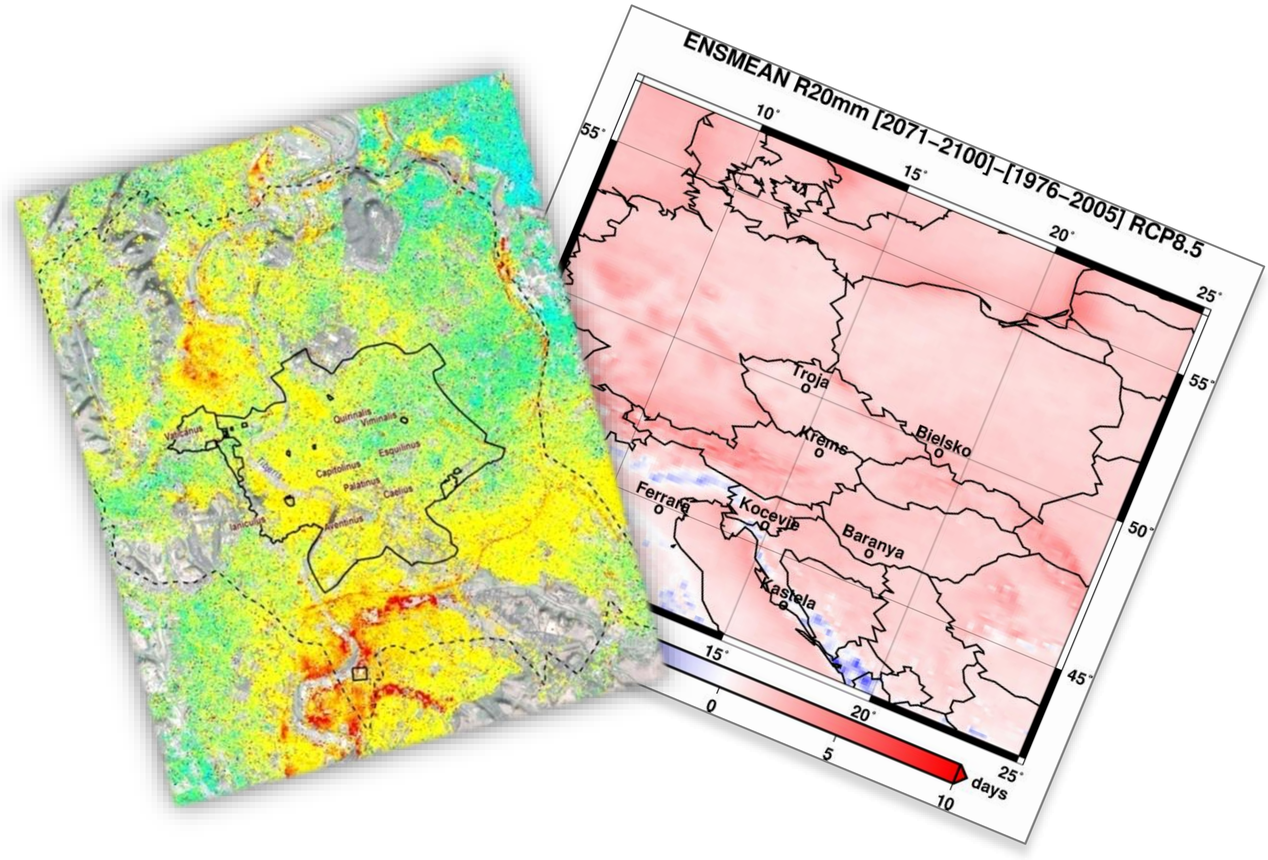
Report on the user requirements in the Copernicus domain to support Cultural Heritage management, conservation and protection



	Name(s)	*Affiliation*
Prepared by:	Nico Bonora[1], Alessandra Bonazza[2], Daniele Spizzichino[1], Andrea Taramelli[1], Anna Conticello[3], Benjamin Ducke[4], Simon Crutchley[5]	[1]Italian Institute for Environmental Protection and research (IT); [2]National Research Council of Italy (IT); Ministry for Cultural Heritage and Activities and for Tourism (IT); [4]Deutsches Archäologisches Institut (DE); [5]Historic England (UK); [6]Rijksdienst voor het Cultureel Erfgoed (NL).
Contributions:	Antonello Bruschi[1], Henk Alkemade[6]	

Task Force Members:	Task Force Chair: Salvatore Nastasi – Ministry for Cultural Heritage and Activities and for Tourism (IT) **Italy**: Antonia Pasqua RECCHIA (Head of Delegation); Nico BONORA, Istituto superiore per la Protezione e la Ricerca Ambientale (ISPRA); Daniele SPIZZICHINO, Istituto superiore per la Protezione e la Ricerca Ambientale (ISPRA); Raffaella GADDI, Istituto superiore per la Protezione e la Ricerca Ambientale (ISPRA); Cristina SABBIONI, Consiglio Nazionale delle Ricerche, Istituto di Scienze dell'Atmosfera e del Clima (CNR-ISAC); Alessandra BONAZZA, Istituto di Scienze dell'Atmosfera e del Clima (CNR-ISAC); Alfonsina RUSSO, Direttore Parco Archeologico del Colosseo (MiBACT); Carlo CACACE, Istituto Superiore per la conservazione e il restauro (MiBACT); Maria Elena CORRADO, Istituto superiore per la conservazione e il restauro (MiBACT); Alberto BRUNI, Parco Archeologico di Pompei (MiBACT); Anna CONTICELLO, Segretariato Generale (MiBACT); Nicola CASAGLI, Università degli Studi di Firenze (UNIFi); Laura CANDELA, Agenzia Spaziale Italiana (ASI). **Belgium**: Jean-Noël ANSLIJN, Service public de Wallonie - DGo4 - Agence Wallonne du Patrimoine - Direction de l'Appui Scientifique et Technique. **Cyprus**: Kyriacos THEMISTOCLEOUS, Eratosthenes Centre of Excellence / Cyprus University of Technology. **France** : Pascal LIEVAUX, Laboratoire de Recherche des Monuments Historique (LMRH) ; Geneviève PINÇON, Laboratoire de Recherche des Monuments Historique (LMRH) ; Alexandre CAUSSE, Fondation des Sciences du Patrimoine; Isabelle BENEZETH, Laboratoire de Recherche des Monuments Historique (LMRH); Aline MAGNIEN, Laboratoire de Recherche des Monuments Historique (LMRH).

	Germany: Reinhard FOERTSCH, Deutsches Archäologisches Institut Zentrale (DAI); Benjamin DUCKE, Deutsches Archäologisches Institut (DAI); Robert KUHN, Wissenschaftlicher Mitarbeiter - Vor- und Frühzeit Ägyptens / Pre- and Early Dynastic Egypt; Anton Gass, Wissenschaftlicher Mitarbeiter - Vor- und Frühzeit Ägyptens / Pre- and Early Dynastic Egypt; **Greece**: Athanasios PALIATSOS, Ministry of Digital Governance; Argyro KAGIA, Ministry of Digital Governance. **Czech Republic**: Ladislav ŠMEJDA, Czech University of Life Sciences Prague - Department of Applied Geoinformatics and Spatial Planning. **Malta**: Kevin BORDA, Superintendence of Cultural Heritage; Claudette FARRUGIA, Arts Council Malta. **Netherlands**: Jasper VAN LOON, Netherlands Space Office; Henk ALKEMADE, Cultural Heritage Agency of the Netherlands. **Norway**: Lars ROGSTAD, Directorate for Cultural Heritage; Kari LARSEN, Directorate for Cultural Heritage; Terje BIRKREM HOVLAND, Norwegian Ministry of Climate and Environment Department for Cultural Heritage Management. **Poland**: Marcin SKRYCKI, Ministerstwo Kultury i Dziedzictwa Narodowego. **Portugal**: Victor SILVA, Foundation for Science and Technology; Ana SUTCLIFFE Foundation for Science and Technology; Paula AMENDOEIRA, Direção Regional de Cultura do Alentejo; Ana Cristina PAIS, Direção Regional de Cultura do Alentejo; Carlo Emanuele BOTTAINI, Universidade de Évora. **Spain**: Laura DE MIGUEL, Ministerio de Cultura y Deporte; María AGÚNDEZ, Ministerio de Cultura y Deporte. **United Kingdom**: Adrian Broad, Met Office; Simon Crutchley, Historic England; Helen Winton, Historic England

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List of acronyms

C3S = Copernicus Climate Change Service
CAMS = Copernicus Atmosphere Monitoring Service
CC = Copernicus Committee
CEMS = Copernicus Emergency Monitoring Service
CH = Cultural Heritage
CHIME = Copernicus Hyperspectral Imaging Mission
CLMS = Copernicus Land Monitoring Service
CMEMS = Copernicus Marine Environment Monitoring Service
CSCDA = Copernicus Space Component Data Access
CSS = Copernicus Security Service
CSS BS= Copernicus Security Service – Border Surveillance
CSS MS= Copernicus Security Service – Marine Surveillance
CUF = Copernicus User Forum
DEM = Digital Elevation Model
DGI = Digital Geographic Information
DIAS = Data and Information Access Services
DSM = Digital Survey Model
ECMWF = European Centre for Medium-Range Weather Forecasts
EE = Entrusted Entities
EEA = European Environmental Agency
EFAS = European Flood Awareness System
EFFIS = European Forest Fires Information Service
EIONET = European Environment Information and Observation Network
EMSA = European Maritime Safety Agency
EO = Earth observation
LSTM = Land Surface Temperature Monitoring/Mission
MSs = Member States
NDVI = Normalized Difference Vegetation Index
NGO = non-governmental organization
NH = Natural Heritage
NRT = Near Real Time
S2GM = Sentinel-2 Global Mosaic
SAR = Synthetic Aperture Radar
SatCen = Satellite Centre
VHR = Very High Resolution

1. Introduction

The present document reports on the results of the activities conducted by the Copernicus Cultural Heritage Task Force. The aim is to assess the current and future potential of Copernicus data, services and products in support of monitoring and protection of Cultural Heritage. It also recommends sustainable actions and strategies for the integration of Earth Observation technologies in Cultural Heritage management.

The establishment of the Copernicus Cultural Heritage Task Force, was proposed by the Copernicus User Forum and formalised by the Copernicus Committee. It is mainly composed of Member States (MS's) national experts, from both the Cultural Heritage and Earth observation domains, and is officially coordinated by Italy and chaired by the Italian Ministry of Cultural Heritage and Activities and for Tourism (MiBACT).

The activity of the Copernicus Cultural Heritage Task Force, based on the outcomes of the study "Copernicus services in support to Cultural Heritage" by PricewaterhouseCoopers (PwC, 2018)[1] aimed at identifying the best option(s) among those identified in the study[2], to facilitate Cultural Heritage community access to Copernicus products.

The study was a first answer to the needs of the user community responsible for Cultural Heritage preservation, monitoring and management, through the identification of dedicated new products, or modification of existing ones, in the Copernicus portfolio.

Building on this basis, the Task Force involved an extended range of stakeholders with a larger set of user needs, and provided a structured model to analyse their compatibility with the Copernicus Services.

Subsequently, the user needs previously identified were analysed, aggregated, filtered and codified into specific requirements. This allowed the Copernicus programme Entrusted Entities to express their views on the current Services portfolio and on which new products might feasibly be developed within the Services capacity.

To reach its objective, the Copernicus Cultural Heritage Task Force implemented the following roadmap:

1) Map the Member States' users' needs for Cultural Heritage in the Earth observation domain, beyond those identified in the "Copernicus services in support to Cultural Heritage" study.
2) Complement, filter, aggregate and codify the user needs into specific requirements.
3) Analyse how existing Copernicus data, services and products could satisfy those requirements,
4) Identify possible enhancement and customization of Copernicus products within already operational Core Services.
5) Analyse possible synergies with National, European or International space related solutions to fill the gaps.

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[1] PwC France, 2018. Copernicus services in support to Cultural Heritage, Final report N° ENTR/341/PP/2013/FC - Framework Contract for Expert advisory support to the European Space Policy and Programmes. Prepared for DG GROW, Ref. Ares (2018)5305294 - 16/10/2018.

[2] Option 1 is relying on existing core products, data and information that are currently suitable for Cultural Heritage applications, but emphasising the existence of such products by raising awareness (no budget allocated).

Option 2 aims at setting up a specific user interface in the form of a web-based platform (i.e. web-based front-end) fully dedicated to Cultural Heritage, where user communities could find existing Copernicus data and information suitable for Cultural Heritage activities, together with additional existing products from core services that have been adapted to Cultural Heritage needs (budget allocation).

Option 3 aims at creating a Copernicus Service, in addition to the existing ones, which would be exclusively dedicated to Cultural Heritage.

Various user communities, who may benefit from specific services aimed at Cultural Heritage monitoring are:

- National Heritage Authorities, responsible for conservation and protection activities (e.g. Public Authorities at different levels - European, National, Regional and local) including Municipalities, with decision making responsibility as primary users;
- Specific International and National organizations (including UNESCO, ICCROM, ICOMOS);
- Public and private research entities bringing innovation into Cultural Heritage monitoring practices;
- Business community to build/supply services for commercial or institutional purposes based on innovation in the cultural heritage sector;
- NGO & non-Profit entities, to improve societal benefits achieved from the enhanced resilience of Cultural Heritage at risk;
- Agencies and bodies involved in emergency management (Civil Protection, Fire Brigades, Environmental security).

List of entities consulted by the Task Force to analyse user needs in order to identify users' requirements is included as **Annex I.**

In agreement with the definition given by the European Commission within the European Year of Cultural Heritage 2018 definition[3], within the present document Cultural Heritage refers to:

- **Tangible** – for example buildings, monuments, artefacts, clothing, artwork, books, machines, historic towns, archaeological sites.
- **Intangible** – practices, representations, expressions, knowledge, skills - and the associated instruments, objects and cultural spaces - that people value. This includes language and oral traditions, performing arts, social practices and traditional craftsmanship.
- **Natural** – landscapes, flora and fauna.
- **Digital** – resources that were created in digital form (for example digital art or animation) or that have been digitalised as a way to preserve them (including text, images, video, records).

In order to maintain coherence with the overall definitions and structure adopted within PwC Study, specific references are made to Cultural and Natural Heritage in identifying the monitoring domains of interest for the Task Force, which correspond to the High-level User needs identified by the PwC study.

[3] https://europa.eu/cultural-heritage/about_en.html. Consulted on March 19, 2020.

2. Safeguarding Cultural Heritage: the policy framework

In 2007 the European Agenda for Culture[4] highlighted the Cultural Heritage priority for the European cultural cooperation. Furthermore, it is considered a strategic resource for a sustainable Europe, as stated in the Council Conclusions of May 2014[5], and the European institutions decided to celebrate it in 2018 with the European Year of Cultural Heritage to encourage the appreciation of Europe's Cultural Heritage as a shared resource,

- raise awareness of common history and values,
- reinforce a sense of belonging to Europe
- better protect, safeguard, reuse, enhance, valorise and promote Europe's Cultural Heritage.

Cultural Heritage has finally been recognized as an incentive for strengthening the resilience of society in facing the impact of catastrophic events and its protection has been highlighted as having a key role in support of socio-economic development and sustainable tourism.

At global policy level, the Sendai Framework for Disaster Risk Reduction 2015-2030[6] represented a significant turning point, by including among its key priorities the protection of Cultural Heritage and by inviting national authorities to cooperate in increasing an awareness of Cultural Heritage impacts in the context of exposure to hazards. Afterwards, the Action Plan on the Sendai Framework, published in 2016 by the European Commission and covering a five-year period, provided for a more systematic disaster-risk-informed approach in EU policy making. In particular, in support of the implementation of Sendai Priority 4 (Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction), 'the development and better integration of transnational detection and early warning and alert systems for better disaster preparedness and response action' is envisaged among measures of Key Area 4[7]. The use of the Copernicus Programme Earth observation data, products and services for monitoring and assessing the potential impact of natural and anthropogenic disasters, humanitarian crises, and conflicts on Cultural Heritage and, consequently, enhancing prevention and management is therefore strongly recommended. This is also highlighted in the recent EU publication Safeguarding Cultural Heritage from Natural and Man-Made Disasters (Bonazza et *al*., 2018)[8].

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[4] Resolution of the Council of 16 November 2007 on a European Agenda for Culture (2007/C 287/01).

[5] Council conclusions of 21 May 2014 on Cultural Heritage as a strategic resource for a sustainable Europe (2014/C 183/08).

[6] Adopted on 15 March 2015 at the third United Nations World Conference on Disaster Risk Reduction and adopted by the UN General Assembly on 3 June 2015.

[7] Sendai Four Priorities for Action:
Priority 1. Understanding disaster risk;
Priority 2. Strengthening disaster risk governance to manage disaster risk;
Priority 3. Investing in disaster risk reduction for resilience;
Priority 4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction.

[8] Bonazza A., Maxwell I., Drdácky M., Vintzileou E., Hanus C., Ciantelli C., De Nuntiis P., Oikonomopoulou E., Nikolopoulou V., Pospíšil S., Sabbioni C., Strasser P., 2018. Safeguarding Cultural Heritage from Natural and Man-Made Disasters - A comparative analysis of risk management in the EU (Contract n ° EAC-2016-0248). DOI: 10.2766/224310.

3. Current status

The term "Cultural Heritage" is here described as a set of resources, a profession, a key market and an employment sector that contribute to both a European cultural and economic asset. Modern Cultural Heritage/resource management is a complex discipline that requires the use of modern digital technology and information systems. Many of the world's most important known monuments, historic old towns, archaeological sites and parks are located within the European Union (Valagussa et *al*., 2019)[9]. 45% of the total UNESCO World Heritage List belongs within Continental Europe (JPI-CH PROTHEGO Project 2018)[10].
Managing these resources in the age of mass tourism and climate change creates a growing challenge that can only be addressed by integrating management models and practices, and by making use of efficient remote sensing technologies.
Many sites and monuments are insufficiently secured and/or protected, particularly if located outdoors and in accessible environments. In such locations they are particularly vulnerable due to their exposure to both natural and anthropogenic threats together with a lack of efficient monitoring tools. This means that current short and long-term management plans and inspections need to be integrated into a more regular monitoring regime so as to provide effective management and a clear view on the state of conservation.
Since the 1990s (Valletta Treaty), heritage management in some EU countries has therefore adopted the practice of producing "predictive" or "value" maps to assess the archaeological potential of unsurveyed areas (Van Leusen et *al*., 2002[11]; Carlucci et *al*., 2011[12]).

Cultural resource management, therefore, requires monitoring services based on a combination of highly detailed digital images (with respect to spectral and geometric resolution), in situ data and 3D models. In addition, accessible sites must be assessed for public safety and patterns of visitor access and subsequent stress. In combination with topographic and land use data, risk assessments and preservation/development plans can then be devised. The same is true for interventions that become necessary due to unforeseen circumstances (e.g. natural and man-made disasters). In any case, this task is one of the most complex and expensive when it comes to cultural resource management. Therefore, there is a high demand to explore cost-effective solutions using remote sensing and related technologies to replace current ones that are time consuming and expensive.

Sites and monuments are affected by various environmental agents acting together that impact with varying frequency and intensity. The majority of them, such as wind erosion, groundwater level changes, air pollution and climate change, can be extremely harmful when they affect a site over a long period of time. Therefore, long-term monitoring of a large number of environmental and climate parameters and indicators, at proper spatial and temporal resolution, is a key requirement. To be most effective, current cultural resource management practice requires information that relies both on remote sensing and environmental (in situ) data to achieve integrated and predictive models.

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[9] Valagussa A.; Frattini P.; Crosta G.; Spizzichino D.; Leoni G.; Margottini C., 2019. Hazard ranking of the UNESCO World Heritage Sites (WHSs) in Europe by multi-criteria analysis. Journal of Cultural Heritage Management and Sustainable Development.
[10] http://www.prothego.eu/home.html
[11] Van Leusen, P. M.; Deeben, J.; Hallewas, D.; Zoetbrood, P.; Kamermans, H. & Verhagen, P., 2002. Predictive Modelling for Archaeological Heritage Management in the Netherlands. Baseline Report NWO, 2002.
[12] Carlucci R.; Di Iorio A.; Placidi A.; Pichini M., 2011. WHERE. Monitoraggio di siti archeologici da satellite; Archeomatica, Anno II, Numero 3 - Progetto WHERE

When sites are located in protected natural environments, their preservation, accessibility and the effects of visitor numbers are closely linked to the characteristics of the natural heritage itself. In such cases, a coordinated management of the cultural resources with the natural ones by integrated actions and plans should be fostered. Beside regular management activities and development plans, in order to protect Cultural Heritage from natural and man-made disasters (e.g. floods, landslides, forest fires, earthquakes, armed conflicts, etc.), the damage assessment immediately after the event is necessary, as well as the development of strategies suitable for Cultural Heritage protection in the domains of emergency and security planning (Lasaponara and Masini, 2018)[13].
Within the research perspective, instruments based on the integration of Earth observation products and in-situ data have been exhaustively proven to be a valuable tool in support of the protection and management of Cultural Heritage at risk (Lasaponara *et al*., 2014)[14].
In recent years, a number of significant European research projects have been established to provide evidence of beneficial use of Earth observation data for Cultural Heritage monitoring and applied analysis purposes, such as:

JPI-CH-PROTHEGO - PROTection of European Cultural Heritage from GeO-hazards project (2015-2018, coordinated by ISPRA) aims at identifying, assessing and monitoring risks and strengthening disaster preparedness at heritage sites in the future, utilizing remotely sensed information on ground stability and motion combined with geo-hazard datasets (to identify the most endangered UNESCO WHL sites across Europe)[15].

H2020 HERACLES - HEritage Resilience Against CLimate Events On-Site (2016 – 2019). Within this project ADAM (a cross-domain application) provides climate and atmospheric data responsive systems/solutions for effective resilience of Cultural Heritage against climate change effects, implementing climate indicators as a combination of Earth observation data and ground measurements[16].

H2020 ATHENA - Remote Sensing Science Center for Cultural Heritage (2015-2018). The goal of the project is to establish a “Remote Sensing Science Center for Cultural Heritage” in Cyprus. The centre aims to support the current Cultural Heritage needs through the systematic exploitation of Earth observation technologies. For the establishment of the centre, the existing Remote Sensing and Geo-Environment Research Laboratory (Eratosthenes Research Center) based at the Cyprus University of Technology (CUT) has been twinned with internationally-leading counterparts from the EU, namely the National Research Council of Italy (CNR, through IMAA and IBAM) and the German Aerospace Centre (DLR)[17].

FP7 Project HERCULES - Sustainable Futures for Europe's Heritage in Cultural Landscapes (2013-2016) seeks to empower public and private actors to protect and sustainably manage cultural landscapes that possess significant cultural, socio-economic, historical, natural and archaeological

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[13] Lasaponara R., Masini N., 2018. Space-Based Identification of Archaeological Illegal Excavations and a New Automatic Method for Looting Feature Extraction in Desert Areas. Surv Geophys (2018). https://doi.org/10.1007/s10712-018-9480-4
[14] Lasaponara R., Leucci G., Masini N., Persico R., 2014. Investigating archaeological looting using satellite images and georadar: the experience in Lambayeque in North Peru. Journal of Archaeological Science, 42, 216-230, http://dx.doi.org/10.1016/j.jas.2013.10.032
[15] http://www.prothego.eu/home.html
[16] http://www.heracles-project.eu/
[17] https://athena2020.eu/

value, at a local, national and pan-European level. Within this project, satellite imagery has been identified as being valuable for achieving the goal of mapping and assessing landscape changes, utilizing CopernicuSentinel-2 data f s, and it has, therefore, become possible to add it to the Knowledge Hub. The latter was created in order to facilitate showcasing the results to the general (non-expert) public. Primarily targeted at the study landscapes of the HERCULES project, users are able to pinpoint and mark the changes they feel mostly affect the cultural landscapes[18].

WHERE Project - World HEritage monitoring by Remote sEnsing - co-financed by Italian Space Agency (ASI) in 2011-2012. It aimed at utilizing and processing the satellite high-resolution images (Cosmo Sky-Med) for monitoring the heritage sites, paying particular attention to the climate and anthropogenic impact (air humidity and temperature, soil temperature and particulate PM2.5 and 10), responsible for physical-chemical deterioration (erosion, physical-stress, soiling). In particular, the structural stability has been addressed using DInSAR Interferometry techniques applied to Cosmo-SkyMed data, while the data processing chains have been integrated into a WebGIS system where multi-temporal analysis is performed and the final results displayed. The final products include updated risk maps addressing critical situations and the evolution of the parameters under monitoring[19].

ArTeK - Satellite enabled Services for Preservation and Valorisation of Cultural Heritage (2016-2018 – European Space Agency) aims at an efficient monitoring of the state of conservation of Cultural Heritage, the improvement of the decision-making and programmatic capacity of institutions responsible for conservation, reducing in this way maintenance costs[20].

H2020 GeoMOP - Modern Geospatial Practices for Ancient Movement Praxis (2018 –on going). The goal of GeoMop is to develop an innovative integrated approach between Earth observation methods and archaeological prediction models in the context of studies aimed at simulating human-environment interaction with particular reference to Upper Mesopotamia in the early Bronze Age. In particular, the project aimed at the study and survey of the network of hollow ways (vie cave) of the early Bronze Age in the Khabur basin in Syria through an interdisciplinary approach based on satellite remote sensing and agent-based model methods[21].

JPI-CH CLIMA - Cultural Landscape risk Identification, Management and Assessment - aims at designing and implementing a WebGIS based multi-task platform that integrates different remote sensing technologies (from satellite and ground-based), which can ensure, on a spatial scale, both macro and micro levels, the mapping, diagnostic and monitoring purpose of cultural landscapes including buried and exposed archaeological remains. The Platform will provide specific products (e.g. periodic vulnerability and warning maps) to allow the authorities in charge of cultural landscape preservation to implement more effective maintenance plans and actions[22].

[18] http://www.herculeslandscapes.eu/tartalom/HERCULES_midterm_assessment_report_public.pdf
[19] Carlucci R.; Di Iorio A.; Placidi A.; Pichini M., 2011. WHERE. Monitoraggio di siti archeologici da satellite; Archeomatica, Anno II, Numero 3 - Progetto WHERE
[20] https://business.esa.int/projects/artek
[21] https://cordis.europa.eu/project/id/747493
[22] http://www.clima-project.eu/

4. User need analysis and requirement approach

Starting from the activities developed by PwC study delivered to European Commission by the end of 2018, that involved a wide range of stakeholders in the consultation process and providing a set of user needs scattered above the different Cultural Heritage disciplines, a specific matrix (Annex 2) was developed to:

1) Provide the Services with clear requirements built on top of the collected needs and on the basis of a geomatics[23] approach;
2) Support the identification of the best option, amongst those proposed by the aforementioned study to allow Cultural Heritage user communities to better access and use Copernicus products.

Subsequently, the previously identified user needs were analysed, aggregated, filtered and codified into specific requirements. This allowed the Entrusted Entities to express their views.
The matrix was submitted by the Task Force members to National stakeholders responsible for Cultural Heritage monitoring and management.

Nine domains of interest have been identified under which are grouped the different users' needs (Tab. 4.1).

1	Detection of underground archaeological sites through the study of the natural environment
2	Non-destructive analysis of the underground / underwater positioning of the CH features
3	Non-destructive analysis of the surface positioning of the CH features
4	Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
5	Monitoring of the evolution of the natural environment of the CH site
6	Monitoring of the evolution of the natural environment of the NH site
7	Observation of changes on the built structure of a CH site
8	Drawing of conclusions to facilitate an emergency intervention
9	Enable public access to the site

Table 4.1 Domains of interest adopted by the Copernicus Task Force on Cultural Heritage (CH = Cultural Heritage). They correspond to the High-level User needs identified by the PwC study.

Each monitoring domain is composed of several user needs, some of which occur in more than one domain.

[23] Geomatics is defined as a systemic, multidisciplinary, integrated approach to selecting the instruments and the appropriate techniques for collecting, storing, integrating, modelling, analyzing, retrieving at will, transforming, displaying, and distributing spatially georeferenced data from different sources with well-defined accuracy characteristics and continuity in a digital format (Gomarasca, M.A., 2010. Basics of geomatics. Appl Geomat 2, 137–146. https://doi.org/10.1007/s12518-010-0029-6).

In total, the nine monitored domains were composed of 73 user needs, identified through the different stakeholders' consultations.

For every identified user need, three simple questions have been proposed:

1. How important is this information for the daily management of your work? – Priority dimension (relative weight from 0 to 5)
2. How frequently do you need or want to check this parameter? – Temporal Resolution dimension;
3. How accurate the information must be for your purposes? – Spatial Resolution dimension.

To validate the information collected, the Entrusted Entities (in charge for the Copernicus Core Services and Space Component), have been directly consulted for their support in the definition of a clear technical requirement; at the end of the consultation with Entrusted Entities 4 specific requirements were identified. After that, for each monitoring domain, the matching of the identified requirements with the Copernicus capacity has been addressed.

In order to provide a detailed understanding of information relating to the matching between the identified requirements and the Copernicus capacity, inputs concerning the Space Component have been provided directly by ESA and EUMETSAT about the contributing missions data made available in the Copernicus Data Warehouse Phase 2 (for more details see Tabs. 8.1 & 8.2).

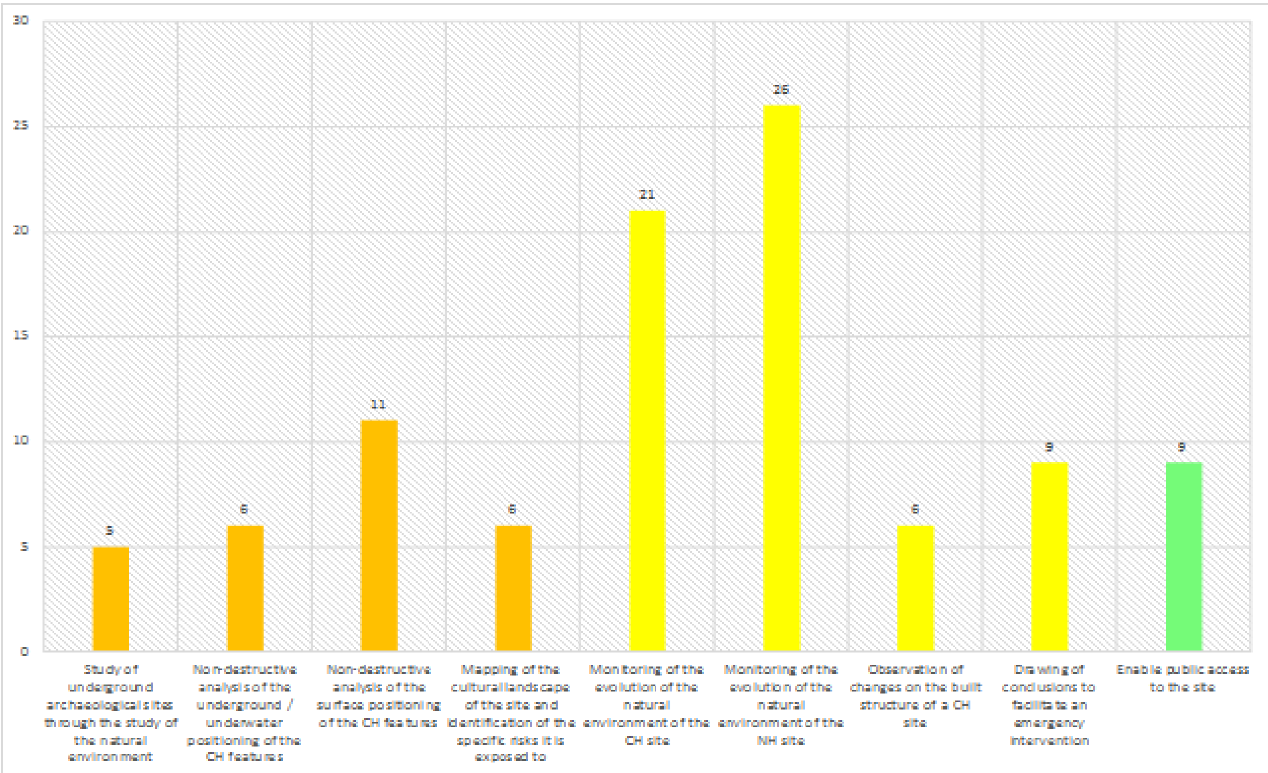

Fig 1. Number of users needs for each of the 9 monitoring domains.

Most of user needs fall into the *"Monitoring of the evolution of both the natural environment of the **CH** and **NH** site" monitoring domains.*
The Figure 2 provides a view of the link between the monitoring domains and the user requirements derived from expressed needs, with indication about the reference Service they should pertain to.

The graphical method chosen to represent the results of feedback analysis is the Sankey diagram; this is a flow diagram that relates entities through lines whose thickness expresses the quantitative relationship between them. This diagram is particularly suited to highlighting and assessing the priorities given by user communities to specific requirements, as in the case of the analysis of their matching with the Copernicus monitoring capacity.

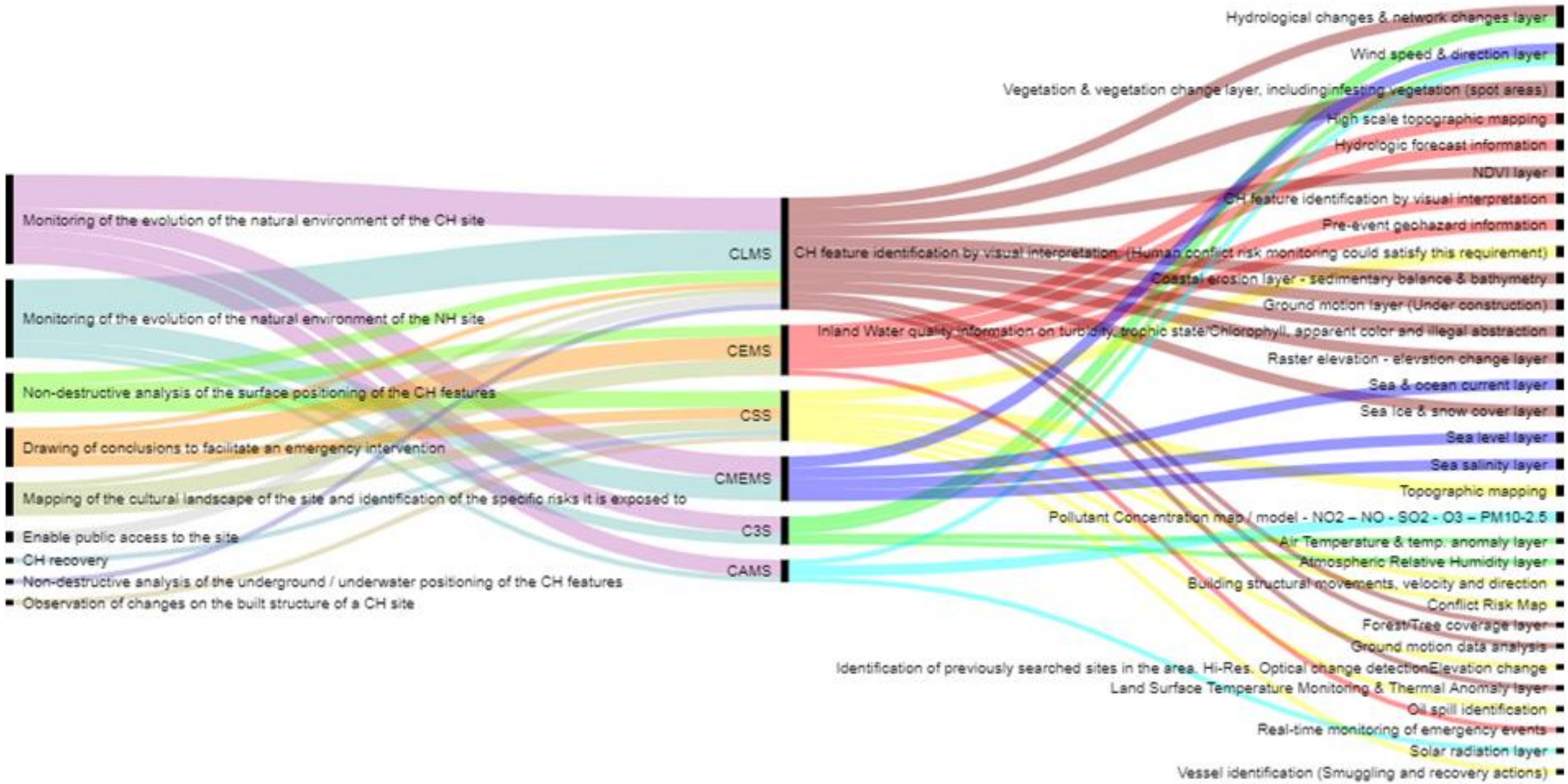

Fig.2 Link between Monitoring domains, Copernicus Core services and user requirements.

As can be clearly seen from the graph, most of the user' requirements relate to the Copernicus Land Monitoring Service (CLMS).

5. Matching the requirements with current Copernicus capacity

In order to demonstrate the extent of the Copernicus potential user uptake by the Cultural Heritage user community, user needs have been codified into specific requirements and analysed by the Copernicus Entrusted Entities so as to match the current and planned programme capacity with the identified requirements. The interaction with the Entrusted Entities allowed the identification of a number of Copernicus products that are suitable to support CH user's activities; these mostly refer to **Global Land Component, Atmosphere, Climate Change and Marine monitoring Services**, as well as **Emergency and Security**.

The following table shows the requirements that are fully satisfied by the current Copernicus product portfolio. Some of the requirements are characterised by a routine approach and they refer to Land, Atmosphere, Climate and Marine domains; on the other hand, requirements presenting on-demand monitoring support mainly refer to Security and Emergency Management domains.

Requirement	Copernicus Services/Component	Spatial resolution	Update frequency	Monitoring domain
Sea Ice & snow cover layer	CLMS Global CMEMS	1 km inland 10 km seaside	Twice per year	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Inland Water quality information on turbidity, trophic state/Chlorophyll, apparent colour and illegal abstraction	CLMS Global	100 - 300 m	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Atmospheric Relative Humidity layer	C3S	5-10 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Solar radiation layer	CAMS	10 km	3h – 1d	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the

				natural environment of the NH site
Air Temperature & temp. anomaly layer	C3S	10 km	6-12 h	Monitoring of the evolution of the natural environment of the NH site
Wind speed & direction layer	C3S/CAMS	10 km inland	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Pollutant Concentration map / model - NO2 – NO - SO2 - O3 – PM10-2.5	CAMS	10 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Wind speed & direction layer	CMEMS	25 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Sea salinity layer	CMEMS	10 km	7 – 15 dd	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Sea & ocean current layer	CMEMS	5 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Sea level layer	CMEMS	10 km	Daily	Monitoring of the evolution of the natural environment of the CH site

				Monitoring of the evolution of the natural environment of the NH site
Pre-event geohazard information	CEMS Mapping - R&R Mapping	1-5m V. / 1-2 cm H.	It depends from user request - 7 days routinely	Drawing of conclusions to facilitate an emergency intervention
Real-time monitoring of emergency events	CEMS Mapping - Rapid Mapping	< 10m	It depends from user request	Drawing of conclusions to facilitate an emergency intervention
CH feature identification by visual interpretation	CEMS Mapping - R&R Mapping	1 m	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
High scale topographic mapping	CEMS Mapping - R&R Mapping	1m (1:500 scale) 5-10m (1:5.000 scale)	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
Topographic mapping	CSS - SEA	1m	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
CH feature identification by visual interpretation (Human conflict risk monitoring could satisfy this requirement)	CSS - SEA	1 m	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
Identification of previously searched sites in the area Hi-Res. Elevation change Optical change detection	CSS - SEA	1-3 m Horiz. – 1-10 cm Vert.	It depends from user request	Non-destructive analysis of the surface positioning of the CH features

Building structural movements, velocity and direction	SEA	(>) 1 m Horiz. – 1cm Vert.	Twice a week – Monthly	Observation of changes on the built structure of a CH site
Conflict Risk Map	CSS - SEA	Up to VHR1 Very High Resolution 1 where resolution <=1m (usually 0.5 m) – depending on the specific users need	It depends from user request	Drawing of conclusions to facilitate an emergency intervention
Oil spill identification	CSS - MS	10m	Routinely (4 days)	Drawing of conclusions to facilitate an emergency intervention
Vessel identification (Smuggling and recovery actions)	*BS*	*10m*	*Routinely (4 days)*	*CH recovery*

Table 5.1 - Copernicus products matching the identified requirements. It is important to note that Copernicus Security Service - Border Surveillance, even though not associated with any of the identified monitoring domains, supports vessel detection through the existing product in the case of potential Cultural Heritage artefacts smuggling and looting.

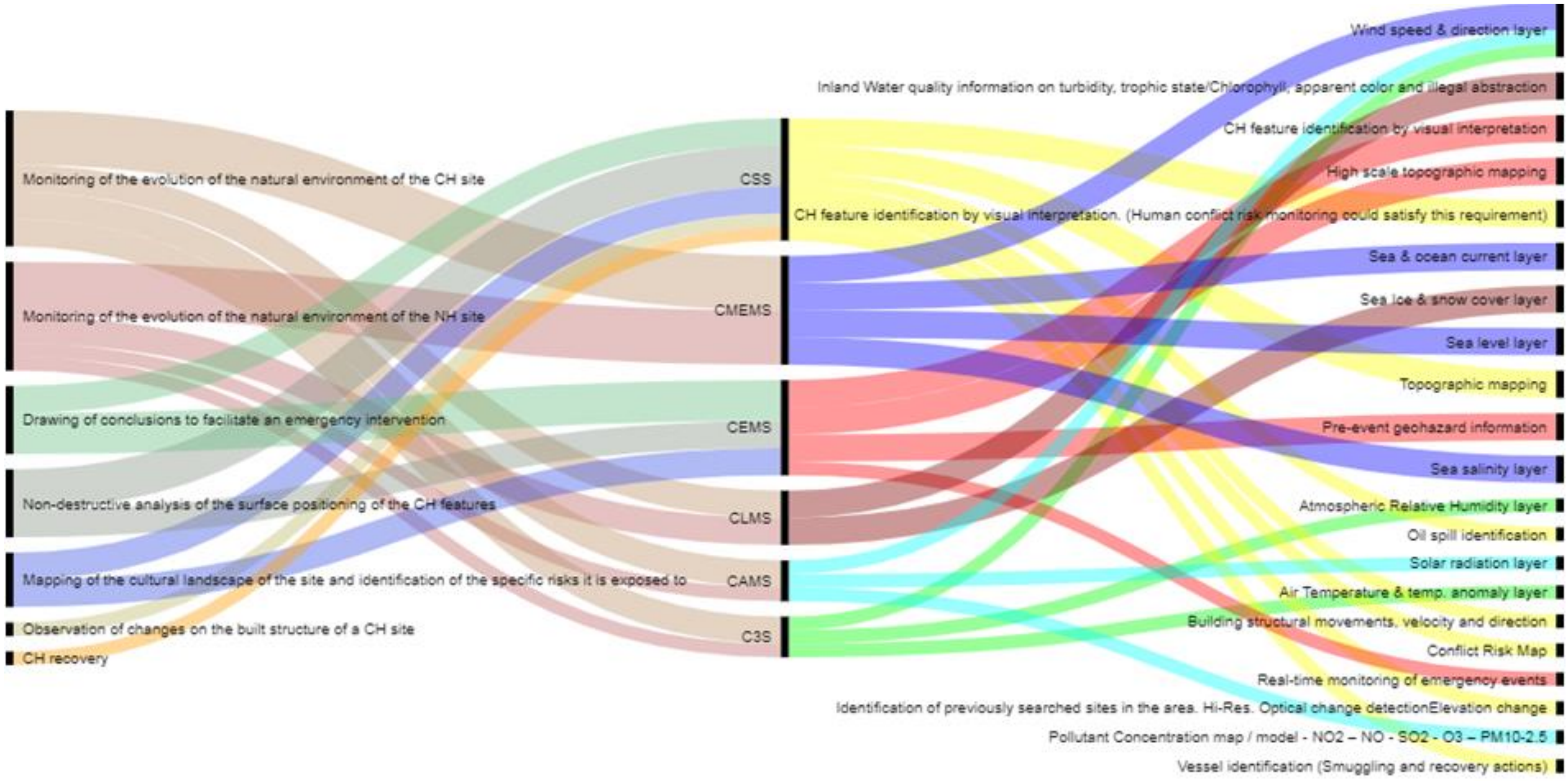

Fig.3 Link between Monitoring domains, Copernicus Core services and user requirements already compliant.

6. The Gap Analysis

6.1 Matching the requirements with Copernicus Land Monitoring Service capacity

The Copernicus Land Monitoring Service (CLMS) is the one where most of the requirements fit. CLMS has 10 significant requirements associated. As shown in table 6.1.1, the requirements express the needs for monitoring vegetation and forest, elevation changes, sea ice and snow cover, water quality and hydrologic changes, together with the identification of linear elements close to or within the Cultural Heritage area, and coastal dynamics, with a focus on erosion trends (Cultural Heritage distributed on the coasts).

Requirement	CLMS Component	Spatial resolution	Update frequency	Monitoring domain
NDVI layer	Global	5-10 m	2 weeks late winter/early summer & 3M the rest of the year	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Raster elevation - elevation change layer	Pan-European	10 - 30m Horiz. 1-10 cm Vert.	Yearly	Non-destructive analysis of the surface positioning of the CH features Enable public access to the site
Vegetation & vegetation change layer, including infesting vegetation	Local (ref. to infesting veg.)	3m	Quarterly	Non-destructive analysis of the surface positioning of the CH features
	Pan-European	5 - 10 m (High Resolution phenology product over EEA39 described into Copernicus WP2020)	Twice per year	Monitoring of the evolution of the natural environment of the CH site
	Pan-European		Yearly	Monitoring of the evolution of the natural environment of the NH site
Ice & snow cover layer	Global	1 km inland	Twice per year	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Inland Water quality information on turbidity, trophic state/Chlorophyll, apparent colour and illegal abstraction	Global	100 - 300 m	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Forest/Tree coverage layer	Pan-European	10 m	Yearly	Monitoring of the evolution of the natural environment of the NH site
Ground motion layer (Under construction)	Pan-European	10m Horiz. - 1 cm Vert.	Twice per year	Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to

				Enable public access to the site
Ground motion data analysis	Pan-European	10m Horiz. - 1 cm Vert.	Twice per year	Drawing of conclusions to facilitate an emergency intervention
Coastal erosion layer - sedimentary balance & bathymetry (Under construction Not yet available)	Local (Coastal Zone Service)	1-5m H. res. / 1cm V. res.	Twice per year (Autumn/Spring)	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Hydrological changes & network changes layer	Pan-European	10 – 30m	Yearly	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Land Surface Temperature Monitoring & Thermal Anomaly layer	CLMS Global	10 - 30m	Monthly	Non-destructive analysis of the underground / underwater positioning of the CH features

Table 6.1.1 – Description of the requirements associated with the Copernicus Services Component to which they should refer and the different monitoring domains. Highlighted in yellow are those requirements that are not satisfied by the current Copernicus provision (Source: Copernicus WP2020).

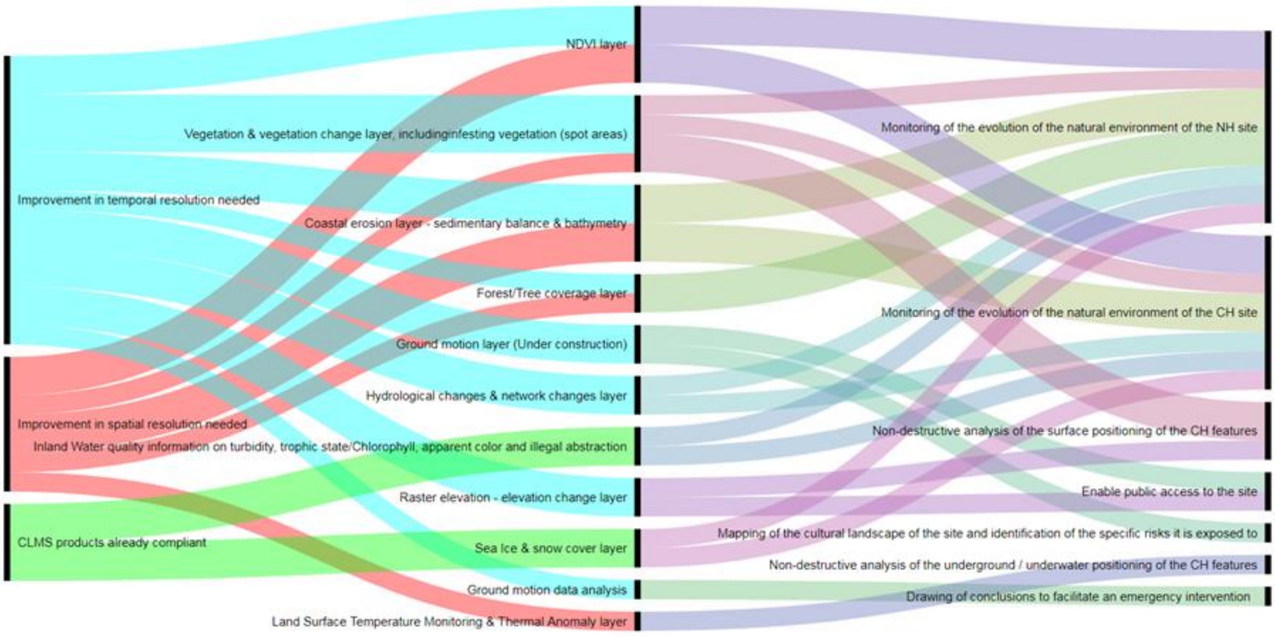

Fig.4 - Link between the requirements (central column), CLMS and monitoring domain (right column) (green: requirement fully satisfied - Cyan: requirement with temporal resolution not satisfied - red: requirement with spatial resolution not satisfied).

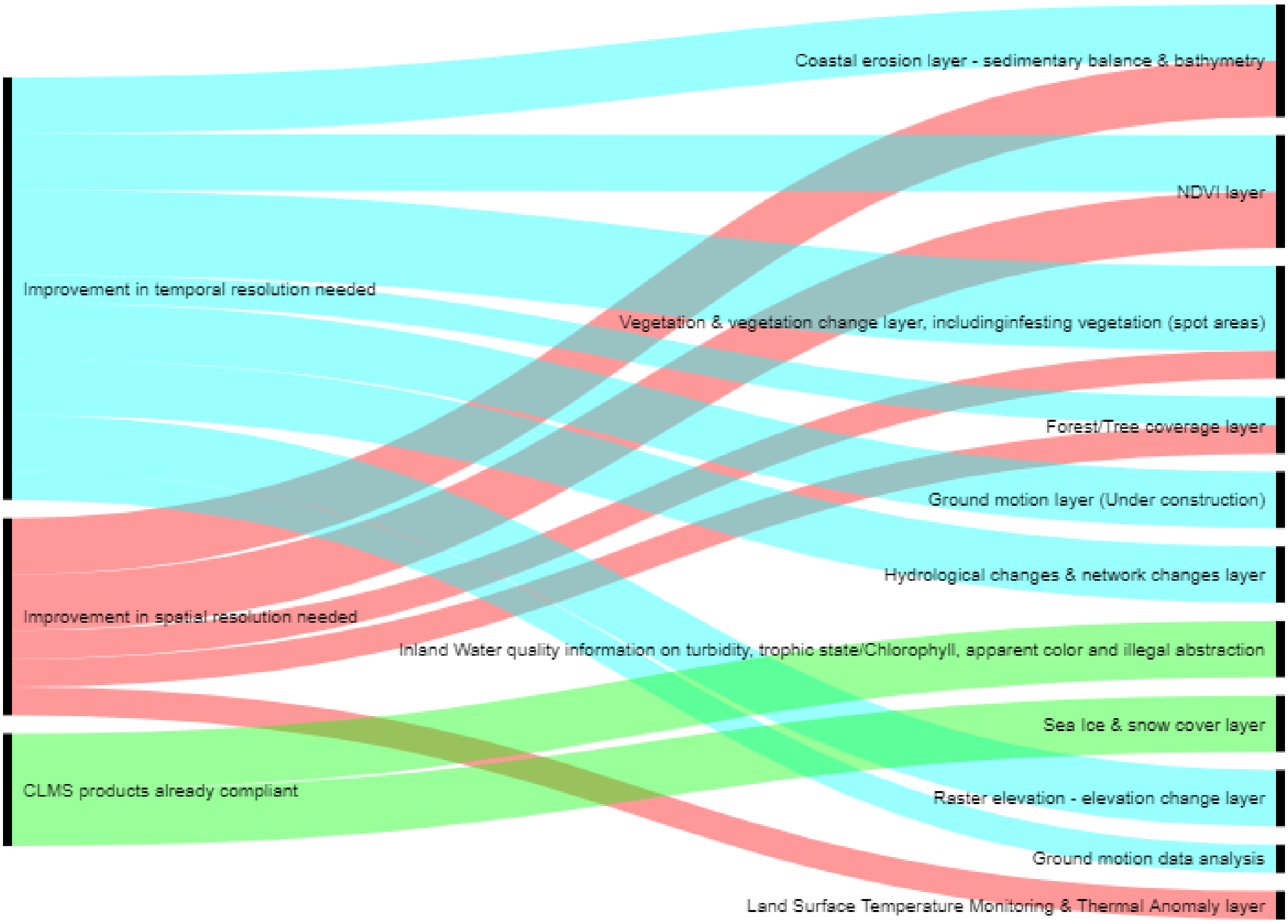

Fig.5 - Detail of the left part of the plot shown in fig.4

Figures 4 and 5 show that the main barriers on the CLMS products uptake relate firstly to temporal resolution and, secondly, to the spatial resolution.

Specifically, with regard to the requirements related to the vegetation domain (NDVI; Vegetation & vegetation change layer, tree/forest cover) the main barrier relates mostly to spatial resolution, which is currently lower than the Sentinel 2 capacity (10m). Thematically, the described *High-Resolution Phenology* (From Copernicus WP 2020) would provide a good base to support specific vegetation pattern identification (support on identifying infesting vegetation).

The required *Forest/tree cover layer* is already released by the Pan-European component (20 m spatial resolution), and would be very suitable for the Cultural Heritage user community if the resolution is improved to 10 m.

With regard to the vegetation pattern for the *analysis of the surface positioning of the Cultural Heritage features,* that considers small monitoring area (local scale), this would require a 3m resolution, such as the one adopted for the *riparian zones layer (3 m)*. For the envisaged improved resolution, CM Group 2b (Optical VHR1/2) would be able to achieve the target.

With regard to vegetation indices, at a global level, Sentinel 2 Global Mosaic (S2GM) Surface Reflectance, (Full spectrum surface reflectance selectable) could help with the monitoring of Natural Heritage, providing a medium-high resolution product (20-60m), with 10 days as a minimum update frequency.

With regard to coastal products that are being implemented in close cooperation with the Copernicus Marine Environment Monitoring Service, it would be of benefit to involve Cultural Heritage User Community in the users' consultation phase. The main requirements expressed in the land domain relate mostly to coastal erosion (and related sedimentary balance) that may affect CH situated on the coast.

With regard to the development of the Ground Motion Service, the Cultural Heritage users' requirement is matched if the product maintains the Sentinel 1 resolution, and the required update frequency is increased to twice per year (currently planned once per year). The Ground motion information is required for *mapping the cultural landscape of the site and identification of the specific risks it is exposed to and to facilitate emergency intervention*[24]*.*

With regard to Hydrology, there is a clear need to monitor the water level of lakes and artificial basins, as well as changes in the hydrological network with a spatial resolution of 20m as the minimum requirement. More information on hydrology can also be related to the in situ reference data described in CORDA (derived from EU-DEM v1.0). Even if the spatial resolution is higher than the required one, the layer refers to the years 2011-2013 and so is not sufficiently up to date. EU-Hydro is a dataset for all EEA39 countries based on photo-interpretation providing river networks, consisting of surface interpretation of water bodies (lakes and wide rivers), and a drainage model (also called Drainage Network), derived from EU-DEM, with catchments and drainage lines and nodes.

With regard to a Digital Surface Model, the possibility to access stereo imagery from Cartosat satellites has been highlighted by EEA; Cartosat DSM data is already listed in the possible datasets of the ESA data warehouse. The stereo is taken North-South, one taken from a Northern position, and one taken from a Southern position. The horizontal resolution is 5m x 5m and +/- 1m vertical resolution. It can distinguish rather small disturbances in the earth's surface. On the other hand, CORDA provides EU-DEM, a digital surface model (DSM) of EEA member and cooperating countries representing the first surface as illuminated by the sensors. It is a hybrid product based on SRTM and ASTER GDEM data fused by a weighted averaging approach. The characteristics can be resumed with the Horizontal resolution at 1 arcsec (+/-30 m - consistent with 1:100.000 scale) and vertical accuracy of +/-7.0 m RMSE.

With regard to thermal anomalies, the requirement could be satisfied by the use of CM Group 2 (Optical HR1/2). Also, it is important to highlight the Copernicus candidate mission LSTM (Copernicus Land Surface Temperature Monitoring), with 30 m resolution in the thermal band. The LSTM mission would carry a high spatial-temporal resolution thermal infrared sensor to provide observations of land-surface temperature. Land-surface temperature measurements may provide support in different application areas, such as climate variability, managing water resources, predicting droughts, addressing land degradation, natural hazards such as fires and tectonic hot-spots, coastal and inland water management as well as urban heat islands.

Among the Copernicus High Priority Candidates that could support different requirements in the Land domain is CHIME (Copernicus Hyperspectral Imaging Mission) mission. CHIME would carry a

[24] The Coastal Zone Service (CZS) will provide land cover and land use (LC/LU) information in Very high Resolution on a 10 km wide coastal strip, with a dedicated nomenclature taking stock of the specific habitats along the coastline and the vulnerability of the coastal ecosystems. This product is being implemented in close cooperation with the Copernicus Marine Environment Monitoring Service (CMEMS).

unique visible to shortwave infrared spectrometer, with a 10-20-30m resolution depending from bands characteristics, to provide routine hyperspectral observations to support new and enhanced services for different application domains tied to biodiversity management, as well as soil property characterization. The mission would complement Copernicus Sentinel-2 for applications such as land-cover mapping.

6.2 Matching the requirements with Copernicus Atmosphere Monitoring Service and Climate Change Service capacity

Requirement	C3S/CAMS	Spatial resolution	Update frequency	Monitoring domain
Hydrological changes & network changes layer	C3S	10 –30m	Yearly	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Atmospheric Relative Humidity layer	C3S	5-10 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Solar radiation layer	CAMS	10 km	3h – 1d	Monitoring of the evolution of the natural environment of the CH site
Air Temperature & temp. anomaly layer	C3S	10 km	6-12 h	Monitoring of the evolution of the natural environment of the NH site
Wind speed & direction layer	C3S/CAMS	10 km inland	Daily	Monitoring of the evolution of the natural environment of the CH site
Pollutant Concentration map / model - NO2 – NO - SO2 - O3 – PM10-2.5	CAMS	1-5 km 10km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site

Table 6.2.1 – Description of the requirements associated with the Copernicus Services to which they should refer and the different monitoring domains. Highlighted in yellow are the requirements that are not satisfied by the current Copernicus provision (Source: Copernicus WP2020).

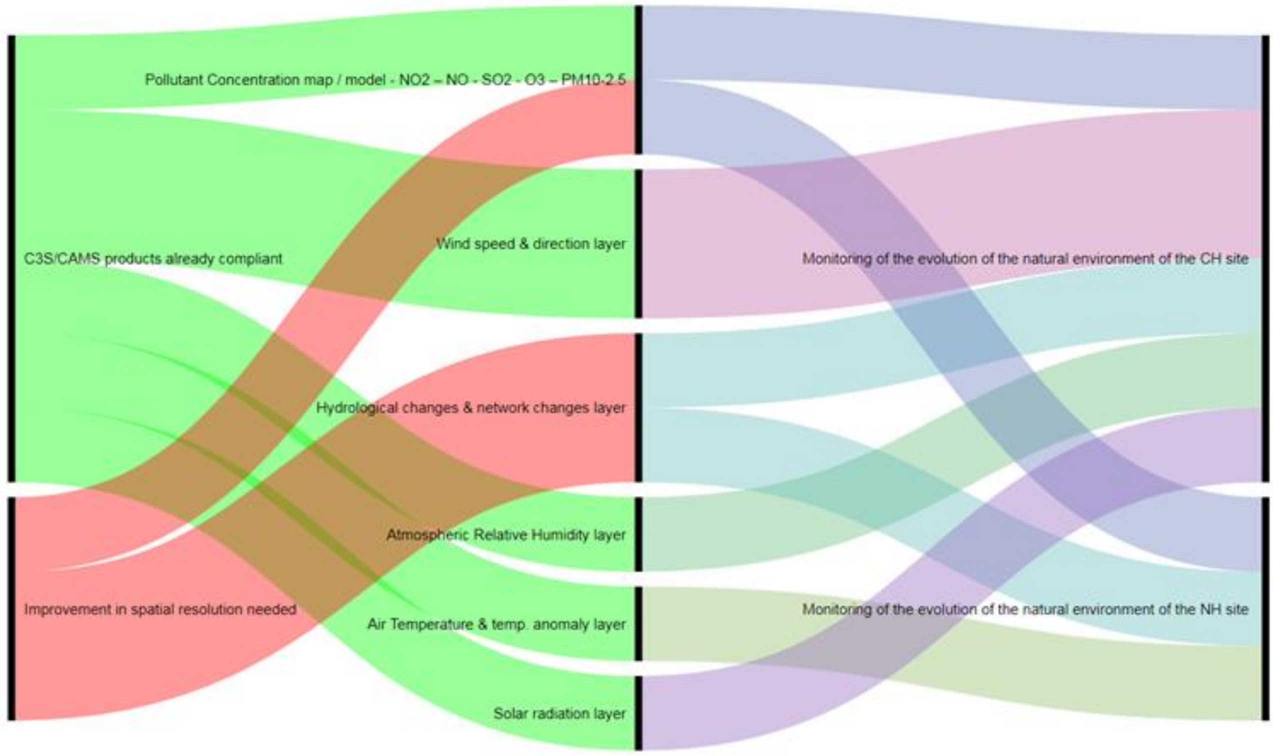

Fig.6 - Link between requirements (central column), CAMS and C3S (left column) and monitoring domain (right column) in relation to the requested spatial resolution (green: compliant - red: to be improved).

Most of the requirements associated with CAMS and C3S are matched by the products already supplied, with the exception of the Hydrologic & network changes, where the spatial resolution of existing products is coarser than the required one and, partially related to Pollutant Concentration where 1 to 5 km spatial resolution is requested for monitoring the built environment (e.g. darkening processes).

The interaction with ECMWF highlights that products related to Hydrology can be provided also by C3S (reference also present in CLMS section), but with coarser resolution than the required one. At European coverage, C3S provides *datasets* at different resolutions with 10 km spatial resolution.
It is also highlighted that C3S and CAMS provide relevant information about the current, past and future state of hydrological variables, as well as retrospective analysis of what has happened in the last few months (e.g. Water quantity indicators for Europe). The dataset contains modelled data for water runoff and wetness, river flow, snow water equivalent, soil water content and other water related quantities for the European region. These variables were computed as part of a proof of concept contract, designed to speed up the workflow in impact assessments and to simplify climate change adaptation of water management practices across Europe. These quantities were modelled using the Swedish Meteorological and Hydrological Institute E-HYPE, the Wageningen University VIC model and the Joint Research Center Lisflood models. These models work at different scales; thus, the data is provided at different resolutions. E-HYPE and Lisflood were upscaled in order to show the model ensemble. Most variables are provided as averages over 30-year periods, either for each calendar month or for the whole period. However, for some of the variables, day, percentile and return periods are also provided. This information, if integrated with highest resolution data, provides optimal boundary condition related to Hydrography description.

With regard to atmospheric humidity information, C3S will permit the derivation of climate indicators (e.g., temperature increase, sea level rise, ice sheet melting, warming up of the ocean) and climate indices (e.g., based on records of temperature, precipitation, drought event). Both spatial resolution and update frequency are met.

With regard to the Sentinel capacity to support the atmospheric humidity monitoring, the S3 (From bands Oa18 - 885 nm, Oa19 - 900 nm) can provide 300m spatial resolution with a 2-day revisit time. In addition, for temperature and wind monitoring, following the recent release of ECMWF’s ERA5 climate reanalysis from 1979 onwards, the release of the first subset of ERA5-Land data covering the period 2001 to 2018 is planned for the next spring (2020). The dataset will be updated in a timely manner together with ERA5 updates. Like ERA5, ERA5-Land is being produced by ECMWF as part of implementing the EU-funded Copernicus Climate Change Service. This is the first time that a global land surface dataset describing the water and energy cycles and spanning nearly two decades will be available at a grid spacing of 9 km and hourly temporal frequency. The main features of this new dataset compared to previous re-analyses and ERA5 are shown in the table.

	ERA-Interim	Era-Int/Land	ERA5	ERA5-Land
Period	Jan 1979–present	Jan 1979–Dec 2010	Jan 1950–present	Jan 1950–present
Spatial resolution	~79 km grid spacing	~79 km grid spacing	~31 km grid spacing	~9 km grid spacing
Uncertainty estimate	None	None	Based on 10-member 4D-Var ensemble	To be based on 10-member atmospheric forcing
			at 63 km	at 31 km
Output frequency	6-hourly analysis fields	6-hourly analysis fields	Hourly (three-hourly for the ensemble)	Hourly (three-hourly for the ensemble)

Table 6.2.2 – Comparison between previous and current ERA climate re-analysis.

Preliminary scientific assessments of the first few years of production have been carried out for temperature, soil moisture, river runoff and lake fields. They show that ERA5-Land is of very good quality, adding value to ERA5 surface fields and providing users with a more accurate dataset for surface applications.

The impact can be particularly important over complex terrain, where accurate orography is very important. ERA5-Land meets the growing requirement from land user communities to gain access to long-term higher-resolution datasets. In the context of the Copernicus Programme, this requirement is of special relevance as water resources management, agricultural activities and drought prediction, among others, demand long-term datasets at a finer resolution than what climate reanalysis can currently provide.

With regard to Solar radiation, by monitoring atmospheric composition, the Copernicus Atmosphere Monitoring Service supports applications in the domains of air quality, climate forcing, ultraviolet radiation, and solar energy with special focus on the Union regions.

The service characteristics present a spatial resolution that depends on the interpolation of the point of interest, an update frequency of 1 min, 15 min, 1 h, day, month and a continental spatial coverage (Europe/Africa/Middle East/Eastern part of South America/Atlantic Ocean).

With regard to temperature monitoring, C3S will permit the derivation of a number of climate indicators (e.g., temperature increase, sea level rise, ice sheet melting, warming up of the ocean) and climate indices (e.g., based on records of temperature, precipitation, drought event) for identified climate drivers and the expected impacts.

With regard to wind speed & direction, improvements are expected for product consistency (especially of reprocessed time series and reanalyses) and quality assessment of some ocean monitoring indicators. Further improvements on wind, waves and current products, sea ice automated products CH requirements are aligned with EMSA ones for polar services (EMSA Communication). C3S and CAMS appear to be relevant as providers of data with regard to surface winds. Once more ERA5, ERA5Land (9 km resolution, hourly) and operational CAMS products may be able to meet the requirements. With regard to atmospheric pollution concentration, the matching between the requirements and product characteristics is satisfied for the monitoring of the natural environment component of CH, while for built environment applications the required resolution is higher (1-5 meters). ECMWF reports that the fulfilment of this requirement may be achieved even where ground monitoring stations are not present, by downscaling the CAMS products to meet local conditions. The product presents 0,1-degree resolution - about 11km, daily updated[25]. In parallel with the C3S/CAMS products provision, EEA will ensure operational provision of up-to-date air quality data through the established EIONET core data flow.

6.3 Matching the requirements with Copernicus Marine Environment Monitoring Service capacity

The Copernicus Marine Environment Monitoring Service assimilates Earth observation data as well as in-situ data into 4-D models. The main parameters calculated and provided are currents, temperature, salinity, sea level, sea ice and biogeochemistry.
All of the identified requirements fall into the CMEMS physical parameter domain. The current provision of CMEMS products satisfies the CH user community requirements.

Requirement	CMEMS	Spatial resolution	Update frequency	Monitoring domain
Wind speed & direction layer	All regional domains	25 km seaward	Daily	Monitoring of the evolution of the natural environment of the CH site
Sea salinity layer	All regional domains	10 km	7 – 15 dd	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Sea & ocean current layer	All regional domains	5 km	Daily	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Sea level layer	All regional domains	10 km	Daily	Monitoring of the evolution of the natural environment of the NH site

Table 6.3.1 – Description of the requirements associated to the Copernicus Marine Environment Monitoring Services they refer to and the different monitoring domains (Source: Copernicus WP2020).

[25] ECMWF can provide *a daily value of salinity at 0.1 degree (about 11 km) from the fisheries contract ECMWF has with Plymouth Marine Laboratories*

For all the CMEMS products, it is possible to refer to the following table (5.3.2) with regard to spatial resolution (only concerns Model output - Reanalysis, forecast and NRT) and update frequency. Forecast products concerns about 5 to 10 days ahead.

Regional Domain	Spatial resolution (km)	Update frequency
Global	8	monthly-mean, daily-mean, hourly-mean
Arctic	12.5	daily-mean, hourly-mean
Baltic	2	daily-mean, hourly-mean
North West Shelf (Atlantic)	1,5	daily-mean, hourly-mean
Iberian Biscay Irish (Atlantic)	2,8-3	monthly-mean, daily-mean, hourly-mean
Mediterranean Sea	4	monthly-mean, daily-mean, hourly-mean
Black Sea	3	daily-mean, hourly-mean

Table 6.3.2 - Spatial resolution and update frequency per regional domain.

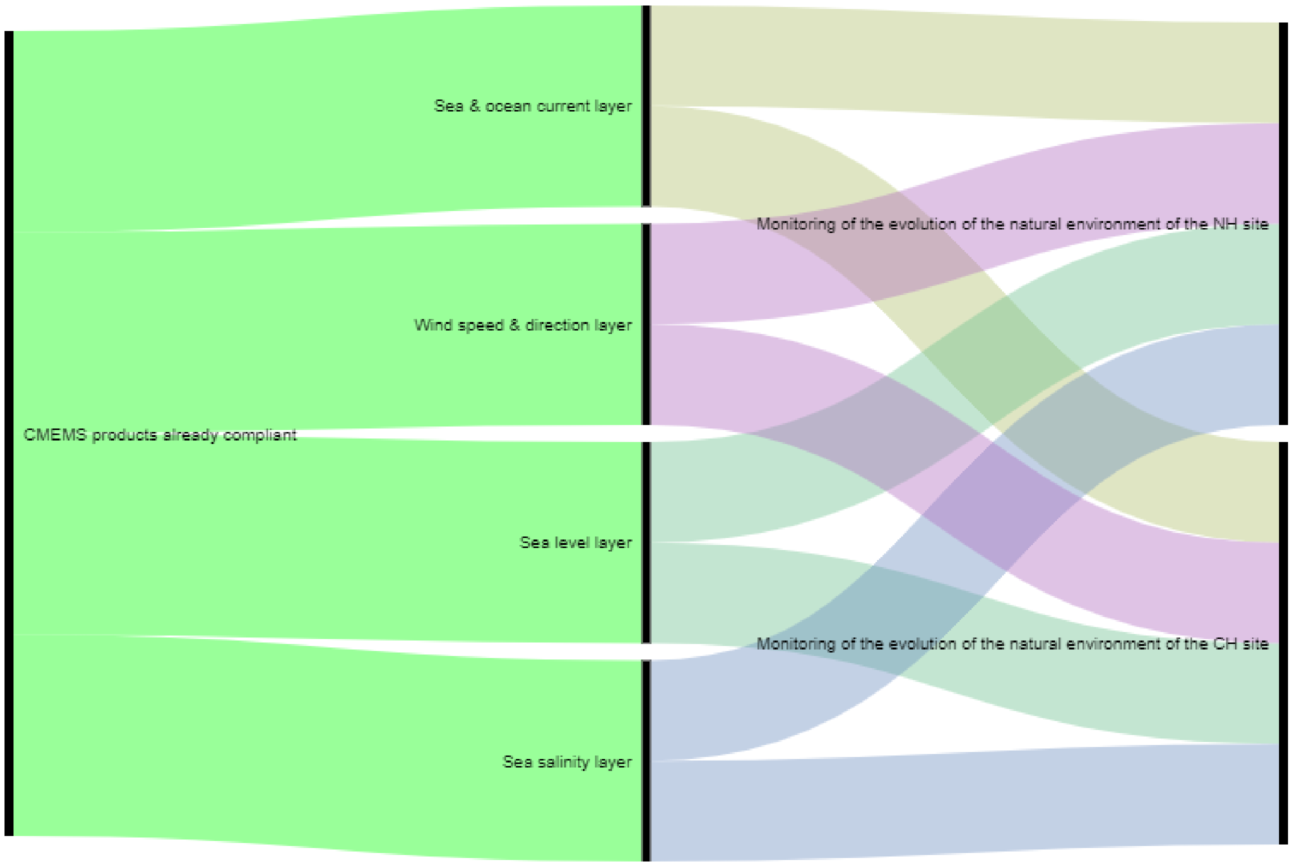

Figure 7 - Link between requirements (central column), CMEMS (left column) and monitoring domain (wright column). All the requirements are satisfied.

As well as C3S, wind speed and direction information are present in the CMEMS portfolio. Five observation products about Wind are available, all of them at Global scale, both NRT or Reanalysis (1992-2018).

With regard to Salinity, Current Velocity and Sea level measurements, there are respectively 31, 39 and 52 products available in the catalogue, from model output reanalysis, NRT and forecast and observation, from Global to European coverage.

Reanalysis (model) and reprocessing (observations) cover the period 1993-2017; they are yearly updated and contain monthly or daily means. For Iberian, Biscay, Irish, and Baltic regions an hourly mean is also provided.

The support of in-situ observations (instantaneous) relates to Current velocity: 7 in situ CMEMS products are available and cover Global and EU water. Data in NRT are available since 2010.

The Ocean Monitoring Indicators also provide information on the trend of Sea Level from 1993 to today. For the time being there is only the global trend (Note by Mercator Océan - regional will be provided soon).

6.4 Matching the requirements with Copernicus Emergency Management Service capacity

Requirement	CEMS	Spatial resolution	Update frequency	Monitoring domain
Pre-event geohazard information	Mapping - R&R Mapping	1-5m V. / 1-2 cm H.	On demand 7 days routinely	Drawing of conclusions to facilitate an emergency intervention
Real-time monitoring of emergency events	Mapping - Rapid Mapping	<10m	On demand	Drawing of conclusions to facilitate an emergency intervention
CH feature identification by visual interpretation	Mapping - R&R Mapping	1 m	On demand	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
Hydrologic forecast information	EFAS - GloFAS	10 –30m	Yearly	Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to Drawing of conclusions to facilitate an emergency intervention
High scale topographic mapping	Mapping - Risk & Recovery Mapping	1m (1:500 scale) 5-10m (1:5.000 scale)	On demand	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to

Table 6.4.1 – Description of the requirements associated with the Copernicus Emergency Management Services Components they refer to and the different monitoring domains. Highlighted in yellow is the requirement that is not satisfied by the current product provision (Source: Copernicus WP2020).

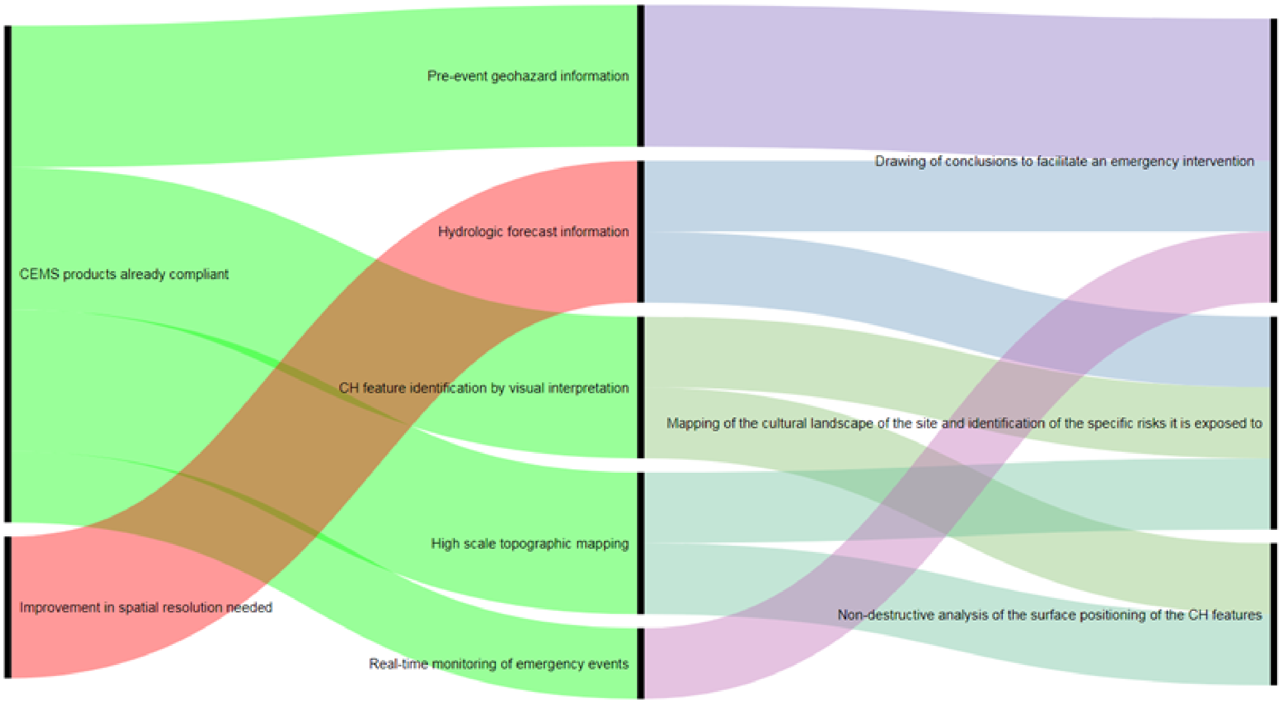

Fig.8 - Link between requirements (central column), CEMS and monitoring domains (right column) in relation to the requested spatial resolution (green: complaint - red: to be improved in spatial resolution).

The Copernicus Emergency Management Service (CEMS) provides information for emergency response in relation to different types of disasters, including meteorological hazards, geophysical hazards, deliberate and accidental man-made disasters and other humanitarian disasters as well as prevention, preparedness, response and recovery activities. The CEMS is composed of an on-demand mapping component providing rapid maps for emergency response and risk & recovery maps for prevention and planning, and of the early warning and monitoring component which includes systems for floods, droughts and forest fires.

The majority of the identified requirements fall into the Risk and Recovery component, where the associated requirements refer to *Pre-event geo-hazard information, CH feature identification by visual interpretation and high scale topographic mapping.*

With regard to topographic mapping, two different application scales have been identified, respectively with application to the CH feature (1:500 scale) and the landscape surrounding the site (1:5.000 scale).

The generic requirement expressed as real time monitoring of emergency events that falls into the Rapid mapping component, relates to the full spectra of anthropic or natural risk.

With regard to the delivery of hydrologic (forecast) information, a central role is played by the early warning and monitoring component (EFAS and GloFAS). The forecasts are derived using in-situ and satellite data as well as hydro-meteorological models and are aimed at assisting users with a wide range of added value (medium-range lead time, probabilistic, river basin wide, flash flood indicators etc.) flood forecast products. Due to the EFAS (buffered) European application scale, the current spatial resolution is coarser (5km) than the required one (10-30m).

Also, CEMS provide information on future changes of hydrological variables as well as retrospective analysis of what occurred in the last few months (state of the climate report) and reanalysis of river flow as well as short-term, medium-range and seasonal forecasts.

In the context of the early warning and monitoring services, the provision of forest fire and drought information is especially relevant to the *monitoring of the evolution of the natural environment of the Cultural Heritage site*.

Among the Early Warning and Monitoring products it should be noted that there are Impact maps (e.g. Rapid Mapping: First Estimate, Delineation, Grading), fire hot spots and burnt area perimeters (EFFIS, GWIS), drought risk (European Drought Observatory Global Drought Observatory), flood risk (European Flood Awareness System and Global Flood Awareness System).

Both for Rapid Mapping and Risk and Recovery Mapping there would be a need for CH managers to liaise with the CEMS National Contact Points (e.g. National Civil Protection Authority authorized to activate the Services) for the inclusion of specific requests (data & information) in the service delivery.

6.5 Matching the requirements with Copernicus Security Services capacity

All the CSS have been contacted to understand the extent of uptake by the CH user community. Most of the requirements fall under SEA/SatCen, with a second set under Maritime Surveillance.

The Border Surveillance Service provides the current Vessel Identification and Tracking for CH smuggling across the Mediterranean Sea, to be activated by National Contact Point.

The identified requirement associated to Maritime Surveillance service relates to CleanSeaNet Services, especially where pollutants may impact on the coasts where CH are located or in submerged areas.

It is clear that currently, using the satellite capabilities deployed for Clean Sea Net product (delivered by the Copernicus Security Service - Maritime Surveillance) it is not possible to determine the concentration of pollutants in the water.

In the pollution monitoring context, both services focus on two main activities:

a. Routine monitoring of European waters (CleanSeaNet) or overseas territories of European interest (Covered by CMS) for the detection of illegal discharges from ships and offshore platforms, the detection of the possible pollution is achieved, but subsequent verification by other means (e.g. aerial surveillance) is required to understand the type of pollutant and associated volumes. The satellite monitoring activity is implemented using Synthetic Aperture Radar (SAR) images from Sentinel-1, Radarsat-2 and TerraSAR-X. This routine process focuses on monitoring systematically the areas of interest of Member States. For example, CleanSeaNet (which focus on European Waters) already monitored 500 million Km2 in the first 6 months of 2019.
b. Support for accidental oil spills. In this case, the focus is in support of response operations, which include monitoring of the accident area, tracking of the resulting oil spill and assessment of the impact/position of oil in coastal areas. In this case usually there is a combination of SAR images as well as very high resolution optical (to monitor the oil on the beach or in coastal areas).

In the future, the addition of other satellite sensors (e.g. hyperspectral) could improve the ability of the existing services to detect both the nature of the pollutant as well as the volume, which can provide a possible contribution to determine pollution concentration. Some research using Sentinel-2 data (multispectral) has shown promising results with regard to the estimation of oil spill volumes derived from these images. Nevertheless, and from a satellite-based service perspective, developments are still required before these capabilities can be deployed into operation.

Many of the identified requirements that present an on-demand provision of information fall within the context of the Copernicus Security Service - Support to External Actions (CSS-SEA). They mainly refer to topographic mapping, CH feature identification, previously searched sites in the area identification, high resolution elevation models/changes, optical change detection, building structural movements, velocity and direction and Conflict Risk Map. These monitoring capacities have been already demonstrated by the Support to External Actions Service.

It is important to highlight that the requirement associated to the *Buildings structural movements, velocity and direction*, could contain a routinely monitoring activity request.

Table 6.5.1 summarizes the characteristics associated to each requirement, fully satisfied.

Requirement	CSS	Spatial resolution	Update frequency	Monitoring domain
Topographic mapping	SEA	1m	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
CH feature identification by visual interpretation (Human conflict risk monitoring could satisfy this requirement)	SEA	1 m	It depends from user request	Non-destructive analysis of the surface positioning of the CH features Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to
Identification of previously searched sites in the area Hi-Res. Elevation change Optical change detection	SEA	1-3 m Horiz. – 1-10 cm Vert.	It depends from user request	Non-destructive analysis of the surface positioning of the CH features
Building structural movements, velocity and direction	SEA	(>) 1 m Horiz. – 1cm Vert.	Twice a week – Monthly	Observation of changes on the built structure of a CH site
Conflict Risk Map	SEA	Up to VHR1 Very High Resolution 1 where resolution <=1m (usually 0.5 m) – depending on the specific users need	It depends from user request	Drawing of conclusions to facilitate an emergency intervention

Oil spill identification	MS	10m	Routinely (4 days)	Drawing of conclusions to facilitate an emergency intervention
Vessel identification (Smuggling and recovery actions)	*BS*	*10m*	*Routinely (4 days)*	*CH recovery*

Table 6.5.1 – Description of the requirements associated with the Copernicus Security Services they refer to and the different monitoring domains (Source: Copernicus WP2020). It is important to notice that Copernicus Security Service - Border Surveillance, even though it does not have any associated requirements, supports vessel detection in case of potential Cultural Heritage smuggling across Seas.

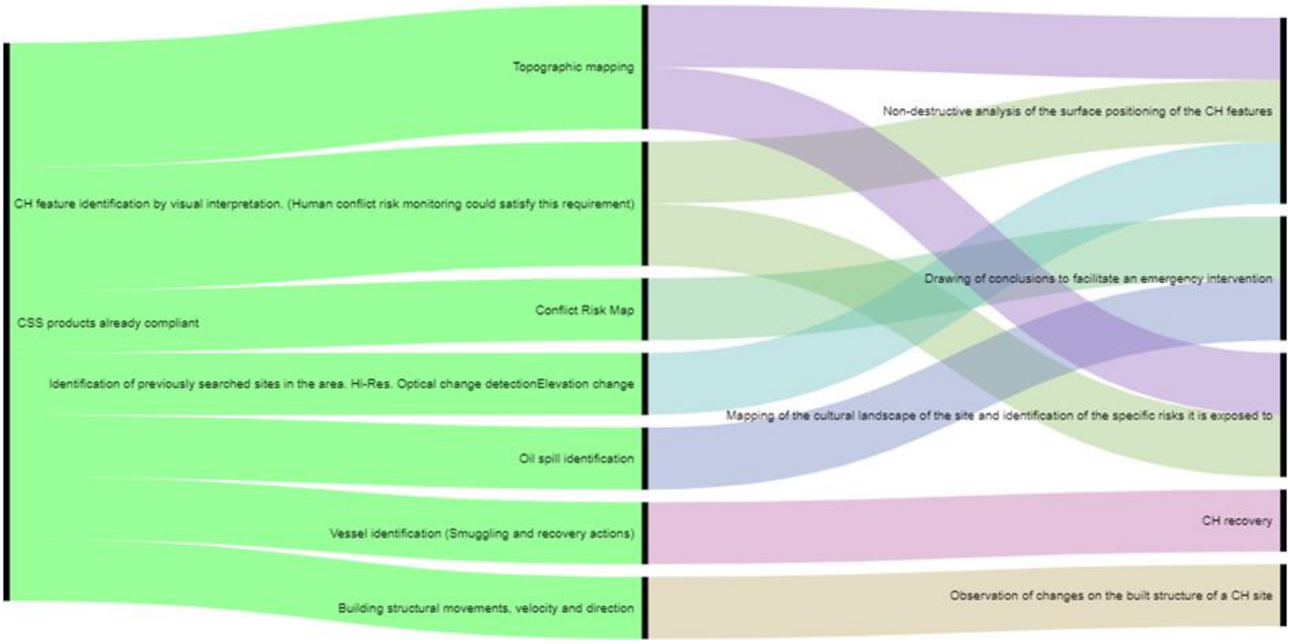

Fig.9 Link between requirements (central column), CSS (left column) and monitoring domain (wright column). All the requirements are satisfied.

6.6 The support of the Copernicus in situ Component

When dealing with the Copernicus in situ Component, it is important to notice that access conditions to in situ data vary according to the data provider policy. In situ data cannot be defined alone as Copernicus products but insofar they are used in the definition of products they pertain to in the Copernicus domain. The in-situ component plays an important role for Service implementation: it provides the information about the in-situ data that Copernicus Services require for integration, validation and calibration purposes. Anyhow, the Copernicus in situ Component can provide information (data owner, update frequency, spatial resolution, coverage, access conditions) about datasets that could be suitable for supporting Cultural Heritage requirements. This information refers to bathymetry, geodetic records, geology, coastal dynamics, and soil distribution, as reported in the following table. Some datasets are available on a free and open basis, whereas others are subject to licensing conditions or access limitations.

Requirement	In situ	Spatial resolution	Spatial Coverage (European)	Update frequency	Monitoring domain
Bathymetry	MSs capacity	5 - 10 m H	Incomplete	3 months	Non-destructive analysis of the

	EMODnet	1 cm V			underground / underwater positioning of the CH features Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Geodetic recording	MSs capacity	1-2 cm vertical	Incomplete	Yearly	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Geologic/stratigraphic/lithologic Map	MSs capacity	250 - 500m	Complete	20Y	Non-destructive analysis of the surface positioning of the CH features Monitoring of the evolution of the natural environment of the NH site
Coastal sedimentary balance – erosion trends	MSs capacity EMODnet	5m H. 1cm V.	Incomplete	3 months	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Soil distribution map	JRC FAO MSs capacity	500m	Complete	20Y	Monitoring of the evolution of the natural environment of the CH site Monitoring of the evolution of the natural environment of the NH site
Hydrological changes & network changes layer	EEA CORDA database	10 – 30m	Complete	Yearly	Monitoring of the evolution of the natural

					environment of the CH site Monitoring of the evolution of the natural environment of the NH site

Table 6.6.1 – Description of the requirements associated to the different in situ resources. The main barriers refer to the required update frequency and jeopardised coverage.

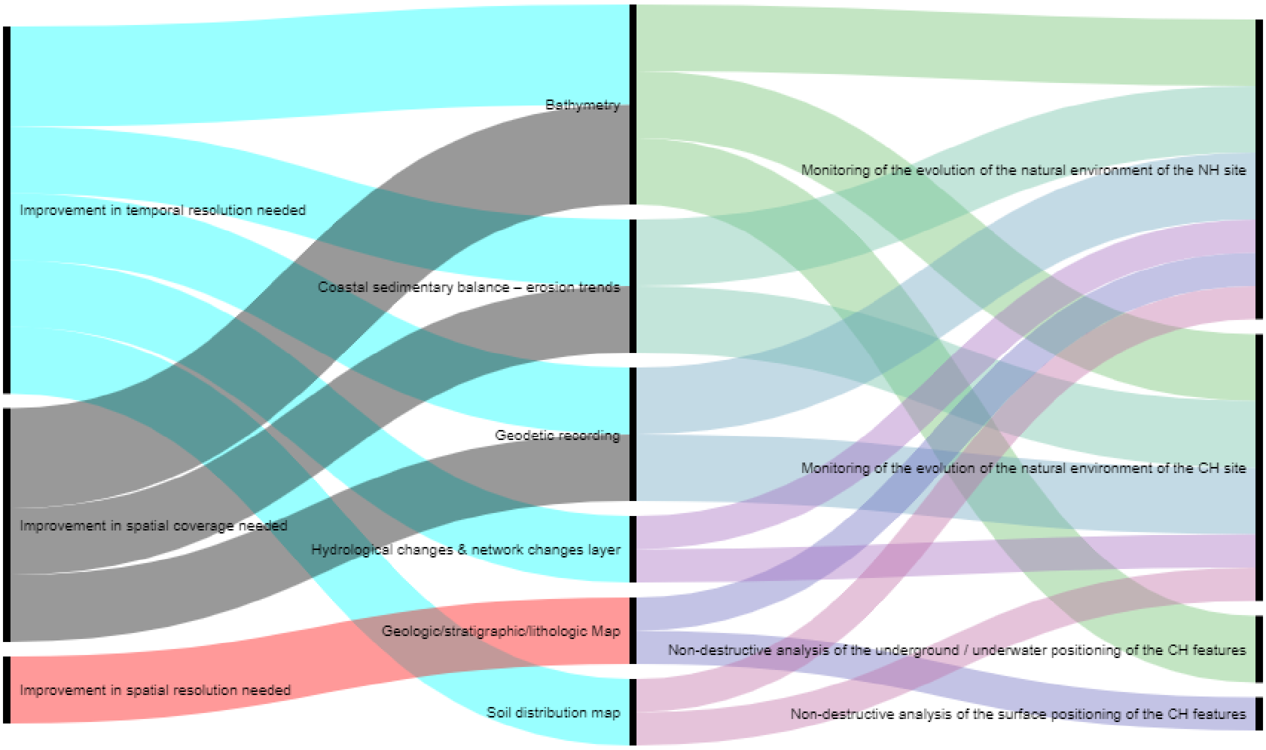

Figure 10 - Link between in situ requirements (left column) and monitoring domain (wright column), sorted by their frequency of request.

Bathymetric data are available as in situ data through the EMODnet portals, as well as seabed habitats and chemistry. Discussions between CMEMS and EMODnet are on-going to establish a timeline for cooperation on the exchange of data like bathymetry and seabed habitats. With regard to Physics and Chemistry, the agreement is already in place. This in situ data has also been required by CMEMS as essential for product generation. Bathymetry can be of support to sediment levels measurement on sandy coastal sectors. In order to fulfil this service capacity, high resolution passive optical (CM Group 2b - Optical VHR1/2) could be used to derive bathymetry in clear waters.

In the context of the Copernicus in situ Component, requirements about Geodetic Recording have been identified and collected to support the production of a Ground Motion layer (calibration/validation purposes). More information will be available from EEA (responsible of the service delivery) in the next future.

The geologic and stratigraphic layer refers to a one time mapping due to the limited changes of geology and lithology during the years. MSs capacity should be investigated, in particular the National Geologic Services. In the frame of EuroGeosurveys data provision, a pan-European

Geologic Map at 1:1M scale is available. OneGeology provides the global coverage but with very different scales.

Soil distribution requirements can be partially satisfied, because of resolution, by the Harmonized World Soil Database provided by FAO and to which the European Soil Data Centre (ESDAC - JRC) contributes. The Harmonized World Soil Database is a 30 arc-second raster database with over 15.000 different soil mapping units that combines existing regional and national updates of soil information worldwide with the information contained within the 1:5.000.000 scale FAO-UNESCO Soil Map of the World (FAO, 1971-1981). The potential High Priority Candidate Mission CIMR (Copernicus Imaging Microwave Radiometer) could provide results suitable for applications aimed at mapping soil distribution.

In situ elements related to hydrography also include the EU-Hydro (Copernicus Reference Data) River Network. It consists of a vector layer related to: Canals, Ditches, River Network, Inland Water, Transits, Coastal and River Basins. EU-Hydro has been derived from 20-meter resolution imagery. The feature data extraction has been performed by photo-interpretation of Very High-Resolution Image Data (2011 - 2013), with a resolution of 2.5 meters. A Beta public version is available, though not yet validated, where the following corrections and improvements have been implemented:

- integration of the relevant information from the drainage network into the river network with the result of one river network containing common properties of both source networks;
- improvement of the coastline;
- correction of geometry and topology errors;
- correction of Strahler codes in certain upstream parts;
- integration into EU-Hydro *public beta* version of national codes of surface water bodies reported by Member states under the Water Framework Directive, allowing linkages between EU-Hydro *public beta* version and the respective national datasets, thus ensuring compliance between the Pan-European and the national datasets, as required by countries.

7. Matching requirements with future potential Copernicus capacity

Amongst the collected requirements, a few of them, although not supportable by existing Services' products, have the potential to be developed within the Services capacity, according to the Entrusted Entities.

These requirements refer to the identification of linear elements within and surrounding the CH sites and Soil erosion and rainfall erosion monitoring.

Requirement	Spatial resolution	Update frequency	Monitoring domain
Vector layer of linear element into and surrounding the site (roads, pipelines, water conducts etc.)	1-5 m	Yearly	Mapping of the cultural landscape of the site and identification of the specific risks it is exposed to Enable public access to the site
Soil erosion & rainfall erosivity monitoring	100 m	5 Years	Monitoring of the evolution of the natural environment of the CH site

Table 7.1 – Description of the requirements associated to the potential Copernicus Services and the different monitoring domains. In this case, Copernicus products both do not exist or are not planned for the near future (source: Copernicus WP2020).

With regard to the identification of (anthropic) linear elements close to/within Cultural Heritage sites (streets, routes, water conducts, pipelines, power lines, etc.), the use of CM Mission Group 2b Optical VHR1/2 would provide the necessary result based on the required resolution (1 – 5 m). The analysis of some types of the aforementioned linear elements are already included in CSS-SEA products, in particular with regard to those categories that relate to the a) Support to evacuation plan, b) road network status assessment and c) Critical Infrastructure analysis included in the products Digital Geographic Information (DGI) – Image Map & City Map, as well as MapBook product.

With regard to Soil erosion and rainfall erosion monitoring, C3S is currently negotiating a demo case which should be able to provide relevant data for Member States. If the demonstrator is a success, the approach will potentially be made more widely available. Also, data and information about European soils are provided by European Soil the Data Centre (ESDAC – JRC) related to erosion by water and included into the 'in situ' section.

8. Identification of routine and on-demand service delivery

This section aims to give a general explanation with regard to the capacity of Copernicus related to routine/cyclical and/or on-demand service supply. For the natural component of CH, regular monitoring services are required, including seasonal varying schedules, while for Cultural Heritage monitoring related to the built environment on-demand is more common (even if exceptions exist for some archaeological features that need a regular monitoring plan), due to the high spatial/temporal resolution needed to measure specific patterns. For some identified requirements, however, the analysis suggests that both approaches are needed as, for example, in the monitoring of natural and anthropic risk affecting Cultural Heritage (e.g. the ground motion service for prevention and response to emergency) or specific vegetation patterns monitoring (e.g. infesting vegetation). Other requirements presenting both routine and on-demand services are tied to provision of Very High-resolution photogrammetry and the monitoring of building movements. The following Table (8.1) puts in relation the identified user requirements with the requested service typology (routine/cyclical and/or on demand). The table gives also indications on the Copernicus Space Component capacity including the Contributing Missions, as specified in the last column.

To help the reading of the last column of table 8.1, the table below presents the full list of Data Warehouse Phase 2 Copernicus Contributing Missions including Sentinels dedicated missions as well as ESA and Third-Party missions, divided per mission group and resolution type (1=SAR VHR1-MR2, 2b=Optical VHR1/2= Optical HR1/2, 3=Optical MR1/2 and 4/5= Atmospheric Missions). The missions in italic bold will be available at a later stage, when launched or integrated into the CSCDA).
In addition, data from EUMETSAT's meteorological satellite missions (Meteosat, Metop) and third-party missions are available (S-NPP) through the EUMETSAT dissemination mechanisms.

Mission Group 1 - SAR VHR1-MR2	Mission Group 2b Optical VHR1/2	Mission Group 2 Optical HR1/2	Mission Group 3 Optical MR1/2	Mission Group 4/5 Atmospheric missions	Others
ALOS-PALSAR	Deimos-2	ALOS-AVNIR-2	Proba-V	ERS-1/2	CryoSat
COSMO-SkyMed Constellation	Dubaisat-2	Deimos-1	Resourcesat-1, Resourcesat-2	Envisat	SMOS
Envisat	GeoEye-1	Landsat-5 Landsat-7 Landsat-8	Oceansat-2	GOSAT	ERS-1/2
ERS-1/2	IRS-P5 CartoSat	Proba	Sentinel-3	ODIN	Sentinel-3
Kompsat-5	Ikonos-2	RapidEye Constellation			
PAZ	Kompsat-2, Kompsat-3	ResourceSat-1, ResourceSat-2			
RADARSAT-2	Pleiades-1A/1B	Sentinel-2			
RISAT-1	QuickBird-2	SPOT-4, SPOT-5, SPOT-6-7			
Sentinel-1	SPOT-5, SPOT-6/7	TH constellation			
TerraSAR-X, TanDEM-X	TH constellation	UK-DMC2			
	WorldView-1, WorldView-2				
	WorldView-3				
	Worldview-4				

Table 8.1 – Missions made available in the Copernicus Data Warehouse.

Copernicus Core Services	Requirement	Routine/Cyclical Service	On-demand service	Copernicus Space Component capacity (- Sentinels and Contributing missions (Contributing Missions made available in data warehouse phase 2*)
Land	NDVI layer	X		Sentinel-2 & CM VHR Group 2b (Optical VHR1/2)
	Raster elevation - elevation change layer	X		Sentinel-1 SAR: InSAR / DInSAR for elevation / elevation change. CM Group 1 (SAR VHR1-MR1) – Potential application using Cartosat constellation
	Vegetation & vegetation change layer, including infesting vegetation (spot areas)	*X*	*X* (increased update frequency during spring/autumn to be routinely applied)	Sentinel-2 Possibly CM VHR Group 2b
	Sea Ice & snow cover layer	X		Sentinel-1 Sentinel-2 Sentinel-3: OLCI (Ocean and Land Colour Instrument), SLSTR and SRAL Possibly future HPCM P-ICE
	Inland Water quality information on turbidity, trophic state/Chlorophyll, apparent colour	X		Sentinel-2 Sentinel-3 OLCI (Ocean and Land Colour Instrument)
	Forest/Tree coverage layer	X		Sentinel-2
	Ground motion layer	X	X (improved update frequency required)	Sentinel-1
	Ground motion data analysis		X	/
	Coastal erosion layer - sedimentary balance & bathymetry	X		Possible optical bathymetry with CM Group 2b (Optical VHR1/2)
	Hydrological changes & network changes layer	X		Jason, Sentinel-3
Atmosphere	Solar radiation layer	X		Sentinel-3 SLSTR Possible future HPCM LSTM
	Pollutant Concentration map / model - NO2 – NO - SO2 - O3 – PM10-2.5	X		Sentinel-5P TROPOMI
	Wind speed & direction layer	X		Sentinel-1 depending on the

Climate Change		X		monitoring area (IW, EW or WV modes)
	Atmospheric Relative Humidity layer	X		(1-5 km) Sentinel-3 OLCI (Ocean and Land Colour Instrument) derived water vapour (10 km) Possibly derived from Sentinel-3, Sentinel-5P, Sentinel-4, Sentinel-5 and meteorological missions (MetOp, MSG, MTG)
	Temperature & temp. anomaly layer	X		Possibly CM Group 2 (Optical HR1/2) Possibly HPCM LSTM
	Hydrological changes & network changes layer	X		Mission group 2b Optical VHR1/2
Marine	Wind speed & direction layer	X		Sentinel-1 depending on the monitoring area (IW, EW or WV modes)
	Sea salinity layer	X		Future possibility with HPCM CIMR to improve current resolution
	Sea & ocean current layer	X		
	Sea level layer	X		Sentinel-3 SRAL and possibly other altimetry
Emergency	Pre-event geohazard information	X (to be defined depending on geohazard typology)	X	Full Space Component Capacity
	Real-time monitoring of emergency events		X	Full Space Component Capacity
	CH feature identification by visual interpretation		X	VHR1 and from VHR2 to HR 2 over extended areas
	Hydrologic forecast information		X	Support of Sentinel 1&2 - VHR1 and HVR2 to HR2
	High scale topographic mapping		X	Sentinel-1 to VHR1
Security	Topographic mapping		X	Sentinel-1 to VHR1
	CH feature identification by visual interpretation		X	Sentinel-2 Possibly CM Group 2b (Optical VHR1/2)
	Identification of previously searched sites in the area Hi-Res. Elevation change Optical change detection		X	Change detection with VHR optical or SAR, possibly with: CM Group 1 (SAR VHR1-MR1) CM Group 2b (Optical VHR1/2)
	Building structural movements, velocity and direction	X	X	VHR1
	Conflict Risk Map		X	VHR1 and VHR2

	Oil spill identification		X	Hyperspectral mission to define the concentration and pollutant typology
	Vessel identification (Smuggling and recovery actions)		X	Sentinel-1 VHR1
Space Component	Coverage of Very High res. Images - Ortho-photogrammetry	X	X	VHR1 and VHR2

Table 8.2 – Matching of the requirements with the nature of the service delivery typology (Routine and/or on-demand).

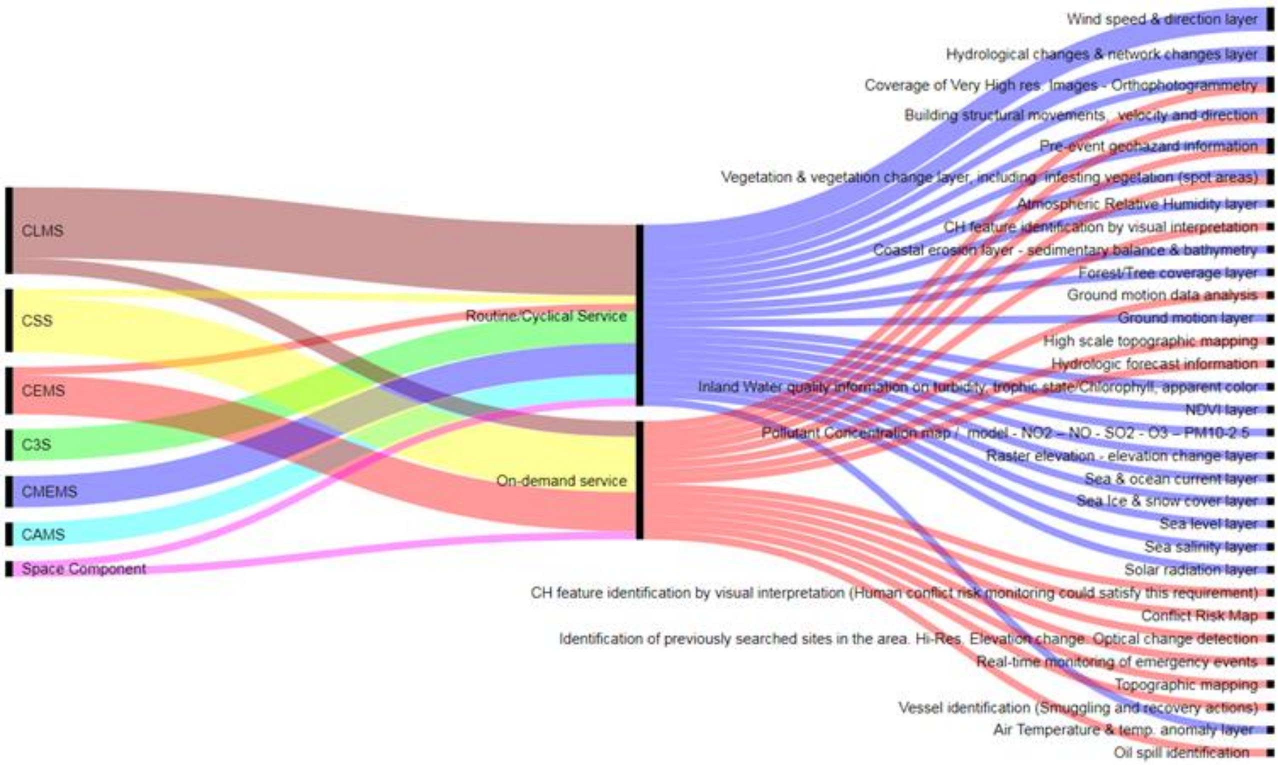

Fig.11 Link between regularly delivered service and on-demand service (central column), Copernicus relative Services (left column) and user requirements (right column).

9. Unmatched requirements

Among the requirements expressed by the Cultural Heritage community, there are some that are not supportable by the Copernicus Program and not directly related to Earth observation. Some of them may be matched by SatCom and the Galileo Programme (real time frequentation information and wildlife tracking), whilst others belong to specific in-situ observation which would be difficult to replace using EO instruments (Identification of signs of mineralisation and organic change related to the built environment).

With regard to the requirement for a stratigraphic description of the archaeological site and identification of individual layers or stratigraphic units, considering no one of the Entrusted Entities provided feedback, it is assumed that with the current or planned Copernicus capacity it isn't possible to satisfy this requirement.

3D reconstruction of Cultural Heritage could be considered within the downstream EO monitoring capacity, to be complemented with in situ and high-resolution surveys, e.g. by drones. VHR Contributing Missions could provide background/ancillary information to support a more detailed monitoring approach.

Concerning the metal detecting requirement, little information has been collected by E.E.; they refer to the use of airborne S-L-P Bands (SAR) in dry soils.

In relation to these unmatched requirements, it would be necessary to investigate the availability of examples produced in research activities.

Requirement	Suggested development context	Spatial resolution	Update frequency	Monitoring domain
Identification of signs of mineralisation and organic change	in situ observations	< 10cm	yearly	Observation of changes on the built structure of a CH site
Material composition analysis	VHR imagery and in situ observations	50 cm	Once	Observation of changes on the built structure of a CH site
Stratigraphic description of the archaeological site and identification of individual layers or stratigraphic units	In situ and Geo-gnostic investigations	1m	Once	Detection of underground archaeological sites through the study of the natural environment Non-destructive analysis of the underground / underwater positioning of the CH features
3D reconstruction	Support of VHR imagery as ancillary	50 cm	Once	-
Metal detecting	S-L-P Bands (SAR) in dry soils	1 m	Once per Year	Non-destructive analysis of the underground / underwater positioning of the CH features

Table 9.1 – List of unmatched requirements

10. Gap analysis results

Through the involvement of the Entrusted Entities, it emerges that most of the Copernicus products have the potential to satisfy the requirements. These mostly relate to C3S, CAMS, CMEMS and partially to CLMS.

The shortfalls within Land Monitoring Service are mostly related to the resolution and update frequency of the Pan-European Component. With regard to resolution, this could be resolved by applying the Sentinel resolution (10m) to the Pan-European products, nowadays released at 20m resolution. Additionally, there could be the possibility to further increase the spatial resolution of existing products through the use of the Copernicus Contributing Missions. Since sites related to Cultural Heritage, with a few exceptions, have a local coverage, the associated costs for the exploitation Contributing Missions would be limited, in so far as the data was only required for specific sites.

With regard to on-demand services, there is a very high matching degree between the identified requirements and most of the Copernicus products delivered.

In particular, products have already been released in the fields of Cultural Heritage monitoring by Copernicus Security Services - Support to External Actions. Some routine aspects of these services are to some extent hoped to satisfy, even partially, the identified requirements (e.g. Building structural movements, velocity and direction).

To give a preliminary and overall analysis, the requirements identified are 41, as shown in the following table.

Copernicus Services or Component	Number of identified requirements
CLMS	10
C3S	4
CAMS	3
CMEMS	4
CEMS	5
CSS – SEA	5
CSS – BS	1
CSS - MS	1
In situ	6
Potential future development	2

Table 10.1 - Number of requirements per Core Service, in situ component, potential future development and unmatched.

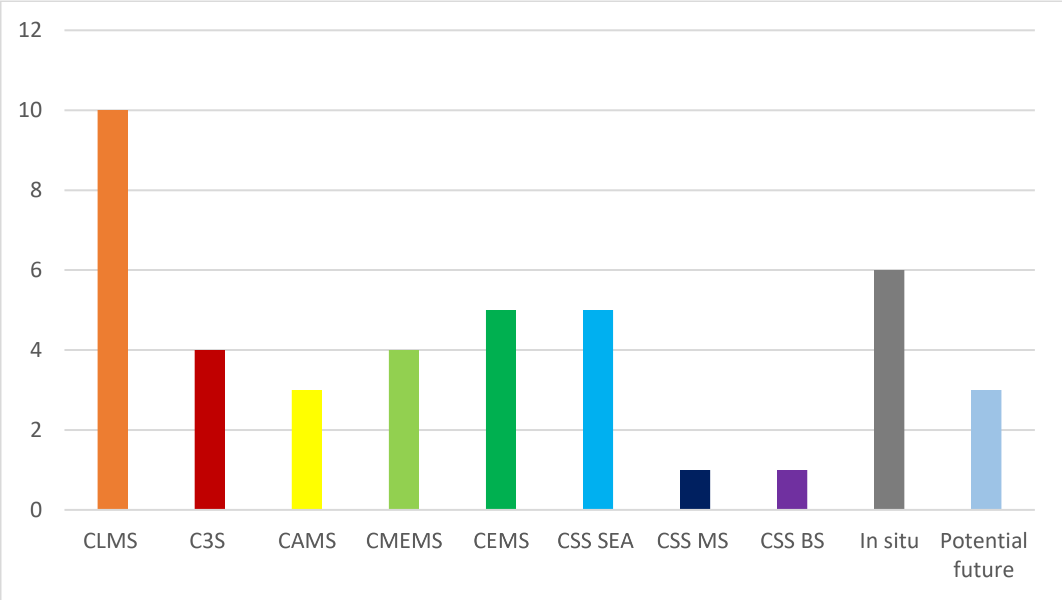

Figure 12 - Number of requirements per Services

It is important to notice that Copernicus Security Service - Border Surveillance, even though it does not have any associated requirements, supports vessel detection through the existing product in the case of potential Cultural Heritage artefacts smuggling and looting across, in particular, the Mediterranean Sea.

The small number of requirements associated with Emergency Management Services reflect a generic need expressed by users (e.g. Real-time monitoring of emergency events; Pre-event information) that have to be associated, case by case, to different situational crises affecting Cultural Heritage (e.g. natural and anthropogenic disasters).

With regard to the current unmatched requirements, an analysis of the available examples developed within research activities would be necessary to evaluate the capacity that might be integrated within the Copernicus service supply. The following table presents a synthesis of the available Copernicus products that can already support the Cultural Heritage users' and products that could support Cultural Heritage users, if improved.

Service	Requirements supported by current products	Requirements supportable by current products with improvements
CLMS		Raster elevation - elevation change layer (update frequency)
	Sea Ice & snow cover layer	
	Inland Water quality information on turbidity, trophic state/Chlorophyll, apparent colour and illegal abstraction	
		NDVI layer (Spatial Resolution)
		Vegetation & vegetation change layer, including infesting vegetation (update frequency)
		Forest/Tree coverage layer (spatial resolution)
		Ground motion layer (Update frequency) *
		Ground motion data analysis (Update frequency) *

		Coastal erosion layer - sedimentary balance & bathymetry*
		Hydrological changes & network changes layer (update frequency)
C3S		Hydrological changes & network changes layer (spatial resolution)
	Atmospheric Relative Humidity layer	
	Air Temperature & temp. anomaly layer	
C3S/CAMS	Wind speed & direction layer	
CAMS	Pollutant Concentration map / model - NO2 – NO - SO2 - O3 – PM10-2.5	if 1 to 5 km spatial resolution for built environment (spatial resolution)
	Solar radiation layer	
CMEMS	Wind speed & direction layer	
	Sea salinity layer	
	Sea & ocean current layer	
	Sea level layer	
CEMS	Pre-event geohazard information	
	Real-time monitoring of emergency events	
	CH feature identification by visual interpretation	
		Hydrologic forecast information (spatial resolution)
	High scale topographic mapping	
CSS	Topographic mapping	
	CH feature identification by visual interpretation (Human conflict risk monitoring could satisfy this requirement)	
	Identification of previously searched sites in the area Hi-Res. Elevation change Optical change detection	
	Building structural movements, velocity and direction	
	Conflict Risk Map	
	Oil spill identification	Pollutant Concentration (Hyperspectral capacity required)
	Vessel identification (Smuggling and recovery actions)	

Table 10.2 - Synthesis of the available Copernicus products that support the Cultural Heritage users' requirements and products that could support Cultural Heritage users, if improved. *In development phase.

It is also important to highlight some potential services that would fit into the Copernicus operational products. The above-mentioned services refer to the following requirements (tab. 10.3), as described in section 5.

Requirement	Spatial resolution required	Update frequency required
Vector layer of linear element into and surrounding the site (roads, pipelines, water conducts etc.)	1-5 m	Yearly
Soil erosion & rainfall erosion monitoring	100 m	5 Years

Table 10.3 - Description of the requirements not satisfied by the current Copernicus products and for which is hoped a future development within the Copernicus Program.

On the basis of the above analysis, this report stresses that the Copernicus Program has the capacity, even if only partial in some areas, to support the Cultural Heritage conservation and protection activities. The Copernicus products uptake by Cultural Heritage users' community would significantly increase if the requirements here described are supported by Copernicus products improvement.

11. Conclusion, recommendations and follow up

Cultural Heritage represents a priceless resource for the sustainable development in Europe and worldwide. Current remote sensing technology, accessible to EU citizens via the Copernicus program, offers an incomparable possibility for fostering its protection and valorisation by delivering tools to diverse target stakeholders, including managers and professionals. These tools can be used to tackle current and emerging challenges, such as climate change, mass tourism and intensive land use.

From the analysis performed it is evident that the current Copernicus Programme capacities cover a considerable portion of the requirements of the Cultural Heritage community. This is especially true, for example, where high-resolution imagery required for large-area inspection and monitoring of individual monuments is available. Moreover, Copernicus is already playing a crucial role by implementing the paradigm IaaS (Information as a Service), which allows for the accessibility of complex data in an "easy to read" and "understandable" format of information. This also supports the Cultural Heritage community, which usually has to manage different data sources and related standards, that require horizontally-high competences and skills, not always owned by those responsible for the protection and preservation of Cultural Heritage, especially in the case of implementation of action plans and management strategies.

Nevertheless, this document highlights that:

i) efforts are still required to customize current Copernicus products on the basis of the identified requirements;
ii) a unique *service-access point* would be of benefit, to permit users to exploit a single infrastructure where Copernicus Products and related information are collected and made accessible e.g. via network-services, being the access to information a still critical issue to be solved.
iii) Ready-to-use integrated information related to land cover/use, geo-hazards, climate as well as atmospheric parameters, will allow a better understanding of the specific phenomena affecting the sites.
iv) the access to Very High-Resolution imagery[26] to test innovative applications aimed at improving monitoring capacity and novel applications is required by the Cultural Heritage research community, having high and specific thematic and geomatic skills.

The Entrusted Entities should support the above points and the activities for the definitions of an improved Cultural heritage monitoring capacity.

As a first main conclusion, this report highlights that the majority of the current products satisfy the identified requirements, and it seems clear that there is no need for a new Core Service dedicated to Cultural Heritage monitoring.

This outcome corresponds to the starting options identified by the PwC Study here reported for easier comparison:

[26] The access to previously acquired Very High-Resolution imagery is already guaranteed to the Public Sector through the Copernicus Space Component Data Access (CSCDA) portal.

a) rely on existing core products, data and information that are currently suitable for Cultural Heritage applications, but emphasizing the existence of such products by raising awareness;

b) setting up a specific user interface in the form of a web-based platform (i.e. web-based front-end) fully dedicated to Cultural Heritage, where user communities could find existing Copernicus data and information suitable for Cultural Heritage activities, together with additional existing products from core services that have been adapted to Cultural Heritage needs;

c) create a Copernicus Service, in addition to the existing ones, which would be exclusively dedicated to Cultural Heritage.

The **first option** *(a)* reflects the current situation, where users should be able to access the different Copernicus Core Services information to be integrated into local desktop/server environment. This approach currently penalizes the users attempting to access Copernicus information, due to the scattered points of access offered by the different Core Services. Also, specific capabilities and skills in terms of thematic and even geomatic competences would be required by users (e.g. data management and post processing by using GIS tools) to manage the different data format and standards.

A single infrastructure, such as a common user web-interface (e.g. sectoral desk), where users can find the required information from the different Services at a unique "*access point*", will save time in searching and displaying this information; such information could be thematically stratified, via network-services, and provide a full thematic view of a specific area. Also, in most cases, this approach would mean that full data download would be unnecessary. This approach supports the above **second option** (*b)*.

To fully support the users' uptake, the second option should include different functionalities, such as:

a) offering a single access point for the required information, were users can integrate the different available products delivered by the different Services including via web- services;
b) the ability to query the system for a multiple return of information related to the same area of interest;
c) the ability to compare different sources of information (Services can provide analogue products with different characteristics depending on the application and scale - e.g. wind measures);
d) the ability to upload user's data and information for integration or validation purposes.

With regard to this option, it would be useful to include a remote computational support, in order to enable users to extract information from the combination of two or more available Copernicus products, in a user-friendly, informative environment providing a suite of ready-to-use tools. All the Entrusted Entities should collaborate to implement the required infrastructure.

Considering that part of the information required by CH's users t is already available, or needs a slight improvement (often the revisit time), it appears clear that there is no need to create a further Core Service for the specific CH requirements (**third option** - *c*). A user interface will definitely provide the same positive impact in terms of uptake with much more limited infrastructural developments and costs.

Among its main objectives, this report intends to communicate key ideas and concepts on how Copernicus can support Cultural Heritage management and protection.

1. Integrated plans, decision support tools and models will bring together the different Cultural Heritage management domains (built and natural) to foster effectiveness, stimulate innovation and address the challenges of climate change and mass tourism. The delivery of products suitable for Cultural Heritage users' community should consider this specific need.

2. A European Cultural Heritage advisory board, composed of expert representatives from all EU member states, should be established to advise the Copernicus User Forum about Cultural Heritage user' needs. The Cultural Heritage advisory board would be open to participation by MSs on a voluntary basis. The establishment of such advisory body would help the exchange of information about EO monitoring practices and CH common requirements leading to further Copernicus product development. In addition, the integration between research results and the requirements of CH public institutions could contribute to the definition and development of novel and even disruptive applications by European industries.

3. In order to create a group of heritage professionals with relevant EO skills in Cultural Heritage monitoring, conservation and protection, the Commission should contribute by promoting academic courses that include both Earth observation and Copernicus monitoring capacity knowledge.

4. A European long-term strategy concerning Earth observation capacity as applied to Cultural Heritage monitoring and protection should be elaborated with related roadmap.

5. There is high potential for Copernicus to stimulate substantial growth of the Cultural Heritage downstream market. The potential of open markets and commercial initiatives in archaeology are already exploited in some EU countries, where the archaeological job markets are particularly strong and involve citizens and entrepreneurs. The creation of a common platform, where different players (users and providers) can interact for the definition and development of user requirements-based services would support the market development process.

With regard to this last point, from both an economic and social perspective, Cultural Heritage is already a heavyweight that still offers enormous growth and innovation potential, although nowadays it is only partially exploited both in the institutional and commercial frameworks. This importance must urgently be reflected by substantial and, above all, sustainable investments into all of the EU's relevant technological programs, Copernicus perhaps being the most obviously important one.

Remote sensing has enormous technological and economic potential for the European Cultural Heritage sector. To name some of the key areas where these technologies offer unprecedented growth opportunities:

- identification of unknown, unregistered or unmanaged heritage sites on public and private lands;
- monitoring and early warning systems for effective Cultural Heritage protection;
- mid- and long-term environmental assessments and damage risk mitigation for large-area sites and archaeological parks;
- integrated management models and action plans for natural and Cultural Heritage sites.

In fact, it is hard to imagine how the challenge of effective site preservation and management, in times of climate change, mass tourism and increasing environmental hazards, should be addressed without the full integration of remote sensing capacity into EU-wide heritage management practice. However, the adoption of these key technologies and methods remains sporadic among Cultural Heritage authorities and institutions, and a dedicated set of monitoring EO based tools applied to Cultural Heritage is still missing. From the point of view of Cultural Heritage management, it is clear that a catalyser investment, both by MSs public and private actors, is needed to increase the market for downstreaming products to be exploited in the professional Cultural Heritage sector.

In support of the above, the EU-wide survey "Discovering the Archaeologists of Europe"[27] provides rich data on the Member states, that point in a clear direction: Employment and entrepreneurship in the archaeological and heritage sector are strongest in those countries that are open to private and commercial initiatives, ranging from field workers to consultants at the highest level of decision making for heritage authorities. In countries such as the United Kingdom and the Netherlands, open markets have produced not only the proportionally highest numbers of jobs (e.g. in archaeology and related horizontal fields) but also a very innovative entrepreneurial sector. The study also reveals that the most sought-after skills, regularly outsourced to external consultants, are in the fields of IT development and applied technologies. In this area, public services generally lack the technical skills that commercial entities can provide, therefore outsourcing these services to commercial providers, that are in turn Copernicus intermediate users, is *a de facto* practice. The Copernicus Programme, in its full operation, is strongly focused on stimulating intermediate and end-user uptake. In general, if intermediate and technical end users' uptake has grown slightly during recent years, adoption at local and regional governmental authorities and commercial market remains quite low.

From the analysis performed, it appears that most of the users' requirements identified come from the institutional domain, with users responsible for Cultural Heritage management and accountable for fulfilling National, European and international obligations. Where an institutional requirement is expressed as a continuous public demand (to fulfil the above-mentioned obligations) an anchor tenant mechanism enables a more fertile, both public-to-market and subsequently market-to-market interaction, with consequent downstream segment development.

In order to catalyse the demand and boost Cultural Heritage downstream services development, therefore, a *market place business model* should support the connection of users and providers of geospatial solutions, using a European institutional demand as an anchor customer. It would support the industry and SMEs by developing a market responding to institutional operational needs around specific themes, useful for different users' communities (not only the Cultural Heritage one). Institutional users would benefit from harmonized and common cost-effective solutions designed specifically to respond to horizontal needs such as tourism management, security of the site and visitors, monitoring of wildlife, real time frequentation of sites, augmented reality, 3D model's reconstruction rendering, etc.

For many decades, the potential of remote sensing in archaeology and Cultural Heritage could only be explored within limited case studies and exemplary applications. Since Cultural Heritage is one of the European assets, it should be consistently supported by Copernicus through a systematic monitoring approach, based on the requirements expressed by users. In addition, the Copernicus Programme owns the capacity to act as a catalyser for a process that would support, in the short-

[27] https://www.discovering-archaeologists.eu/

medium term, the conditions for a market expansion. It would do so by offering added value information on which the commercial sector would build applications, and also by providing society with an increased knowledge, tied to a better conservation and protection mechanism for those features and elements that link our past with future generations. In conclusion, any planned Copernicus support should consider natural and Cultural Heritage together when designing or customizing products. Our built heritage and natural environment have co-evolved over countless generations, are inseparable and can only be protected and preserved effectively together. Such a holistic approach to the management of Cultural Heritage will not only foster innovation and efficiency by means of cross-fertilization and harmonization of management practice, but it is also an ideal starting point for remote sensing technologies and derived monitoring products that have already been developed for different applications domains.

11.1 IMPLEMENTATION ROAD MAP TIME TABLE EXAMPLE

	June-July 2020	September-December 2020	January -April 2021	April – September 2021	September 2021 - ongoing
1st phase	Individuation of the Entrusted Entities hosting the CH User platform				
2nd Phase		Cultural Heritage advisory board definition (the aim of the board should be to identify further requirement, exchange of information on monitoring practices/activities and promote the use of Copernicus in the CH field)	Cultural Heritage advisory board consultation meeting	Cultural Heritage advisory board consultation meeting: CH infrastructure/user interface prototype presentation CH infrastructure/user interface prototype testing	Cultural Heritage advisory board consultation meeting (twice per year)
3rd Phase			Tendering and procurement phase CH User Web-based infrastructure development	Development and pre-operational phase of the infrastructure	Operational phase

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Images in the cover of the present document refer to:

- Interreg Central Europe Project ProteCHt2save Risk Assessment and Sustainable Protection Of Cultural Heritage In Changing Environment - https://www.interreg-central.eu/Content.Node/ProteCHt2save.html
- JPI – CH Prothego - PROTection of European Cultural HEritage from GeO-hazards - http://www.prothego.eu/

Annex I
List of consulted Entities

Country	Consulted Institution/Authority/Entity
BE	Service public de Wallonie - DGo4 - Agence Wallonne du Patrimoine - Direction de l'Appui Scientifique et Technique
CY	Cyprus University of Technology
	Department of Electromechanical Services
CZ	Department of Anthropology, University of West Bohemia in Pilsen
	Department of Applied Geoinformatics, Czech University of Life Sciences Prague
DE	Deutsches Archäologisches Institut (DAI)
	Stiftung preußischer Kulturbesitz (SPK)
	Auswärtiges Amt (AA)
	Beauftragte für Kultur und Medien (BKM)
	Bundesministerium für Verkehr und Information (BMVI)
	Geoforschungszentrum Potsdam (GFZ)
	Deutscher Verband für Archäologie (DVA)
ES	Centro para el Desarrollo Tecnológico Industrial (CDTI).
	Ministerio de Cultura y Deporte
FR	Ministère de la Culture (MC)
	Laboratoire de Recherche des Monuments Historiques (LRMH)
	Centre de Recherche et de Restauration des Musées de France (C2RMF)
	Centre national de préhistoire (CNP)
GR	Ministry of Digital Governance
IT	Ministry of Cultural Heritage and Tourism
	ISPRA - Italian Institute for Environmental Protection and Research
	CNR ISAC - National Research Council of Italy - Institute of Atmospheric Sciences and Climate

	ISCR -Istituto Superiore per la Conservazione e il Restauro
	ASI - Italian Space Agency
	National Archaeological Parks (Pompei, Colosseum, Ostia Antica)
	Italian Space Economy advisory board for the Cultural Heritage satellite downstream service implementation
	Department of Civil Protection
MT	Superintendence of Cultural Heritage
	University of Malta
NL	Rijksdienst voor het Cultureel Erfgoed (RCE)
	Staatsbosbeheer (SBB)
	Convent van gemeente-archeologen
	RAAP (Commercial Archeological Company)
NO	Klima- og miljødepartementet (KLD)
	Riksantikvaren (Directorate for Cultural Heritage)
	Norwegian Institute of Bioeconomy Research (NIBIO)
	Norwegian University of Science and Technology
	The Norwegian Institute for Cultural Heritage Research (NIKU)
	The Norwegian Water Resources and Energy Directorate
PL	Ministerstwo Kultury
PT	FCT Fundação para Ciência e a Tecnologia
	Universidade de Évora
	Direção Regional de Cultura do Alentejo
UK	Historic England
	English Heritage
	The National Trust
	Historic Environment Scotland
	The Royal Commission on the Ancient and Historical Monuments of Wales – RCAHMW

Table 0. Entities consulted by the Copernicus Cultural Heritage Task Force to analyse the user needs in order to identify specific requirements.

Annex II

Copernicus Task Force on Cultural Heritage Users' needs Matrix

Annex III

Show cases