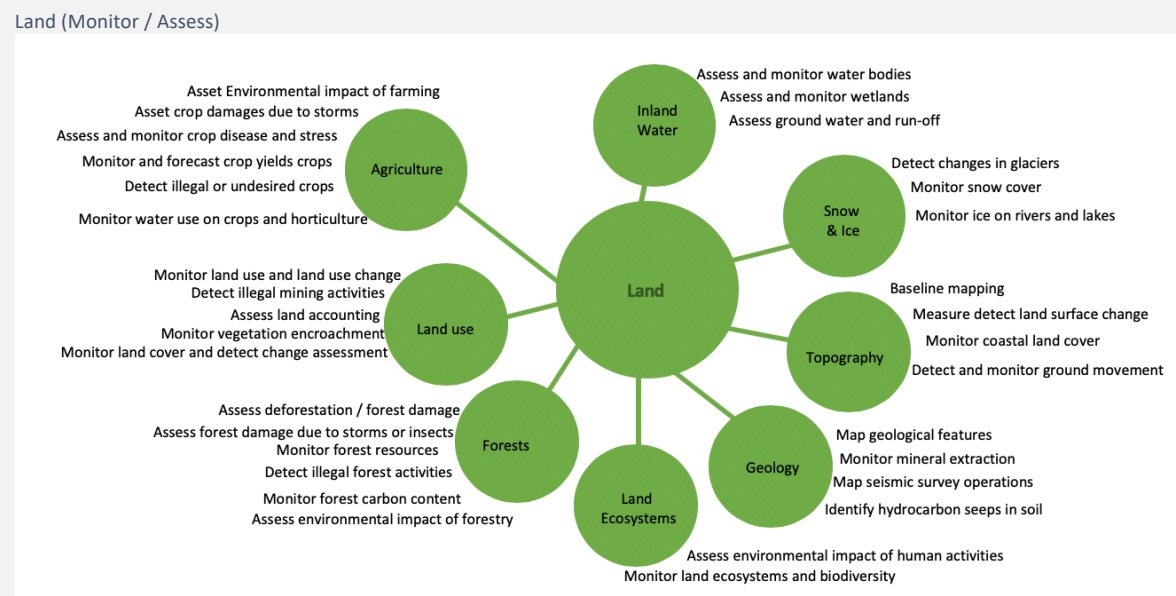
Disasters & Geohazards (Assess)

Thematic area	EO services	Description & keywords
Assess disasters & geohazards (emergency)	Map and assess flooding	Map and assess the extent of the flooding event (floods map, exposure), floodplain mapping, flood risk dynamic assessment and management of water buffer areas (overflow). Measure a variety of physical and biological parameters (incl. turbidity levels) in aquatic ecosystems over small and large areas. Products look into the flood impact and extent in phases such as early warning (early/quick/rapid detection), response and recovery monitoring.
	Forecast and assess landslides	Mapping, monitoring, early warning (quick/rapid detection) and assessment of trigger events, unstable areas (rainfall influence) such as landslides (dynamic risk damage, slope instability, subsidence detection, fault and discontinuity maps (vector or raster), ground deformation and motion). Associated services include support for the evacuation of areas prone to collapse or the identification of suitable areas for urban replacement.
	Assess and monitor volcanic activities	Assess ground deformation associated with volcanoes, seismic activity, volcanic eruptions (pre-eruptive, sin-eruptive, gas emissions, atmospheric ash, dispersion, heat flux). Rapid damage estimation (prevention), earthquake damage extent (loss adjuster dispatch). Impact on land cover and landscape (changes). Early warning (quick/rapid detection) and tracking of unrest / eruptive activity using satellite data in support of hazards mitigation activities. Map of the recent lava flows.
	Detect and monitor wildfires	Use optical data to detect and monitor the heat emitted by the fires [forest fire risk (extent, burnt scars) under rapid damage estimation, fire weather index[46] damage, fire protection, rapid damage estimation (prevention, insurance)]. Impact on global atmospheric emissions, with biomass burning to contribute to the risk on human health (besides direct effects, PM2.5, PM10 health impacts) and also to global budgets of greenhouse gases (GHG) like carbon dioxide etc. Monitoring of risk prevention factors [early warning (early/quick/rapid detection)] and issuing alerts for high risk locations.
	Assess damage from earthquakes	Mapping and monitoring of seismic exposure (e.g. population distribution and density in high-seismic-hazard areas). Earthquake disaster prevention, early warning (early/quick/rapid detection), recovery (reconstruction monitoring, residual risk assessment, dynamic risk assessment, information, damage). Extracting background information on seismic, inter-seismic deformations, slip rates & active faults, stress transfer on faults, rapid damage

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[46] Fire weather index: Copernicus emergency management service: Fire danger forecast https://effis.jrc.ec.europa.eu/about-effis/technical-background/fire-danger-forecast/

		estimation (prevention), change detection and preliminary damage map earthquake damage extent (loss adjuster dispatch).
	Map disaster areas and multi hazard assessment	Assess overall disaster risk maps in an appropriate format by using space, in-situ and location-based disaster risk information, vulnerability, capacity, exposure, hazard characteristics and their possible sequential effects at the relevant social and spatial scale on ecosystems, in line with national circumstances. Products will include disaster recovery maps and rapid mapping for crises, humanitarian aid maps (population density, infrastructure, logistical information), vulnerability assessment, damage assessment. Important to note the Sendai Framework for Disaster Risk Reduction 2015-2030.

3.4.4. Land (Monitor / Assess)

Table 20- Land EO services

Thematic area	EO services	Description & keywords
Monitor agriculture	Assess environmental impact of farming	Assess how yields and production are evolving and how agricultural activities are impacting the environment (i.e. the monitoring of farm-produced dust and particulate matter, polluted runoff, etc).
	Assess crop damage due to storms	Protect crops from extreme weather events (hailstorms, lightning and extreme temperatures) using early warning systems. Accurately and repeatedly assess current and historic losses for crop insurance, identify the plant growth stage, warning-service loss assessment, food-security, impact.
	Assess and monitor crop disease and stress	Map agricultural areas and crop health production (disease and stress). The vegetation indices are used to understand the amount of farmland in stressed conditions taking as inputs weather forecasts or climate factors, and being used in harvest predictions, agricultural forecasts, monitoring terrain for irrigation or the use of fertilisers.
	Monitor and forecast crop yields	Monitor and forecast specific crop types i.e. predicting certain crop characteristics on a day-by-day basis after a planting date, near-real-time data which helps make day-to-day farming decisions, to assess crop status, and predict how changes in the plant growth stage will

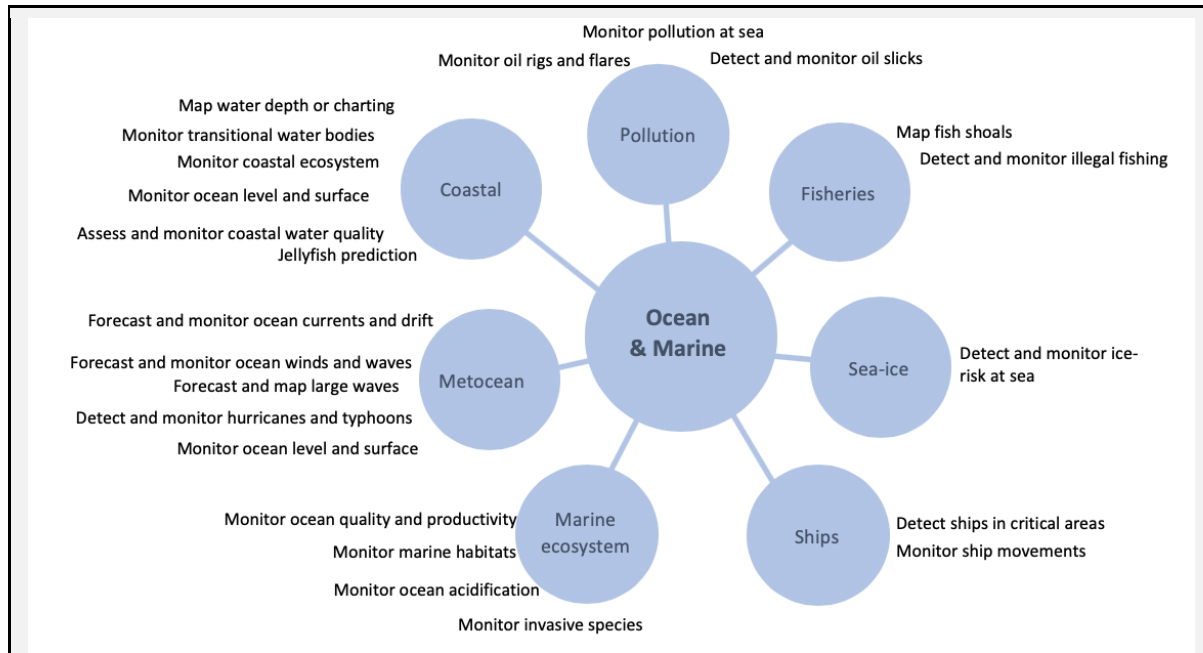|		
		affect crop acreage and yield harvest (inventories / statistics), crop types (extent, growth, health, stress), land surface and temperature. Seasonal forecasts with adaptive decisions such as (choosing crop varieties, crop–grazing balancing, commodity trading and food emergency preparedness, return on investment (nutrients & fertilisation monitoring)).
	Detect illegal or undesired crops	Crop planting area monitoring, crop area information acquisition, multi-temporal data and multi-spectral time series are two major aspects for improving crop identification accuracy and illicit crops, estimates, cultivation patterns, hyperspectral thematic crop type mapping.
	Monitor water use on crops and horticulture	Monitoring of run-off, improved agricultural water management, overall irrigation, taking into account soil water index, surface soil moisture, map vegetation index, etc.
Monitor the forest	Assess deforestation / forest degradation	Assessment and monitoring of forest biomass (above-ground, deforestation, reforestation, afforestation and degradation). Time series analysis of forest loss, disturbance index, carbon emissions, greenhouse gas (GHG) emissions, disturbance, measurement reporting and verification (MRV), Reducing Emissions from Deforestation and Forest Degradation (REDD+).
	Assess forest damage due to storms or insects	Assessing and managing damaged timber due to events such as storms, fires, insect damage etc. Elaboration of impact maps including sudden changes in forest stock volume, pest infestations modelling, ice and snow damages, etc.
	Assess, monitor & manage forest resources	Mapping forest and classifying forest type/cover change (classification/capacity) such as biomass (diversity, health, height, volume stress, location, extent), tree cover density (canopy coverage) and tree species, tree height and diameter), growth predictions, harvesting analysis (timber volume, inventory, clear cuts, accreditation and certification), forest condition mapping, time series, change detection monitoring of moist, etc.
	Detect illegal forest activities	Detect and identify illicit logging, change-detection, forest cover, forest types, biomass, density, etc.
	Assess environmental impact of forestry	Assess changes in the forestry and tree line (fragmentation, capacity, location, extent and tree cover density, atmospheric deposition and GHG emissions, transboundary atmospheric pollution, climate change effects on forestry, etc.).
	Monitor & assess forest carbon content	Monitor carbon balance, carbon tracking, global carbon stocks, greenhouse gas emissions from deforestation and forest degradation, land use, land use change and forestry (LULUCF). Support to the UN Framework Convention on Climate Change, REDD+.
Monitor bodies of inland water	Assess and monitor water bodies	Provides qualitative and quantitative information (e.g. time series and/or/of maps) concerning inland water quality, regarding chlorophyll content (algal blooms), suspended matter (turbidity, suspended sediment concentrations), and the water body (surface water extent, water quality, pollution, temperature, volume, level, alkaline water, evaporation, surface temperature) for permanent, ephemeral, inland water bodies.
	Assess and monitor wetlands	Water bodies monitoring and assessment, surface water dynamics, wetland ecosystem extent, water quality, ecosystem service mapping (e.g. carbon sequestration, flood regulation).
	Assess groundwater and run-off	Assess water run-off (water quantity), hydrological network and catchment areas (water catchment), hydrological simulations, run-off season, groundwater, integrated water management, soil moisture as relevant on the threshold runoff response in a small headwater catchment.

Monitor snow & ice	Detect changes in glaciers	Long term monitoring of glacial variations especially at the glacier margins and terminus location. Mapping and charting fluctuation, ice caps, landslides, etc. or measuring parameters such as ice thickness, surface ice velocities, and changes in surface elevation over time.
	Monitor and assessment snow cover	Monitoring snow cover area extent (depth, temperature), fractional snow cover, snow water equivalent and snow mass.
	Monitor ice on rivers and lakes	Monitor grounded and floating ice covers on shallow water and lakes (ice cover concentration, extent and phenology, inland ice, ice sheets, thickness, freezing period, melting period, land fast ice, ice/lake extent, snow/ice surface temperature).
Assess land ecosystems	Assess land ecosystems and biodiversity	Assessment of the ecosystem condition and pressure mapping of biodiversity with critical habitat maps, monitoring wildlife corridors, linear features (hedges and boundaries), soil moisture, vegetation indices (e.g., normalized difference vegetation index (NDVI), greenness and biomass, leaf area index (LAI), estimation of stem volume, etc.
	Assess environmental impact of human activities	Monitoring anthropogenic impact on land resources; LU/LC, productivity, Soil Organic Carbon (SOC), burnt area mapping, Forest & wooded land, Cropland, Pasture (improved grassland), Wetland, Settlements (villages, urban), Cropland/ grazing land management, Long-term cultivated; improved pasture, unimproved pasture, new set aside, old set aside, wetland/paddy, shifting agriculture, abandoned/ degraded, etc.
Monitor land use	Monitor land use and land use change	Monitoring Land Use (LU) and Land Cover Change (LC) is the measure available to monitor pressures on terrestrial ecosystems and biodiversity; mapping surface imperviousity, canopy structure phenology, etc., its classification and change detection (accuracy assessment procedures), Land Use, Land Use Change, and Forestry (LULUCF) reporting, land use studies, baseline map, etc.
	Detect illegal mining activities	Monitor and address various impacts of mining and hydrocarbons extraction studying environmental changes like acid mine drainage, illegal surface mining supporting law enforcement and allowing the regulatory agencies helping to avoid or minimize the adverse effects of illegal mining. These activities monitor the progression of disturbance caused by illegal mining, identifying and tracking reclamation sites, and assessing land use and land cover changes.
	Assess land accounting (land value, ownership, type use)	Measure land use statistics and land accounting (land administration, baseline map, land use studies and statistics; life populations, human settlement patterns, impact of drought on agricultural production, impact of loss of agricultural land on production, pollution caused by use of fertilizers/ pesticides, threats to wildlife due to habitat destruction, land evaluation for agriculture, areas at risk to land degradation, remedial measures to counter inappropriate land management, soil sealing). Monitoring human–environmental interactions such as landscape changes e.g. land use land cover (LULC), soil and terrain forms, surface hydrology (including shallow lakes, rivers, marshes and swamps) as well as ecological services (conservation), anthropogenic usage and land take (urban planning and management), land accounting and land administration, land use studies and statistics (use, parcels), cadastral.
	Monitor vegetation encroachment	Monitoring terrain surrounding infrastructure such as railways, pipeline and high voltage power line corridors. Major products to support this service are vegetation condition index (VCI), ancillary data, risk identification layer, prioritization layer.
	Monitor land cover and detect change assessment	A range of direct and indirect measurements to monitor pressures on land cover which is changing over time. Land cover assessment includes mapping from wide coverage (land cover and use) to locally or regionally focussed (habitat mapping). High-resolution Layers (characterization & classification), soil sealing, arid areas, wet areas,

		erosion potential, LCCS (Land Cover Classification System), imperviousness (e.g. CORINE land cover inventory).
Monitor topography and motion	Baseline mapping	Surface deformation maps and profiles elevation data products such: Digital Elevation Models (DEMs), Digital Surface Model (DSM), Digital Terrain Model (DTM), terrain roughness measure, slope stability (curvature, aspect), etc
	Measure & detect land surface change	Measure ground and infrastructure displacements (change detection monitor), surface movement (sand dunes, pipeline routes, corridor status, soil erosion) or landslides and subsidence.
	Monitor coastal land cover	Monitor coastal land cover, coastline, shoreline change and coastal morphology (coastal terrain models), including pollution by oil, litter etc.
	Detect and monitor ground movement	Detect reservoir compartmentalization & optimization, permafrost zone stability, ground displacement: fault identification, reactivation & discontinuities, uplift, subsidence, heave, thawing, landslides, earthquakes.
Extract information about subsurface geology	Map geological features	Detect and map features extraction, near surface features, lithology features, linear disturbance features (faults & discontinuities).
	Map seismic survey operations	Map seismic (survey, coupling, logistics), gravity-seafloor classification maps, onshore seismic survey operations (hydrocarbon exploration), satellite derived bathymetry products (water depth, water clarity - turbidity).
	Monitor mineral extraction	Monitoring the environmental impacts of mineral resources exploitation (ground surface), illegal activities, recovering abandoned sites, mine waste mapping and monitoring (erosion, land subsistence, biodiversity/habitat loss, destruction & disturbance of ecosystems).
	Identify hydrocarbon seeps in soil	Identification of hydrocarbon seepage (oil seeps) detection (near surface geology: faults, fractures, unconformities or carrier beds) as indicators of petroleum charge.

3.4.5. Ocean & Marine (Monitor)

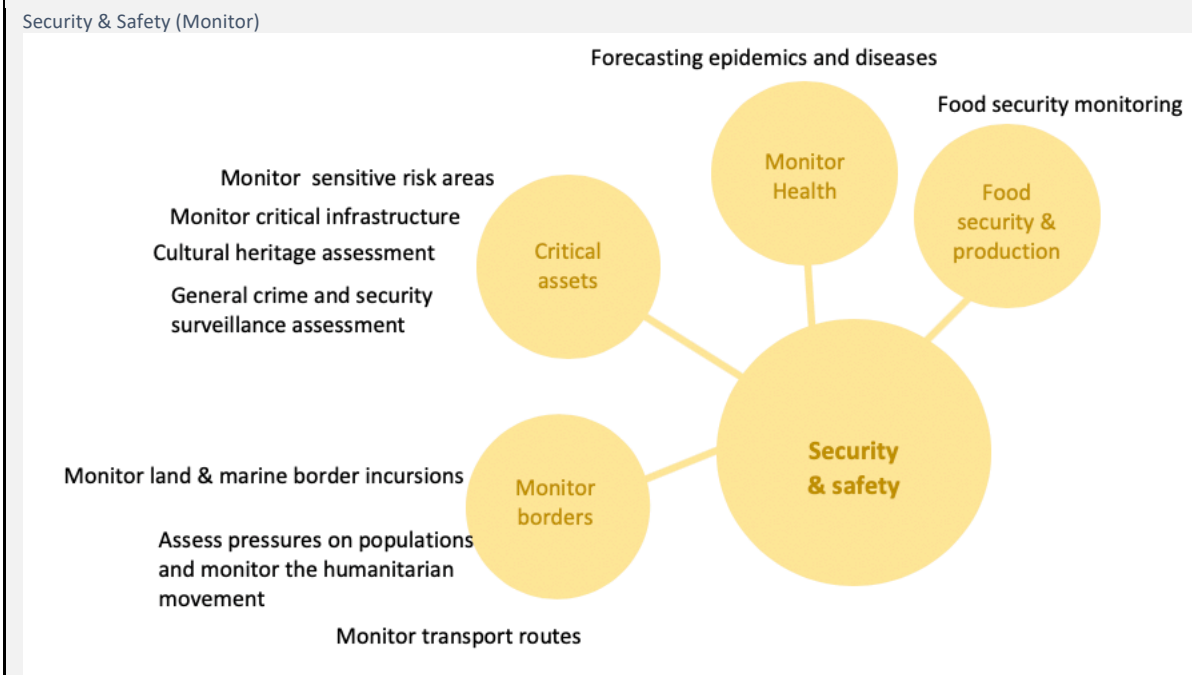Table 21- Ocean and Marine EO services

Ocean & Marine (Monitor)

Thematic area	EO services	Description & keywords
Meteocean	Forecast and monitor current movement and drift	Ocean water forecasting including ocean dynamics and circulation: tides and ocean currents (surface current models for tides), sea level, sea surface salinity (internal waves, eddies and frontal areas), upwelling, sea state, etc.
	Forecast and monitor ocean winds and waves	Wind resource mapping, derived winds (speed, direction, stress) and waves (current veins, swell-maps, sea surface height), wave exposure (fetch, averaged directional wind speed and bathymetry). The sea surface roughness is impacted by wind (waves) and rain cells.
	Forecast and map large waves	Forecasting extreme waves / tsunami, inundation forecasting (flow depth distribution), vulnerability maps, bathymetry, current velocity.
	Detect and monitor hurricanes and typhoons	Monitoring atmospheric front, local weather phenomena, cloud structure, winds and waves, sea-surface temperature and sea-surface height.
	Monitor ocean level and surface	Monitor (changes in) sea level, physical characteristics such as gravity, currents, temperature and salinity, ocean circulation (currents and eddies at the edges of holes and bumps), seasonal or inter-annual variations, or even longer periods (long-term rise in sea level), hindcasting.
Monitor coastal areas	Monitor water depth or charting	Satellite derived bathymetry mapping and charting. Surveying shallow waters.
	Monitor transitional water bodies	Essential environmental monitoring and management in aquatic ecosystems focus on rivers (inland waters, watershed) and lagoon/estuary-coastal region-ocean/Sea. Research projects now aiming to harmonise monitoring approaches across different water bodies.
	Assess and monitor coastal water quality	Detecting and mapping suspended sediment concentrations sediment (qualitative, quantitative), turbidity (quality, quantitative), visibility, chlorophyll-a concentration, suspended sediment may be indicative of estuarine processes, re-suspension or pollution.

	Jellyfish prediction	Assess the impact of jellyfish in human activities through ocean physics analysis maps (salinity, currents, sea level (SS hight), temperature (SST), ocean colour), ocean biogeochemistry analysis maps (ocean chlorophyll), policy objectives (marine policy, coastal management, common fisheries policy, marine strategy framework).
Monitor the marine ecosystem	Monitor ocean quality and productivity	Assessing water-related ecosystems. Water quality status (sea surface temperature (SST), transparency or turbidity, and ocean colour ocean colour composite (chl-a, transparency, swath, qualitative, quantitative), which enable eutrophication assessments and the detection of algal bloom (phytoplankton, harmful blooms - HABs), ocean productivity (carbon content, primary production).
	Monitor marine habitats	Monitoring generic life marine ecosystem (algal blooms, marine mammals...), sea surface temperature, sediments, plumes, nutrients, dredging operation, coral reef health assessment (bleaching), marine non-indigenous species (NIS), etc.
	Monitor ocean acidification	Monitoring the ocean carbonate chemistry, bio-geo-chemical cycles, ocean salinity, insitu (partial pressure of carbon dioxide in the water, dissolved inorganic carbon, alkalinity and pH).
	Monitor invasive species	Sargassum detection for seasonal planning (estimate drift and eventual landings on the coasts), Products such as drifting simulation modelling, together with weather and surface currents.
Monitor fisheries	Map fish shoals	Fish-shoal location, fish population dynamics fed by-catch reports (ERS-Electronic recording and reporting system) and catch efforts estimated from VMS (Vessel Monitoring System), collection of catch reports. Other products in consideration such bathymetry, waves, current movement and drift, pollution, ocean colour, surface temperatures (SSTs), sea surface height anomalies and sea surface colour revealing the abundance of chlorophyll a).
	Detect and monitor illegal fishing	Track and localization of licensed fishing vessels movements and detect suspicious activity, fleet management services (ocean colour, PP, SST, etc).
Monitor sea-ice and icebergs	Detect and monitor ice-risk at sea	Detect sea-ice and icebergs (ice cover, sea ice thickness, height of the ice surface, water body extent) during ship routing.
Ships monitoring, detection and tracking	Detect ships in critical areas	Detect and monitor the movement of ships and activity at associated ports and infrastructures (baseline activity), shipping and navigation.
	Monitor ship movements	Monitor sea-traffic, shipping lanes, ship-source pollution, discharges, sea surface temperature (SST).
Monitor marine pollution	Monitor pollution at sea	Monitoring turbidity & pollutants at sea such marine litter, marine plastics, hazardous and noxious substances (HNS) with relevant parameters (altimetry, sea-surface salinity, sea-surface temperature, ocean colour and sea-ice data) and policy objectives (integrated maritime policy, environmental action programme, etc).
	Detect and monitor oil slicks	Detect and monitor size, extent and location of oil spills, as well as providing information on wind, current and waves to predict oil movement. The oil spill threats are on early warning stages of natural oil seepage and during the disaster monitoring and characterization).
	Monitor oil rigs and flares	Monitoring of methane and other gases flared from gas flares and oil rigs, oil wells due to possible malfunctioning. Typically service accompanying forecast weather conditions.

3.4.6. Security & Safety (Monitor/Assess)

Table 22- Security & Safety EO services

Security & Safety (Monitor)

Forecasting epidemics and diseases

Food security monitoring

Monitor sensitive risk areas
Monitor critical infrastructure
Cultural heritage assessment
General crime and security surveillance assessment

Monitor land & marine border incursions

Assess pressures on populations and monitor the humanitarian movement

Monitor transport routes

Thematic area	EO services	Description & keywords
Monitor critical assets	Monitor sensitive risk areas	Geospatial intelligence analysis, sensitive risk areas (mines, unexploded objects (UXO), de-mining) mapping, high risk areas mapping, precision mapping, activity detection, auxiliary research and judgment on anti-terrorism in important areas of public security.
	Monitor critical infrastructure	Risk evaluation, threat analysis, vulnerability assessment, dams monitoring, water treatment monitoring facilities monitoring, oil fields monitoring, pipelines monitoring, pumping stations monitoring, airports monitoring, governmental buildings monitoring, transport networks monitoring.
	Cultural heritage assessment	Mapping heritage sites and in supporting the archaeological investigation, understand the scale, impact, opportunities, responses and tools for conserving world heritage and mitigating threats, vulnerability assessment, damage assessment, risk evaluation, looting tracking. Detect ground deformation and monitor subsidence at archaeological sites, monuments and historic urban centres to detect different types of surface changes caused by erosion, floods, vegetation or human actions.
	General crime and security surveillance assessment	Border control monitoring, terrorism threat risk assessment, piracy, illegal cropping analysis, cross-border state disputes analysis.
Monitor borders	Monitor land & marine border incursions	Border area monitoring, coastal area monitoring, migration monitoring.
	Assess pressures on populations and monitor the humanitarian movement	Monitor movement of people, population pressures, monitoring of settlements, evolution, characterization, situation maps, migration and cleansing monitoring, population pressures, displacement of population assessment, planning of contingency operations and operations security & coordination maps (moving objects such vehicles), impact on the surrounding environment, humanitarian camps.

	Monitor transport routes	Monitor economic activity, transportation of legal and illegal goods monitoring, tracking and identification (drug trafficking monitoring), smuggling location, maritime traffic assessment.
Monitor health	Forecasting epidemics and diseases	Health maps and epidemic vector control mapping (daily disease risk maps, NDVI, land cover, soil type), environmental monitoring of endemic diseases and chronic diseases, public health emergencies disaster/danger, pollution-health risks profiling in the urban environment.
Food security & production	Food security monitoring	Map and assess the extent and intensity of the drought. support food security throughout the cycle, from design to implementation, monitoring, evaluation, and adaptive decision making. Assess a variety of physical and biological parameters in ecosystems and economy; maximize sustainable yield and productivity by providing timely and accurate information (early warning system) like; drought, insect plagues, pest and diseases, infection risks, storm damage. Monitor crop's growth, monitor groundwater and water levels in rivers, radiation and soil, etc.

4. Conclusions

Earth Observation is influential and plays an increasingly important role in the value chain of many industries providing, not only sector-specific, timely and holistic data and information but overall intelligence on global supply sectors. There is an explosion of new business models arising to exploit the growth of space-derived data fuelled by: open data policies; reduction in cost of innovative satellite missions delivering daily high-resolution global coverage; and a massive increase in the accessibility of computer storage, computing power and complex algorithms laying the path to develop and deliver new EO solutions. These new solutions can provide benefit to a wide range of new and existing users of EO-derived products. This document and the taxonomy described herein attempts to make this landscape of new services navigable to these potential users through definition of a "common language".

To define this common language, it is necessary to establish a formal and standardized representation of the interests and the knowledge of both the provider and the potential user communities. This report aims to describe the process of updating the existing EARSC taxonomy and the main elements of the taxonomy update methodology.

The introduction section gives background information on different approaches to taxonomies.

The Terminology and Methodology section first gives an overview of the shared language required to ensure that all stakeholders are on the same page in terms of what words and phrases, which will be used to define elements of the taxonomy, are considered to mean. These definitions, including the Domains and Areas of the Thematic view, the Markets and Sectors of the Market view, user language, in terms of Standardised verbs & comparison with other taxonomies such Bloom & DIWK as well as technical language used to define EO service construction are presented. This section goes on to outline the steps taken to update the existing EARSC methodology, which can be summarised as:

i. Definition: Defines the existing EARSC taxonomical approach, giving a validation for the two-view (Market and Thematic) approach taken. The Market view of EO services is the view from the users' point of view and focusses on the market in which the users thinks of themselves in. The Thematic view gives a perspective on the services from the technical domain in which the provider thinks of themselves.

The taxonomic levels are described: The Markets view is subclassified into sectors with more precision on the markets in which the user operates and the Thematic view (Domains) are sub-classified into Areas of more precision in terms of the technical domain from which the provider is coming. The third level is formed by the EO services themselves which form the bridge between the market and thematic views (both are views on the same set of services from the point of view of different stakeholders). These services are further described by the data, outputs and applications which comprise them. This section answers the questions 'What is the taxonomy?' and "How do we ensure it remains up to date?"

ii. Results – Taxonomy evolution: Describes the results of discussions with industry and academic stakeholders and the update to the categories employed in the market and thematic views on the taxonomy. The updated tables that form the EARSC taxonomy are presented in this Section. These include descriptions of the categories of both the Thematic (Themes and Areas) and Market (Markets and Sectors) views on the taxonomy as well as descriptions of the EO services which form the bridging layer between the two views. This section answers the questions "How was the taxonomy upgraded?" and "What does it look like now?"

iii. Uptake: Describes the applicability of the updated EARSC taxonomy to a range of other industry stakeholder approaches to show the benefit of this unified approach which encompasses all other approaches. This section answers the question "What is the applicability to other communities?"

In summary this document has presented the EARSC taxonomy and answered the question "**How can an end user know what EO services are available that are relevant for their field/activity?".**