Copernicus Services and Products - Modelling

Water-ForCE

Project Identification

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History of Changes

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Date	Version	Comments
07.07.2021	V0	First contents added
18.10.2022	V1	First complete draft
28.10.2022	V1.1	Review
09.11.2022	V2.0	Second version incorporating review suggestions
07.12.2022	V3.0	Pre-final version
22.12.2022	V4.0	Final version

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List of Acronyms

AI	Artificial Intelligence
Atot	Total absorption coefficient
Aphy	Phytoplankton absorption coefficient
AT	Air Temperature
Bbp	Particulate Backscattering Coefficient
CAMS	Copernicus Atmosphere Monitoring Service
CDM	Coloured Dissolved Organic Matter
CDS	Climate Data Store
CEMS	Copernicus Emergency Management Service
CGLS	Copernicus Global Land Service
CHLA	Chlorophyll-A
CLMS	Copernicus Land Monitoring Service
CMEMS	Copernicus Marine Environment Monitoring Service
DEM	Digital Elevation Model
DIAS	Data Information Access Service
DOC	Dissolved Organic Carbon
ECMWF	European Centre for Medium-Range Weather Forecasts
EDO	European Drought Observatory
EFAS	European Flood Awareness System
EO	Earth Observation
EU	European Union
ESA	European Space Agency

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GDO	Global Drought Observatory
GEOSS	Global Earth Observation System of Systems
GloFAS	Global Flood Awareness System
IWT	Inland Water Temperature
Kd	Diffuse attenuation coefficient
LST	Land Surface Temperature
LSWT	Lake Surface Water Temperature
LU/LC	Land Use / Land Cover
MCC	Mass concentration of Chlorophyll-A
NRT	Near real Time
OC	Ocean Colour
pCO2	Partial pressure of CO2 or CO2 concentration
RS	Remote Sensing
RSR	Remote Sensing Reflectance
SDD	Secchi Disk Depth
SPM	Suspended Particulate Matter
SST	Sea Surface Temperature
TN	Total Nitrogen
TP	Total Phosphorus
TSI	Trophic State Index
TSS	Total Suspended Solids
TWS	Total Water Storage
WL	Water Level
WLR	Water Leaving Reflectance

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WP	Work Package
WPP	Water Primary Production

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Executive summary

This deliverable analyses and evaluates the availability and suitability of Copernicus products and services for water modelling, both for the case of water quantity and water quality, and comprising all types of use of EO data in modelling (forcing data, calibration data, validation data, evaluation data, assimilation data), and makes recommendations for improvement that can be incorporated in the Water-ForCE roadmap. It is based on the requirements collected in deliverable **D5.1 Copernicus EO needs assessment for modellers and decision makers** (IHE Delft, 2022) and on the characterization of relevant variables provided by Earth observation collected in the document **Earth Observation for Water Resources Management** (World Bank, 2016).

From these two documents, a list of water quality and water quantity variables that can be useful in water modelling are identified.

All of them are related to five types of modelling for water management (based on the classification from the World Bank): biogeochemical models, hydrodynamic models, river models, crop or pasture growth models and landscape water balance models.

In this deliverable, the availability of products in the Copernicus portfolio is analysed by checking the water quantity and water quality inventories done in Water-ForCE deliverables **D2.2 Analysis of current Copernicus water quality portfolio** and **D3.2 Review document on Copernicus products related to the hydrological water balance**. An update on the availability of new products has also been done.

In addition to the availability, a characterization of the products based in their spatial coverage, data access, file formats, validation, uncertainty and spatial and temporal resolutions has been made and their utility in different types of water modelling has been analysed. Finally, recommendations on improvements of the existing Copernicus products are made. The main conclusions are:

- A **bathymetry** product is required for water modelling.
- For **Chlorophyll-a**, the 1 km products are not suitable for coastal zones.
- Marine (coastal) and lake reflectances are not calculated in the same way.
- Users asked for new products related to **water quality**.

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- There is a demand for higher resolution soil moisture products.
- No detailed **regional products** (only global products) are available for some water surface products.
- Better-structured information is needed when accessing data in product platforms and websites
- Recommendations can be done to provide products in **Cloud Optimized GeoTIFF** (COG) in the near future
- Need to increase **validation** in water quantity products
- Need to provide uncertainty information for some products.
- Spatial resolution of **surface water** variables such as surface runoff or river discharge should be improved to less than 1km.
- For the **river discharge** and the **water quality** variables, the temporal resolution could be improved for monitoring water quality.
- Spatial resolution of **snowmelt** products should be higher (<1000 m) and temporal resolution of **groundwater** products should be higher also (<24 h).
- An **evapotranspiration** product is needed for river modelling, crop or pasture growth modelling and landscape water balance models.
- Major needs are continuous and consistent long-term archives of **vegetation** biophysical parameters coupled with **land cover** information.

1 Introduction

1.1 Water-ForCE

The **Horizon2020** project Water-ForCE (Water scenarios For Copernicus Exploitation) is going to develop a Roadmap for Copernicus **Inland Water Services**, aiming to better integrate the entire inland **water cycle within the** Copernicus Services. It addresses current disconnects between remote sensing / in-situ observation and the user community. Clarity in terms of the needs and expectations of both public and private sectors, as well as the wider research and business innovation opportunities will be delivered. This Roadmap will advise on a strategy to ensure effective uptake of water-related services by end users and further support the implementation of relevant directives and policies.

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The Water-ForCE consortium is led by the University of Tartu (Estonia) and consists of 20 organisations from all over Europe. It connects experts in water quality and quantity, in policy, research, engineering and service sectors. Through close collaborations with these communities, Water-ForCE aims to:

- Analyse EU policies to identify where the Copernicus Services can improve monitoring programs and how the Copernicus data can be more effectively used in developing and delivering the next versions of the directives.
- Specify the requirements for future Copernicus missions (e.g. optical configuration of Sentinel-2E and onward, hyperspectral sensors).
- Optimize future exploitation for inland water monitoring & research and, consequently, (a) enlarge the service portfolio and (b) improve the performance of current Services.

The project is divided in eight work packages (WP), each of them focusing on a specific problem and/or target of the Copernicus Service (Figure 1). The following report is part of **WP5** which focusses on **Modelling and data assimilation**.

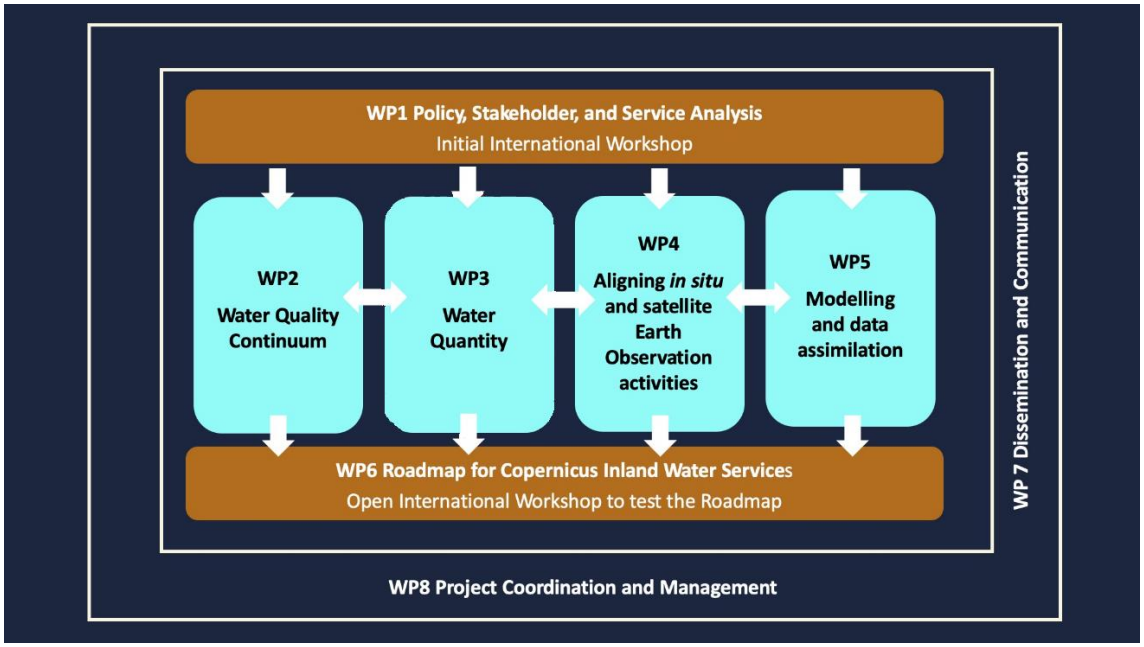

Figure 1.- Organizational structure of the different work packages in the Water-ForCE project.

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1.2 Context WP5

WP5 identifies the potential for future use of different satellites in modelling of water resources for support of decision makers towards adaptive management of water resources and policy implementation. Available satellite data are evaluated on how monitoring and modelling of water bodies dynamics is done and where they can be improved. The use of Artificial Intelligence (AI) to optimize the exploitation of satellite and modelling data is also explored. Finally, the findings will be integrated to demonstrate the value of satellite-enhanced models for decision making, including recommendations.

There are four main tasks that are being carried out in order to achieve the main objectives of WP5:

- The first task (**Task 5.1**) defines and creates a working group consisting of inland water specialists and modellers to assess current issues in Copernicus hindcast/forecast capabilities and to provide recommendation for future services and data for modelling purposes.
- The second task (**Task 5.2**) looks at the value of satellite Earth Observation (EO) data to modelling.
- The task **Task 5.3** explores the use of Artificial Intelligence (AI) to optimize the exploitation of satellite EO and modelling data.
- In the fourth task (**Task 5.4**) the future added value of satellite EO supported modelling in policy and decision making is explored.

1.3 Objectives & context T5.2

This report forms the output of Task 5.2. The main objective of this task is a provision of technical recommendations for the Copernicus services and related data in order to improve the monitoring and modelling of water bodies' dynamics. It will specially address data quantity and quality and uncertainty of inputs and outputs of the models involved in Water Copernicus Services.

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To this end, available satellite EO data has been evaluated on how monitoring and modelling of water bodies dynamics is currently done and where they can be improved. This report contains the main conclusions of this task and provides input for Task 5.4 on demonstrating the value of satellite EO-enhanced models for policy and decision making and for the Water-ForCE Roadmap as well.

1.4. Content of the report

The objective of the report is to analyse and evaluate the availability and suitability of Copernicus products and services for water modelling in the different Copernicus Services and to make recommendations for improvement that can be incorporated in the Water-ForCE roadmap.

This deliverable first presents the identified **EO needs** in water modelling, based on the process led in Task 5.1 and collected in *D5.1 Copernicus EO needs assessment for modellers and decision makers* (IHE Delft, 2022). In D5.1 a set of requirements and recommendations from external documents and reviews were identified. Within this framework, the types of variables needed for modelling, their recommended spatial and temporal resolutions, and their use in different modelling approaches are identified (Section 2).

After that, Section 3 provides a screening of existing Water **EO products** for modelling at Copernicus Services. In this section, the availability of variables identified in Section 2 within the Copernicus portfolio is evaluated through the developed Copernicus inventories prepared within Water-ForCE Tasks 3.2 and 2.2 and collected in deliverables D3.2 and D2.2. The list of available products is identified, and the spatial and temporal resolutions are analysed to be further compared with the needs and recommendations from Section 2.

Section 4 offers a screening of existing Water EO products for modelling at non-European agencies in order to give a picture of what is available outside Copernicus for modelling.

In the same line, Section 5 provides a view of the modelling capabilities on Copernicus DIAS (Data and Information Access Services).

In Section 6 the characterization of Copernicus available EO products for modelling is analysed and compared to the recommendations from Section 2.

Finally, Section 7 provides the conclusions and recommendations obtained from the analysis and comparison process and derived from the entire document.

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2 EO needs for water modelling

Within WP5, the submitted deliverable **D5.1 Copernicus EO needs assessment for modellers and decision makers** presents the needs for remote sensing data for modelling water quantity and water quality; such that decision makers will use it, with a special focus on Copernicus data services. The methodology used to evaluate the EO needs in water modelling included the analysis of Water-ForCE previous workshops and the outcomes of the deliverables D2.2 (2021) and D3.2. (2022), a structured literature review and the conduction of online surveys based on the conclusions of this literature review, as well as in-person interviews with researchers and consultants working with remote sensing (RS) data.

In Section 3 of D5.1, the results of the conducted needs assessment are detailed, for each type of data source (literature review, surveys and interviews). In all cases, water quantity and water quality modelling are addressed. In addition, the deliverable summarises, in its Section 4, the outcome of the analysis by recommending a set of possible improvements to current Copernicus services.

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Based on the findings of the EO needs assessment in D5.1, a new approach is presented here, in order to detect, from the information gathered, the EO requirements gaps that the new Copernicus services and satellite missions should cover.

To complement the analysis of EO needs for water modelling as well as to obtain a framework classification for the different types of models and variables involved, we develop our analysis based on the classification proposed by the World Bank in the work *Earth Observation for Water Resources Management - Current use and future opportunities for the water sector* (World Bank, 2016) which collects the main required variables in water modelling and their needs in terms of spatial and temporal resolution, as illustrated in Table 1.This report compares the World Bank water modelling related activities with the relevant variables that can be estimated with the aid of Earth observation. The key types of variables and their minimum spatial and temporal resolution requirements are evaluated for each WRM issue. Other existing classifications exist that are focused on the integrated water cycle, such as the one used in the GEOSS Water Strategy Report (Lawford, 2014), which defines Priority Water Variables in relation with Essential Climate Variables. The report also includes recommended specifications of measurements of water cycle parameters in terms of the required accuracies, resolutions, and frequencies of observations. The approach of such classifications is very broad and not only focused on modelling, that is why we preferred to base our analysis here on the identification, classification and recommendations of variables for water modelling made by the World Bank in its report (2016).

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MODELING APPROACH	PRECIPITATION	EVAPOTRANSPIRATION	SOIL MOISTURE	VEGETATION AND LAND COVER	GROUNDWATER	SURFACE WATER	SNOW AND ICE	WATER QUALITY	OTHERS
BIOGEOCHEMICAL MODELS						Very fine to medium spatial resolution (<1000m), high to medium temporal resolution (3 hours-30 days)		**Very fine to medium spatial resolution (<1000m), high to medium temporal resolution (3 hours-30 days)**	
HYDRODYNAMIC MODELS	Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)		Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)			Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)			**Elevation (DEM)**
RIVER MODELS	Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)	**Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)**	Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)	Fine to medium spatial resolution (10-1000 m), medium temporal resolution (1-30 days)	Coarse spatial resolution (>1000 m), high temporal resolution (3-24 hours)	Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)	Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)		

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CROP OR PASTURE GROWTH MODELS	Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)	Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)		Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)					
LANDSCAPE WATER BALANCE MODELS	**Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)**	**Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)**	**Coarse spatial resolution (>1000 m), high or near continuous temporal resolution (<24 hours)**	**Fine to medium spatial resolution (10-1000 m), medium temporal resolution (1-30 days)**	Coarse spatial resolution (>1000 m), high temporal resolution (3-24 hours)	Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)	Fine to medium spatial resolution (10-1000 m), high to medium temporal resolution (3 hours- 30 days)		Elevation (DEM)

Table 1. - Characterization of relevant variables provided by Earth Observation for different types of water management modelling approaches. Adapted from: Earth Observation for Water Resources Management - Current use and future opportunities for the water sector (World Bank, 2016). Text in bold indicates that the data are highly valuable, normal text indicates that they are valuable, and no text indicates that they are not relevant.

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The following tables (Table 2 and Table 3) summarize the main identified used or required EO parameters in modelling reported in deliverable D5.1 (both from literature review and from surveys and interviews), taking water quantity and water quality separately. The relationship of the identified parameters with the data needs indicated in the World Bank report (World Bank, 2016) is also indicated. For information and details on the type of literature reviewed and the interviewed users, please refer to D5.1.

EO WATER QUANTITY PARAMETERS			
Parameter	**Reported in literature**	**Reported by users**	**Related category in World Bank classification**
Air temperature (AT)		√	-
Bathymetry	√	√	-
DEM	√	√	Others
Drought	√		-
Evapotranspiration	√	√	Evapotranspiration
Flood extent	√	√	Surface water
Groundwater	√		Groundwater
Inland water temperature (IWT)		√	Surface water
Lake ice cover	√		Snow and ice
Land surface temperature (LST)	√	√	-
Land use/land cover (LU/LC) and Vegetation products	√	√	Vegetation and Land cover
Precipitation	√	√	Precipitation
River discharge	√	√	Surface water
River width	√		Surface water
Snowmelt	√		Snow and ice
Soil moisture	√	√	Soil moisture
Surface runoff		√	Surface water
Total water storage (TWS)	√		Grondwater + Surface water

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Water levels in lakes and rivers (WL)	√	√	Surface water

Table 2.- Identified EO required parameters for water quantity modelling in D5.1 and related categories in the World Bank variables classification.

EO WATER QUALITY PARAMETERS			
Parameter	**Reported in literature**	**Reported by users**	**Related category in World Bank classification**
Chlorophyll-a (Chl-a)	√	√	Water quality
Aquatic habitats	√		Water quality
Coloured Dissolved Organic Matter (CDOM)	√		Water quality
Diffuse attenuation coefficient (K_d)		√	Water quality
Lake Surface Water Temperature (LSWT)	√	√	Water quality
Particulate Backscattering Coefficient (bb_p)		√	Water quality
Phytoplankton absorption coefficient (a_{Phy})		√	Water quality
Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance (WLR)		√	Water quality
Sea Surface Temperature (SST)		√	Water quality
Secchi Disk Depth (ZSD)	√	√	Water quality
Suspended Particulate Matter (SPM)		√	Water quality
Total absorption coefficient (a_{TOT})		√	Water quality
Total Suspended Solids (TSS)	√		Water quality
Trophic State Index (TSI)	√	√	Water quality
Turbidity	√		Water quality

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Table 3.- Identified EO required parameters for water quality modelling in D5.1 and related categories in the World Bank variables classification.

As can be seen, there is a great correspondence between the parameters identified by users in D5.1 and the ones specified by the World Bank for water modelling, since most of the variables have a clear correlation with the World Bank categories. Some variables or data needs for water modelling identified in the literature and from the surveys and interviews made in WP5 have no correspondence to a category from the World Bank work, but they mainly correspond to reference data indirectly related to water modelling parameters: air temperature, bathymetry, and Land surface temperature

In the same way, as the characterization made in Table 1 where the needs in terms of spatial and temporal resolutions are indicated, the recommended or required spatial and temporal resolutions for each of the identified parameter were also analysed in D5.1, based on the surveys conducted. Results are collected in Figure 2 (water quality parameters) and Figure 3 (water quantity parameters).

EO WATER QUALITY PARAMETERS	SPATIAL RESOLUTION (% of recommended)				
Parameter	50 m x 50 m	100 m x 100 m	200 m x 200 m	1 km x 1 km	Other
Chlorophyll-A (CHLA)	38,9	33,3	5,6	5,6	16,7
Diffuse attenuation coefficient (Kd)	30,8	38,5	0,0	7,7	23,1
Lake Surface Water Temperature (LSWT)	44,4	22,2	11,1	11,1	11,1
Particulate Backscattering Coefficient (Bbp)	30,8	46,2	0,0	0,0	23,1
Phytoplankton absorption coefficient (Aphy)	35,7	28,6	7,1	0,0	28,6
Remote Sensing Reflectance (RSR)	33,3	33,3	0,0	13,3	20,0
Sea Surface Temperature (SST)	31,3	31,3	12,5	12,5	12,5
Secchi Disk Depth (SDD)	30,8	46,2	0,0	15,4	7,7
Suspended Particulate Matter (SPM)	41,2	41,2	0,0	11,8	5,9
Total absorption coefficient (Atot)	35,7	28,6	7,1	7,1	21,4
Trophic State Index (TSI)	42,9	21,4	0,0	14,3	21,4
Water leaving reflectance (WLR)	40,0	33,3	0,0	6,7	20,0

Figure 2.- Percentages of recommended spatial resolutions for each of the water quality parameters as indicated in D5.1. Dark brown colours indicate higher frequencies than light colours.

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As showed in Figure 2, the preferred spatial resolution for most of the parameters is 50 m or 100 m, and there is a clear consensus on having these high resolution products available, as shown by the low values in the 200 m or 1 km columns. In some cases, the Other category (not indicated by the users) is important as well, as for example in the desired resolution for phytoplankton absorption coefficient (a_{phy})„ with nearly a 27% of votes for Other, but in all those cases the majority of users are still recommending the higher resolutions.

In terms of temporal resolution, the water quality parameters are mainly recommended to be daily.

EO WATER QUANTITY PARAMETERS	SPATIAL RESOLUTION (% of recommended)				
Parameter	50 m x 50 m	100 m x 100 m	200 m x 200 m	1 km x 1 km	Other
Precipitation	12,5	37,5	6,3	37,5	6,3
Soil moisture	31,3	25,0	12,5	31,3	0,0
Evapotranspiration	33,3	20,0	20,0	26,7	0,0
Surface runoff	26,7	26,7	13,3	33,3	0,0
River discharge	28,6	21,4	7,1	28,6	14,3
Flood extend	23,1	38,5	15,4	7,7	15,4
Inland water temperature (IWT)	44,4	22,2	0,0	8,3	16,7
LU /LC	33,3	41,7	0,0	0,0	23,1
Land surface temperature (LST)	35,7	35,7	7,1	21,4	0,0
Air temperature (AT)	22,2	44,4	0,0	33,3	0,0
Bathymetry	50,0	25,0	0,0	12,5	12,5
DEM	62,5	12,5	0,0	12,5	12,5
Water levels in lakes and rivers (WL)	56,3	12,5	0,0	12,5	18,8

EO WATER QUANTITY PARAMETERS	TEMPORAL RESOLUTION (% of recommended)		
Parameter	Daily	Hourly	Other
Precipitation	56,3	43,8	0,0
Soil moisture	82,4	11,8	5,9
Evapotranspiration	73,3	26,7	0,0
Surface runoff	56,3	43,8	0,0
River discharge	46,7	53,3	0,0
Flood extend	42,9	50,0	7,1
Inland water temperature (IWT)	45,5	45,5	9,1
LU /LC	50,0	16,7	33,3
Land surface temperature (LST)	60,0	40,0	0,0
Air temperature (AT)	50,0	50,0	13,3
Bathymetry	55,6	22,2	22,2
DEM	75,0	12,5	12,5
Water levels in lakes and rivers (WL)	64,7	35,3	0,0

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Figure 3.- Percentages of recommended spatial resolutions (top) and temporal resolutions (down) for each of the water quantity parameters as indicated in D5.1. Dark brown colours indicate higher frequencies than light colours.

As indicated in Figure 3, the preferred spatial resolutions for the water quantity parameters are lower than 1km, in most cases 50m or 100 m. In the survey, users also indicated that the parameters are mostly used as modelling inputs, followed by calibration and validation. Similar to water quality, the main limitations found in using the data are the data quality followed by the insufficient spatial resolution.

As shown in Figure 3, except for LU/LC clear preferences are indicated for hourly products.

3 Screening of existing Water EO products for modelling at Copernicus Services

In this chapter, the availability of EO products for water modelling at Copernicus Services is analysed through the inventories conducted in WP3 (water quantity) and WP2 (water quality), described in deliverables *D3.2 Copernicus products – hydrological* (Vrije Universiteit Brussel & Antea Belgium nv, 2021) and *D2.2 Recommendations on Copernicus products - Water Quality* (FvB/IGB, 2021). While those inventories covered all water products available, here we will focus on the products used for modelling as specified in Section 2.

The availability of products for the water quantity and water quality parameters identified in Section 2 is described here, along with the spatial and temporal characterization of the products. The indicated spatial and temporal resolutions have been translated to the specifications mentioned in the characterization of variables in the World Bank document (World Bank, 2016), in order to make them comparable. The correspondence of the categories is slightly different than the terminology used in remote sensing and is indicated in Table 4.

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SPATIAL RESOLUTION		
S1	Very fine / Very high	Pixel size less than 10 meters
S2	Fine /High	Pixel size: 10–100 meters
S3	Medium	Pixel size: 100–1000 meters
S4	Coarse /Low	Pixel size more than 1000 meters
TEMPORAL RESOLUTION (revisit times)		
T1	Near continuous	Less than 3 hours
T2	High frequency	3–24 hours
T3	Medium frequency	1–30 days
T4	Occasional	Once only or ad hoc

Table 4.- General categories of resolution as specified in Box 5.2 of (World Bank, 2016) and used in this deliverable.

3.1 Copernicus EO products for water quantity modelling

The data analysis presented in this section 3.1 is based on the inventory from WP3 on Copernicus products and services for water quantity, collected in D3.2. When no available there, information has been searched in the Copernicus portals and platforms directly. In this sense, given that deliverable D3.2 was submitted in June 2021, new products have been incorporated in the Copernicus Services portfolios during the period June 2021-December 2022 that have been also taken into account in this deliverable.

Deliverable *D3.2 Review document on Copernicus products related to the hydrological water balance* (Vrije Universiteit Brussel & Antea Belgium nv, 2021) describes the detailed inventory of relevant water quantity products provided by the Copernicus Services. The inventory focusses solely on data products (datasets, time series or maps) and does not include any applications or tools, but it refers to datasets, indices, projections, in-situ observations or forecasts. Hence, the inventory is not strictly limited to raw EO datasets: it also includes derived, value-added products as these often are more suitable for downstream users. Thus, the inventory comprises data products related to the hydrological cycle, all originating from the following Copernicus Services: Copernicus Marine

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Environment Monitoring Service (CMEMS), Copernicus Land Monitoring Service (CLMS), Copernicus Emergency Management Service (CEMS), Copernicus Atmosphere Monitoring Service (CAMS) and Copernicus Climate Change Service (C3S).

Precipitation

There are more than 100 products related to precipitation in Copernicus, provided by the C3S, the CEMS and the CAMS. The ones from the CEMS come from the European Flood Awareness system (EFAS), the Global Flood Awareness System (GloFAS), the European Drought Observatory (EDO) and the Global Drought Observatory (GDO). The available precipitation products include meteorological products, seasonal forecasts, reanalysis data, climate projections, initial conditions, flash flood products, and drought indices.

In this review, the new datasets recently published (May 2021) by C3S "Temperature and precipitation climate impact indicators from 1970 to 2100 derived from European climate projections" and "Hydrology related climate impact indicators from 1970 to 2100 derived from bias adjusted European climate projections" are also included.
The specific outputs offered by the different services are listed in Table 5.

Accumulated precipitation	Mean large-scale precipitation rate
Accumulated rainfall (mm)	Mean precipitation flux
Convective precipitation	Mean total precipitation rate
Convective rain rate	Minimum total precipitation rate since previous post-processing
Highest 5-day precipitation amount	Monthly precipitation
Instantaneous large-scale surface precipitation fraction	Number of dry spells
Large scale rain rate	Precipitation
Large-scale precipitation	Precipitation amount
Large-scale precipitation fraction	Precipitation flux
Liquid precipitation duration fraction	Precipitation type
Long range precipitation forecasts	Rainfall accumulation

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Longest dry spells	Solid precipitation duration fraction
Maximum total precipitation rate since previous post-processing	Standardized precipitation index (SPI)
Mean annual precipitation	Synop 24 hours precipitation
Mean convective precipitation rate	Total precipitation
Mean large-scale precipitation fraction	Total precipitation anomalous rate of accumulation

Table 5.- List of precipitation specific output parameters available at the Copernicus Services and listed in D3.2.

Most of the precipitation-related products are global and can be directly downloaded. Spatial resolutions offered go from 2.5 to 250 km, 50 km being the most frequent, as well as 25 km and 100 km. Monthly and daily temporal resolutions are more frequent, although sub-daily products are also frequent. The available spatial and temporal resolutions are shown in Figure 4.

		C3S	CAMS	CEMS
Regions	African domain, Arctic domain, European domain, North American domain, Mediterranean domain	x		
	Europe	x		x
	Global	x	x	x
	West/East domain	x		
Data access		Data download (CDS)	Data download	Download CDS, FTP, MARS archive (ECMWF), OGS WMS
File format		GRIB, GRIB2, NetCDF, NetCDF4	GRIB, NetCDF	NA
Validation reports		External (1,4%), Known issues (4,2%), Bias adjustment (53%), Validation report (7%)	EQA reports	EQA reports (EFAS and GloFAS) (40%) and external reports (EDO and GDO) (60%)

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Uncertainty information	Depending on the product (80%)

Table 6.- Summary of the spatial coverage and means of access for the identified precipitation products.

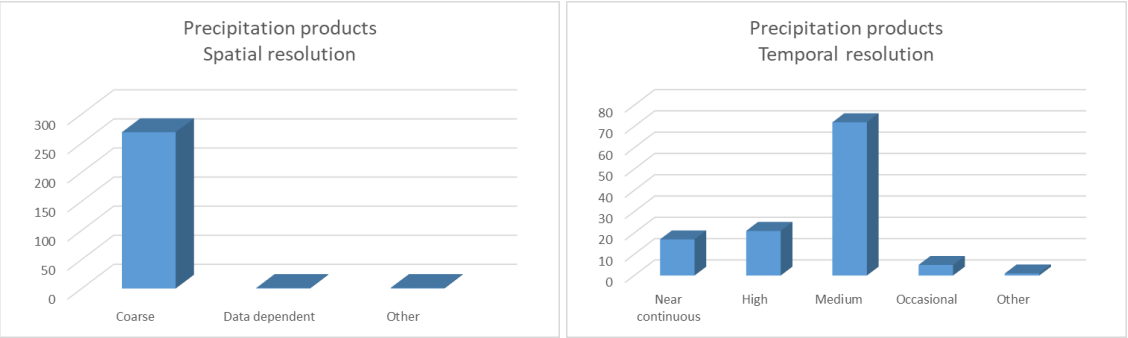

Figure 4.- Spatial and temporal resolutions available at the Copernicus services for the precipitation products.

Although for the different types of water modelling the World Bank report recommends a coarse spatial resolution for the precipitation products, according to the requirements collected from users in D5.1, precipitation is required at a spatial resolution of 100 m – 1 km, that is at medium spatial resolution. As seen in Figure 4, precipitation products are clearly offered at coarse resolution, so a recommendation could be to try to improve the spatial resolution of this kind of products, given that near all of them are greater than 2 km, far away from medium resolution.

For the temporal resolution, daily and hourly products are required by users (high frequency) as well as recommended by the World Bank report (<24 hours). Although a lot of products offered have a medium resolution (monthly), quite a number of products exist which have high or near continuous resolution (daily or less) that can cover the requirements.

Soil moisture

There are 54 soil-related products identified in the water quantity inventory. 37 from the C3S, 11 from the CEMS and 6 from the CLMS. The ones from the CEMS come from the EFAS, the GloFAS, the EDO and the GDO. The ones from the CLMS are near-real-time products and the ones from the C3S are all gridded products.

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The available soil products include forecasts (2), reanalysis (30), seasonal forecasts (2), climate projections (1), initial conditions (5), monitoring products (4), climate indices (1) and near-real-time (6).

The specific outputs offered by the different services are listed in Table 7:

Initial soil moisture	SMI anomaly
Initial soil moisture anomaly	Soil depth
Last daily SMI	Soil water content
Last daily SMI forecast	Soil Water Index
Last daily SMI anomaly forecast	Surface soil moisture
Mean soil moisture	Volumetric soil moisture
Percolation	Volumetric soil water layer 1
Relative soil moisture	Volumetric soil water layer 2
Soil Moisture	Volumetric soil water layer 3
Soil Moisture Anomaly	Volumetric soil water layer 4
Soil moisture content	Volumetric wilting point
Soil moisture index (SMI)	

Table 7.- List of soil moisture specific output parameters available at the Copernicus Services and listed in D3.2.

Global and Europe products are offered by the three services, but the Climate Change is the one offering more soil related products (Table 8). The CLMS has its own product portal for data consulting. The majority of the products have 25, 50 or 100 km, but also there are some of them with 10 km resolution. The most frequent temporal resolution is monthly, but especially for the CEMS and CLMS products, the daily resolution is also common (Figure 5). In case of the CEMS products, the temporal and spatial resolution for some products is not easily indicated.

		C3S	CEMS	CLMS
Regions	Europe	x	x	x
	Global	x	x	x

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Pan European West/East domain	x x		
Data access	Data download (CDS)	Download CDS, FTP, MARS archive (ECMWF), OGS WMS	Product Portal
File format	GRIB, GRIB2, NetCDF, NetCDF4		GeoTIFF, XML, NetCDF4
Validation reports	EFAS Evaluation Products + reports	45% Evaluation Products (EFAS and GloFAS), not for EDO and GDO (54%)	Validation study
Uncertainty information	Some products (22%)		

Table 8.- Summary of the spatial coverage and means of access for the identified soil moisture products.

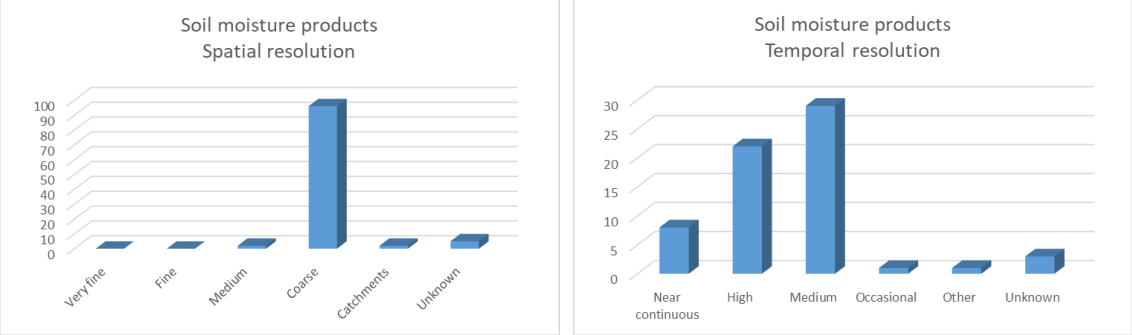

Figure 5.- Spatial and temporal resolutions available at the Copernicus services for the soil moisture products.

Evapotranspiration

No evapotranspiration products are available in the production Copernicus services Some prototypes are generated from fusion methodologies using Sentinel-3 LST (Sen-ET project : https://www.esa-sen4et.org/) (Guzinski et al 2020).

Surface runoff

There are 42 products identified in the water quantity inventory related to runoff, all of them from the C3S.

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The available runoff products include climate indices (2), seasonal forecasts (9), reanalysis (29) and climate projections (2).

The specific outputs offered are the following:

Mean runoff	Runoff
Mean runoff rate	Runoff anomalous rate of accumulation
Mean sub-surface runoff rate	Sub-surface runoff
Mean sub-surface runoff rate anomaly	Surface runoff
Mean surface runoff rate	Total run-off flux
Mean surface runoff rate anomaly	Water runoff

Table 9.- List of runoff specific output parameters available at the Copernicus Services and listed in D3.2.

As mentioned, only the C3S provides surface run-off products. In addition to surface run-off, also sub-surface run-off is provided, as well as other related parameters. The majority have a global coverage and all of them are available for download through the Climate Data Store (CDS). 50 km, 100 km and 25 km are the most frequent spatial resolutions and monthly is the most frequent temporal resolution.

		C3S
Regions	African domain, Arctic domain, European domain, North American domain, Mediterranean domain	x
	Europe	x
	Pan-European domain	x
	Global	X
	West/East domain	x
Data access		Data download (CDS)
File format		GRIB, GRIB2, NetCDF, NetCDF4

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Validation reports	Bias adjustment (57%), Known issues (33%), Validation report (7%)
Uncertainty information	Yes (74%)

Table 10.- Summary of the temporal coverage and means of access for the identified surface runoff products.

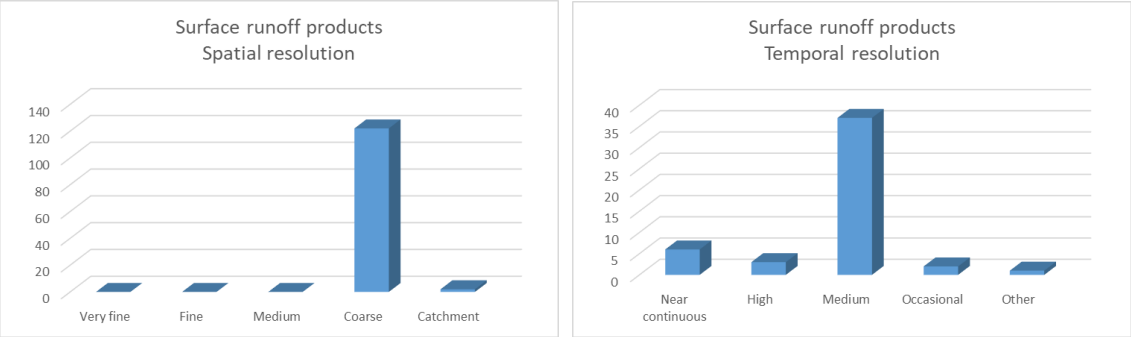

Figure 6.- Spatial and temporal resolutions available at the Copernicus services for the surface runoff products.

River discharge

There are 9 products informing about river discharge according to the Water-ForCE water quantity inventory, all of them from the Climate Change Service. 3 of them are climate indices, 2 are seasonal forecasts and 4 correspond to reanalysis. The specific outputs offered are the following:

River discharge in the last 24 hours	Minimum river discharge
River discharge in the last 6 hours	River discharge
Maximum river discharge	

Table 11.- List of river discharge specific output parameters available at the Copernicus Services and listed in D3.2.

The area covered by these products is Europe and global (except for Antarctica). All of them are available for download from the CDS (Table 12). They are released mainly daily and monthly and in 5 km resolution (Figure 7).

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		C3S
Regions	Europe Global (except for Antarctica)	x x
Data access		Data download (CDS)
File format		GRIB2, NetCDF4
Validation reports		Bias adjustments (climate indices 33%) and Evaluation products (EFAS 67%)
Uncertainty information		No

Table 12.- Summary of the temporal coverage and means of access for the identified river discharge products.

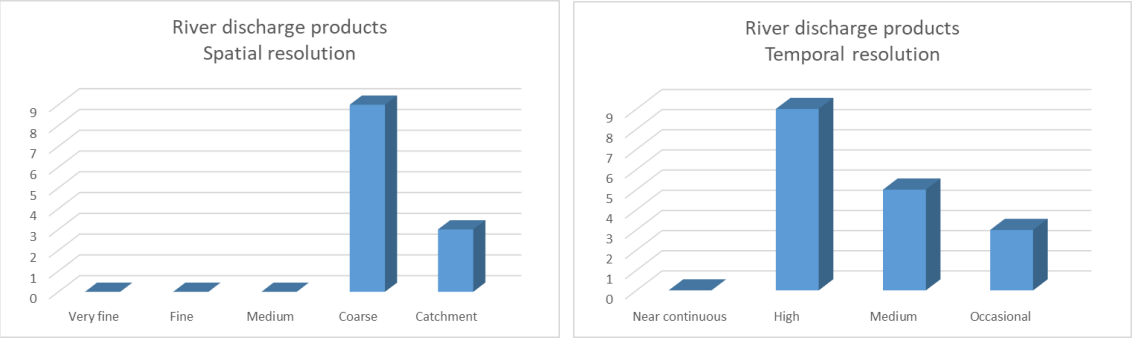

Figure 7.- Spatial and temporal resolutions available at the Copernicus services for the river discharge products.

Flood extent

Flood events are monitored in Copernicus by the CEMS through the Global Flood Monitoring (GFM) product, which offers eleven output layers, generated in near real-time from Synthetic Aperture Radar imagery from ESA's Sentinel-1 (S-1) satellites, one of them being the S-1 observed flood extent. Other products related to flood extent are available through the EFAS.

36 products are described in the water quantity inventory related to flood extent. although there is a great variety in the specific parameters, which include flood summary products,

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hydrological medium range products, flash flood products, static layers products, notification products, medium-range and seasonal forecasts and near real time products. All of them are provided by the Emergency Management Service under the EFAS or the GloFAS, and include the following parameters:

Flood awareness	River basins
Affected locations	Flood probability persistence
Drainage area affected by the forecasted heavy precipitation and potential flash floods	Flood probability
Flash flood hazard levels	Observed flood extent
Flash Flood Notifications	Flood probability <48h
Flash flood hazard maps	Flood probability >48h
Flood	Flood affected population
Flood impact assessment	Flood affected land cover
Flood impact forecasts	**Mission**
Flood mapping	COSMO > 20-year RP
Flood monitoring	COSMO >5-year RP
Flood Protection Levels	**Thresholds**
Formal Notifications	Threshold Level Exceedance layers
Impact	Threshold level exceedance >5 days
Informal Notifications	Threshold level exceedance 1-2 days
Number of forecasts exceeding the EFAS 20-year return period threshold	Threshold level exceedance 3-5 days
Number of forecasts exceeding the EFAS 5-year return period threshold	Threshold level exceedance ongoing
Reporting points	**Outlooks**

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Return period DWD forecast	Seasonal hydrological outlook
Return period ECMWF forecast	Sub-Seasonal hydrological outlook

Table 13.- List of flood extent specific output parameters available at the Copernicus Services and listed in D3.2.

These products are all offered for Europe and global and available for download, although EFAS real time forecasts are only accessible for EFAS Partners (Table 14).

		CEMS
Regions	Europe Global	x x
Data access		Download CDS, FTP, MARS archive (ECMWF), WMS
File format		GRIB2, NetCDF, GeoTIFF, Shapefile
Validation reports		Evaluation products
Uncertainty information		Uncertainty values (3%)

Table 14.- Summary of the temporal coverage and means of access for the identified flood extent products.

Most of the products from EFAS and GloFAS have 5 km of spatial resolution and 6 hours of temporal resolution, but the summary of the available resolutions is shown in Figure 8:

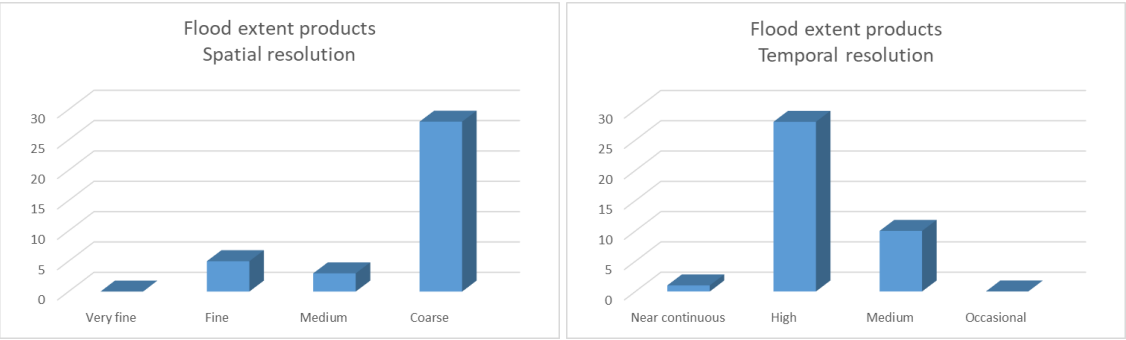

Figure 8.- Spatial and temporal resolutions available at the Copernicus services for the flood extent products.

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Inland water temperature (IWT)

Available products in Copernicus about Inland water temperature are related with Lake Surface Water Temperature (LSWT), which is covered under section 3.2 (water quality).

LU /LC and Vegetation products

This category includes variables related to Land Use/Land Cover and to the characterization of the vegetation. Vegetation products are not strictly related to water variables, but they are used in water modelling and mentioned in the literature as well as by the users as a required variable for modelling. They are used for correctly describing land-surface properties in hydrologic models (Ariza Salamanca, 2019) and even for assessing flood hazard areas (Danbara, 2022). This dataset then covers a variety of parameters, but include the ones mentioned in D3.2 which are the following:

Agroclimatic indicators	Leaf area index
HRL Forest	Reference
Imperviousness	Urban
Interception	Fraction of green vegetation cover
Land cover	Normalized Difference Vegetation Index
Type of high vegetation	Type of low vegetation

Table 15.- List of LU/LC and vegetation specific output parameters available at the Copernicus Services and listed in D3.2.

Regarding Land Cover/Land Use (LU/LC), 61 products are identified in the inventory, 41 from the CLMS, 10 from the C3S and 10 from the CAMS. They include the parameters shown in Table 15. In our analysis, the Lucas 2018 survey, the Urban Atlas LCLU 2018, the Urban Atlas LCLU Change 2012-2018, the Urban Atlas Street Tree Layer (STL) 2018 and the Natura 2000 products are not included since they are vector and dataset types.

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Vegetation products are offered by the Land Monitoring Service (Fraction of green vegetation cover and Normalized Difference Vegetation Index) and by the Atmosphere Service (Type of high and low vegetation). All of them are global products and with temporal resolution lower than 10 days. Some of them are discontinued.

The coverage, means for data access and file formats for those parameters are collected in Table 16:

		C3S	CAMS	CLMS
Regions	Eastern Partnership countries (Armenia, Azerbaijan, Belarus, Georgia, Republic of Moldova and Ukraine)			x
	EEEA39			x
	Eu countries (28)			x
	Global	x	x	x
Data access		Data download (CDS)	Data download	Webservices, Product portal, WFS, WMS, WCS
File format		GRIB,NetCDF, NetCDF4	GRIB, NetCDF, NetCDF-4, HDF-5, GeoTIFF	100 m GeoTIFF, ESRI Geodatabase, Geopackage, Shapefile, SQLite database, GeoTIFF, Global files, HDF-5, NetCDF, NetCDF4, Raster, Vector, JPEG2000
Validation reports		EQC Evaluation and Quality Control (60%), Other (40%)	Evaluation and quality assurance (EQA) reports	Validation reports (73%), Other (7%), Not yet validated (5%), N/A (15%)
Uncertainty information		Quality flags (10%)		Quality layers (51%), geometric and thematic accuracy (19%), N/A (15%), other (15%)

Table 16.- Summary of the temporal coverage and means of access for the identified LU/LC and vegetation products.

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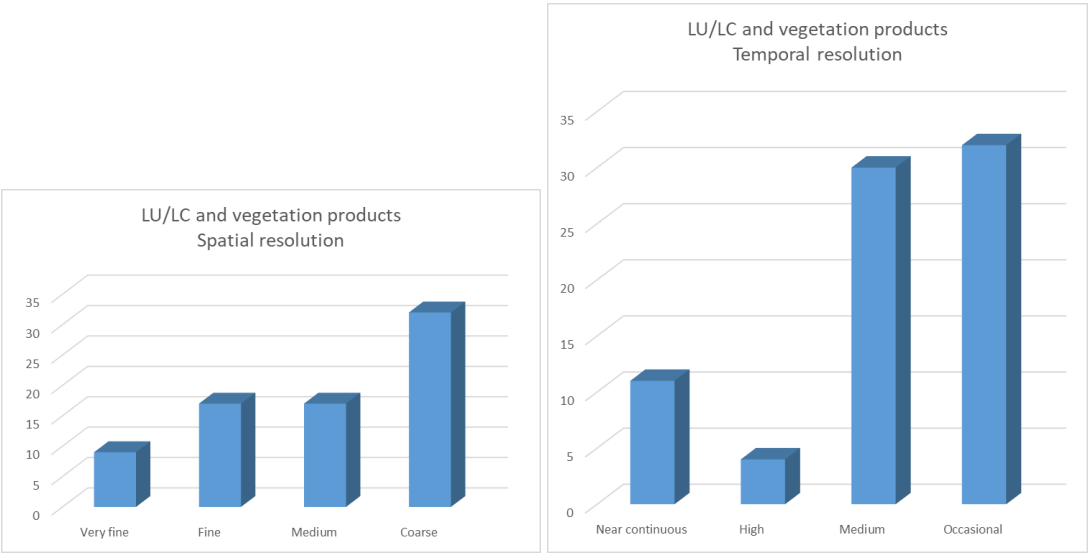

Figure 9.- Spatial and temporal resolutions available at the Copernicus services for the LU/LC and vegetation products.

Land surface temperature (LST)

Although they were not collected in the inventories, the list of available Land Surface Temperature products existing in Copernicus is shown in Table 17. LST is useful for improving the estimates of water fluxes (Corbari, 2019) and has been used for modelling the spatial distribution of permafrost and associated mean annual ground temperature (MAGT) and active layer thickness (ALT) in hydrological studies (Zorigt, 2020).

	Regions	Variable	Temporal coverage	Spatial resolution	Temporal resolution	Validation report	Uncertainty information
CLMS	Global	LST	Oct/2010 - Jan/2021	5 km	Hourly	Validation report	Error bar for LST + Quality flags
		LST	Jan/2021 - Present	5 km	Hourly	Validation report	Error bar for LST + Quality flags

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		LST10-DC	2017 - present	5 km	10 days	Validation report	Fraction of valid observations
		LST10-DC	Jan 2021 - present	5 km	10 days	Validation report	Fraction of valid observations
		LST10-TCI	2017 - present	5 km	10 days	Validation report	Fraction of valid observations
		LST10-TCI	Jan 2021 - present	5 km	10 days	Validation report	Fraction of valid observations

Table 17.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified land surface temperature products.

The CLMS offers hourly LST from instantaneous observations, 10-day Land Surface Temperature with Daily Cycle and a Thermal Condition Index with a 10-day composite of Land Surface Temperature. The summary of the spatial and temporal resolutions of those products is shown in Figure 10.

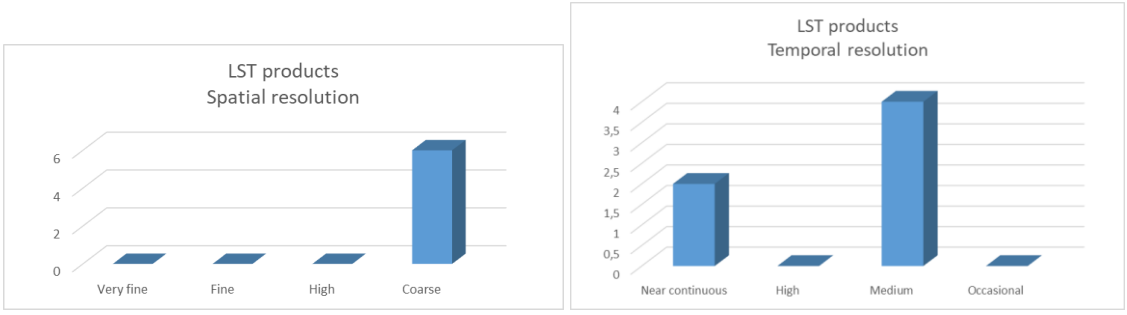

Figure 10.- Spatial and temporal resolutions available at the Copernicus services for the land surface temperature products.

Air temperature (AT)

Information on air temperature was not directly available in the inventories, but we include it here because it was a demand derived from D5.1.

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The C3S offers one product on Surface air temperature. It produces surface air temperature maps as a data product, but data can be viewed directly. From April 2019 onward, the temperature summaries are based on ERA5. ERA5 is a global atmospheric reanalysis from 1979 onwards. The resolution is hourly, but for the reports the 'monthly means of daily means' are used. The native horizontal grid is ~31 km (reduced Gaussian grid N320), but data can be downloaded on a 0.25 deg regular lat/lon grid. ERA5 data are also used for precipitation, soil moisture and sea ice.

Regions		Variable	Temporal coverage	Spatial resolution	Temporal resolution	Validation report	Uncertainty information
C3S	Global	Surface air temperature	1979 - Present	25 km	Monthly	Known issues	Ensemble means and standard deviations

Table 18.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified air temperature products.

The summary of the spatial and temporal resolutions of those products is shown in Figure 11.

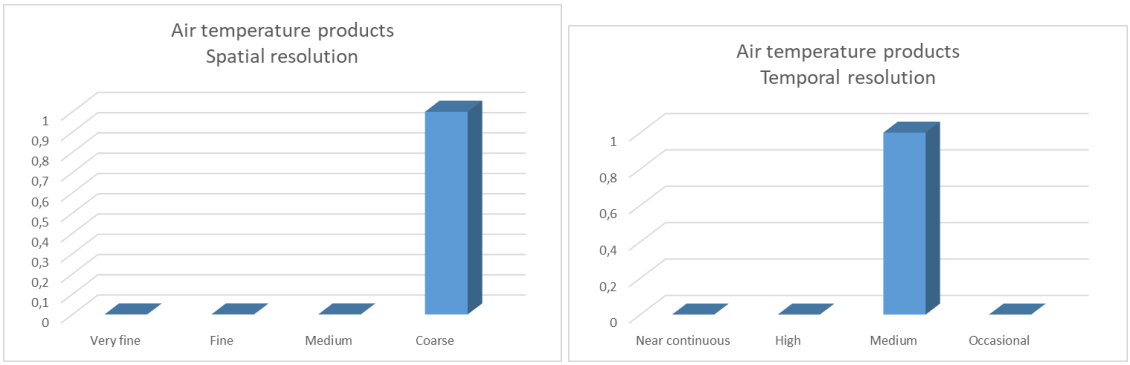

Figure 11.- Spatial and temporal resolutions available at the Copernicus services for the air temperature products.

Bathymetry

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No bathymetry remotely sensed products are directly available in Copernicus.

DEM and DTM

We identified five Digital Terrain Models (DTM) products in the inventory, all of them offered by the Land Monitoring Service. They include the European Digital Elevation Model (EU-DEM), version 1.0 and 1.1, and the derived slope, aspect and hillshade. The covered parameters are:

Elevation	Aspect
Slope	Hillshade

Table 19.- List of DEM specific output parameters available at the Copernicus Services and listed in D3.2.

All these products are offered for the EEA39 zone and with a spatial resolution of 25m.

	CLMS
Regions EEA39	x
Data access	Webservices,WFS, WMS, WCS
File format	Raster, GeoTIFF
Validation reports	Only version 1.0
Uncertainty information	RMSE (v1.1)

Table 20.- Summary of the temporal coverage and means of access for the identified DEM products.

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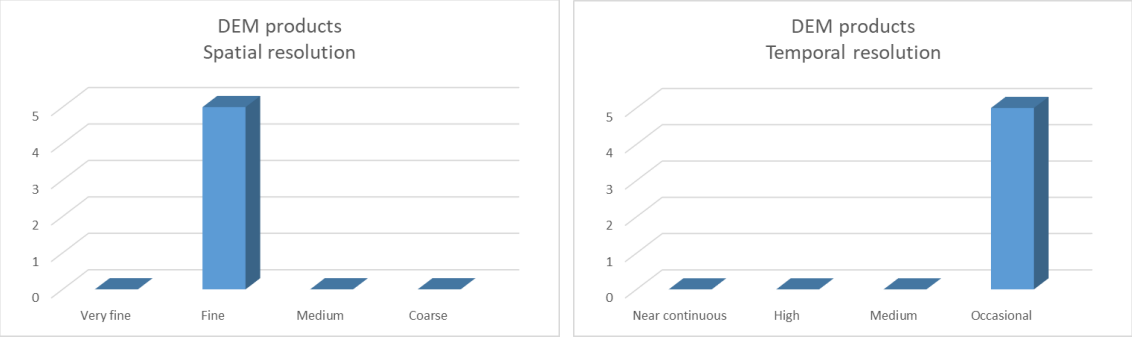

Figure 12.- Spatial and temporal resolutions available at the Copernicus services for the DEM products.

Water levels in lakes and rivers (WL)

There are 3 products monitoring water level, 2 of them from the Land Monitoring Service (vector, global and near-real time) and 1 from the Climate Change (point data).

The specific outputs are the following:

Water level (lakes)	Water level (rivers)
Water surface height	

Table 21.- List of water level specific output parameters available at the Copernicus Services and listed in D3.2.

In all cases, products are offered globally, and at a daily and 10 days temporal resolution (Table 22). The products from the CLMS are non-gridded products (vectors). The C3S products are referred to the Individual lakes and offered as point data. Thus, spatial resolution does not apply in any case and will not be analysed here.

		C3S	CLMS
Regions	Global		x
	Global (94 lakes on 4 continents)	x	
Data access		Data download	Product Portal

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File format	NetCDF	GeoJSON, XML, NetCDF, ENVI, HDF5
Validation reports	Product Quality Assessment Report	Validation report
Uncertainty information	Water surface height uncertainty	Water surface height uncertainty, Number of observations

Table 22.- Summary of the temporal coverage and means of access for the identified water level products.

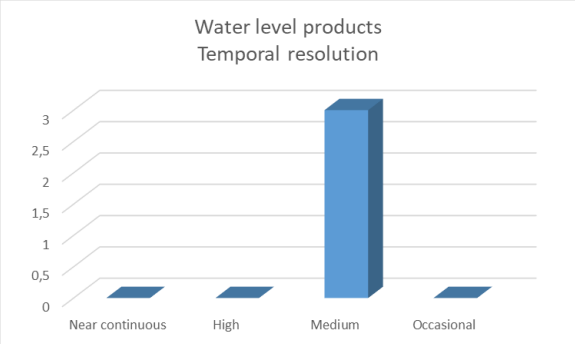

Figure 13.- Temporal resolutions available at the Copernicus services for the water level products.

Drought

15 products are available in Copernicus related to drought monitoring for water modelling. 6 from the CGLS, 4 from the C3S and 54 from the CEMS. The variables covered are the following:

Combined drought indicator	Water and Wetness
Aridity	Heatwaves
Low-flow Index (LFI)	Risk of drought impact for agriculture (RDrI-Agri)

Table 23.- List of drought specific output parameters available at the Copernicus Services and listed in D3.2.

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Drought indicators offered by the C3S are available since 1970 while other products from CGLS and CEMS are offered since 2001 or later. CEMS offers Global and Europe products through the GDO and EDO, while C3S and CLMS only provide data for Europe.

		C3S	CLMS	CEMS
Regions	Global			x
	EEA39		x	
	Europe	x		x
Data access		Download	WMS, download	WMS, download
File format		NetCDF-4		GeoTIFF, NetCDF
Validation reports		Bias adjustment	Validation report (2015), Not yet (2018)	Strengths and weaknesses
Uncertainty information		-	-	-

Table 24.- Summary of the temporal coverage and means of access for the identified drought products.

The summary of the spatial and temporal resolutions of the products is shown in Figure 14.

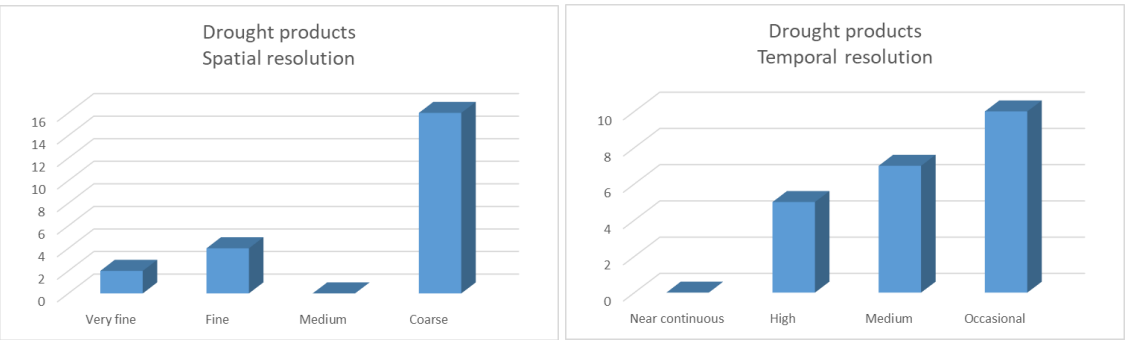

Figure 14.- Spatial and temporal resolutions available at the Copernicus services for the drought products.

Groundwater

Only one product is available for groundwater in Copernicus, provided by the C3S. It corresponds to the Groundwater recharge and it is included in the Water sector indicators of hydrological change across Europe from 2011 to 2095 derived from climate simulations.

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		C3S
Regions	Greater Europe	x
Data access		Download
File format		NetCDF-4
Validation report		External
Uncertainty information		Ensemble approach

Table 25.- Summary of the temporal coverage and means of access for the identified groundwater products.

The summary of the temporal and spatial resolutions is shown in Figure 15.

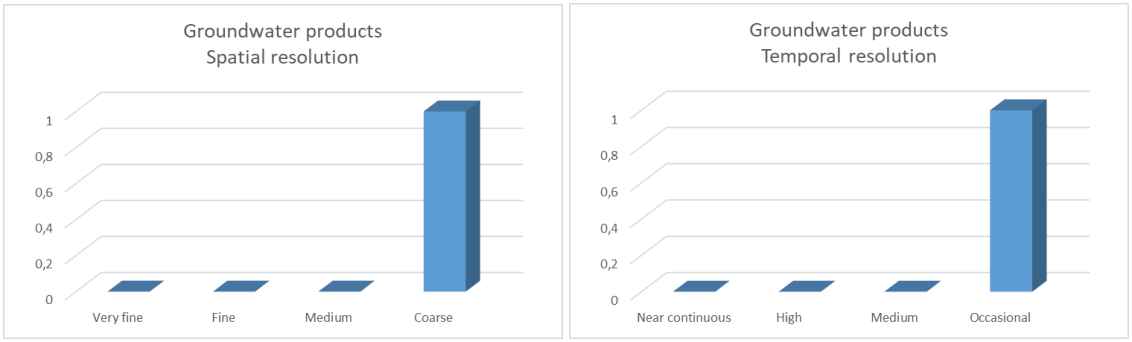

Figure 15.- Spatial and temporal resolutions available at the Copernicus services for the groundwater products.

Lake Ice Cover

There are 13 products about Lake Ice Cover in Copernicus, 7 from the CGLS and 6 from the C3S. Some of them are strictly related to ice cover and some are related to ice thickness. There are also products dealing with rivers and lakes at the same time. The list of specific parameters is offered in Table 29.

Lake ice extent	River and Lake Ice Extent (RLIE)
Aggregated river and lake ice extent	Lake ice depth

Table 26.- List of lake ice cover specific output parameters available at the Copernicus Services and listed in D3.2.

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Products related to Ice Extent are provided by the CGLS at high spatial resolutions, while products about Ice depth are provided by the C3S at coarse spatial resolutions. The summary of temporal and spatial resolutions is shown in Figure 16.

		C3S	CGLS
Regions	Northern Europe	x	x
	Global		x
	EEA39		x
Data access		Data download	FTP, Product portal
File format		GRIB	GeoTIFF, XML, NetCDF4
Validation reports		Evaluation and Quality Control (C3S)	57% Validation report, 43% Not yet validated
Uncertainty information		Available as part of the ERA5 dataset,	57% Quality indicators, 43% On-going validation activities

Table 27.- Summary of the temporal coverage and means of access for the identified lake ice cover products.

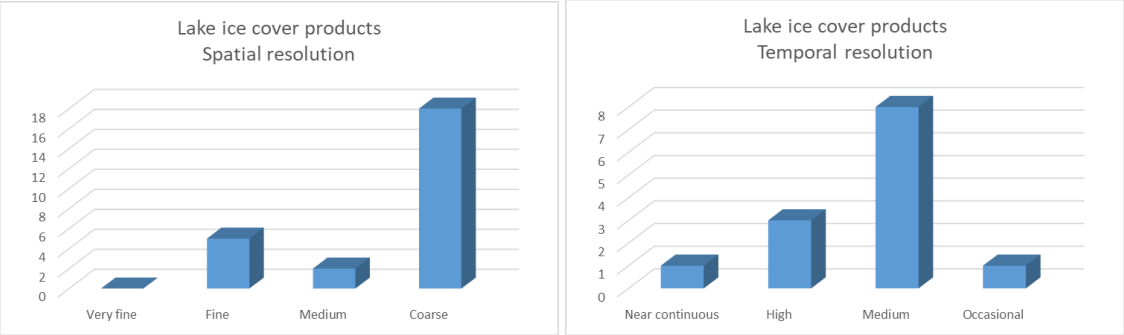

Figure 16.- Spatial and temporal resolutions available at the Copernicus services for the lake ice cover products.

Snowmelt

There are 20 snowmelt related products available in the Copernicus Services, 12 from the C3S, 4 from the CEMS, 1 from the CLMS and 3 from the CMEMS. The covered parameters are:

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Snowmelt	Mean snowmelt rate
Snowmelt anomaly	Snow thickness
Snow water equivalent	Surface snow thickness

Table 28.- List of snowmelt specific output parameters available at the Copernicus Services and listed in D3.2.

There is a variety of spatial coverages, data access and file formats, as well as validation methods and uncertainty documentations, depending on the Service providing the product, as shown in Table 29.

		C3S	CEMS	CLMS	CMEMS
Regions	Global	x	x		
	Arctic				x
	Northern hemisphere			x	
	Pan European domain	x			
	Europe		x		
Data access		Data download	Download CDS, FTP, MARS archive (ECMWF), WMS	FTP, Product Portal	WMS
File format		GRIB, NetCDF-4	Map	GeoTIFF, XML, NetCDF4	CSW, SUBSETTER, FTP, DGF
Validation reports		Evaluation and Quality Control (EQC), Known issues, Product Gap analysis (92%)	Evaluation products	Validation report	Quality information documents
Uncertainty information		Ensemble means and standard deviations (58%)	No	Uncertainty layer	Bias, RMS; correlation; MAD

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Table 29.- Summary of the temporal coverage and means of access for the identified snowmelt products.

The summary of the spatial and temporal resolutions is shown in Figure 17.

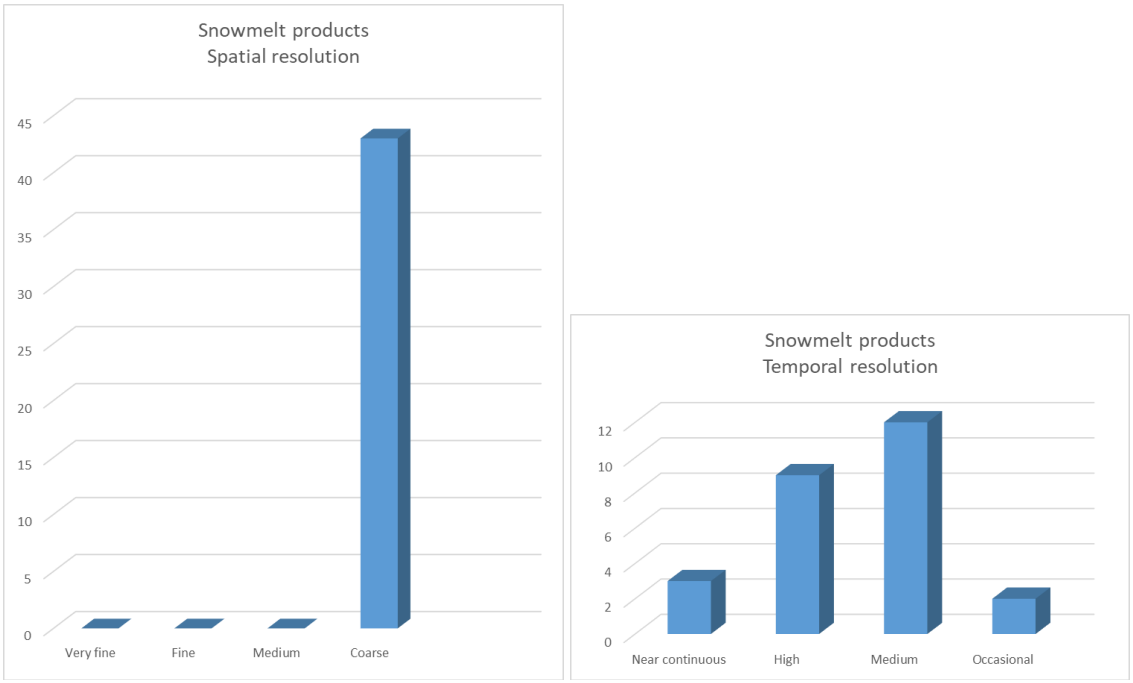

Figure 17.- Spatial and temporal resolutions available at the Copernicus services for the snowmelt products.

Total Water Storage (TWS)

2 products are available in Copernicus Services about Total Water Storage. They refer to GRACE total water storage (TWS) Anomaly and are provided by the CEMS in the GDO (global scale) and EDO (European scale).

		CEMS
Regions	Global	x
	Europe	x
Data access		WMS, Download
File format		GeoTIFF, NetCDF

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Validation reports	Strengths and weaknesses
Uncertainty information	-

Table 30.- Summary of the temporal coverage and means of access for the identified TWS products.

The spatial and temporal resolution are summarized in Figure 18.

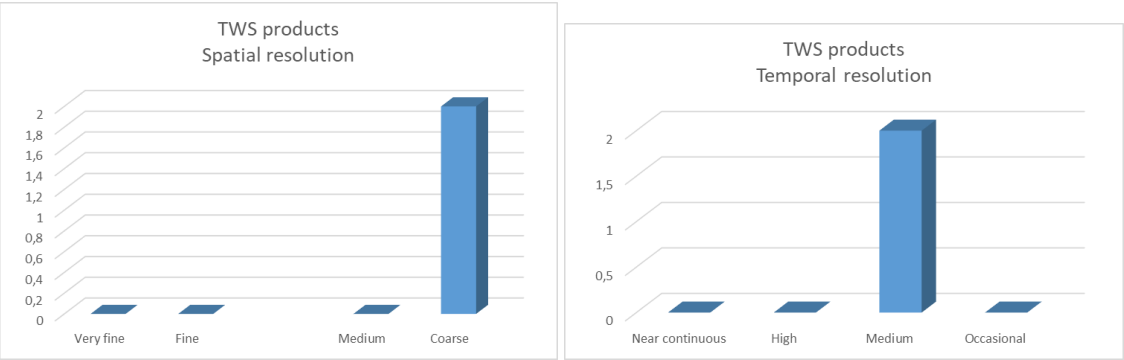

Figure 18.- Spatial and temporal resolutions available at the Copernicus services for the TWS products.

3.2 Copernicus EO products for water quality modelling

The data analysis presented in this section 3.2 is based on the inventory from WP2 on Copernicus products and services for water quality, collected in D2.2. When no available there, information has been searched in the Copernicus portals and platforms directly. In this sense, given that deliverable D2.2 was submitted in July 2021, new products have been incorporated in the Copernicus Services portfolios during the period July 2021-December 2022 that have been also taken into account in this deliverable.

In the context of WP2, deliverable D2.2 provides detailed inventory of relevant water quality products provided by different Copernicus Services and identifies gaps in the current product portfolio. In that deliverable water quality products from the three Copernicus services (CMEMS, CGLS and C3S) are introduced with their respective metadata information,

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including geographic coverage, estimated parameters, temporal coverage, frequency of data processing and other characteristics of the products.

Following the same approach, the availability of products for the water quality parameters identified in Section 2 is described here, along with the spatial and temporal characterization of the products. The detailed indicated spatial and temporal resolutions have been translated to the specifications mentioned in the characterization of variables in the World Bank document (World Bank, 2016), in order to make them comparable.

Chlorophyll-a (Chl-a)

Many Chlorophyll-a products are available in the Copernicus Marine Service. Chl-a is offered daily, monthly and multi-yearly, depending on the product. The Service is delivering new products since the end of 2021, and they have been incorporated in the analysis. In the beginning of July 2022, the Service launched a significant update to its satellite ocean colour products. They have recently also updated the Service catalogue (now called Marine DataStore) to provide better usability to users and have implemented access through API.

According to its catalogue, 54 satellite observation products are available containing the variable Mass concentration of chlorophyll a in sea water (CHL). 18 are global ocean products and the rest are for regional seas. Global products are offered mainly at 1km and 4 km spatial resolution while the regional seas products have mainly 1 km and 100 m resolution.

In addition, the C3S provides a global daily estimate of chlorophyll-a derived from multiple satellite sensors. The product has global coverage and is available from September 1997 to present at a daily and monthly basis.

		CMEMS	C3S
Regions	Global Ocean	x	x
	Black Sea	x	
	Arctic Ocean	x	
	Baltic Sea	x	
	Mediterranean Sea	x	
	Iberia Biscay Ireland Regional Seas	x	
	North/South Pacific Ocean	x	
	North/South Atlantic Ocean	x	

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European North West Shelf Seas	x	
File format	NetCDF	NetCDF 4
Validation reports	Quality Information Documents	Validation report
Uncertainty information	RMS, bias, standard deviation, uncertainty band, quality index (49%).	RMS, bias and other

Table 31.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified chlorophyll-a products.

The spatial and temporal resolutions available for the Chlorophyll-a products are indicated in Figure 19.

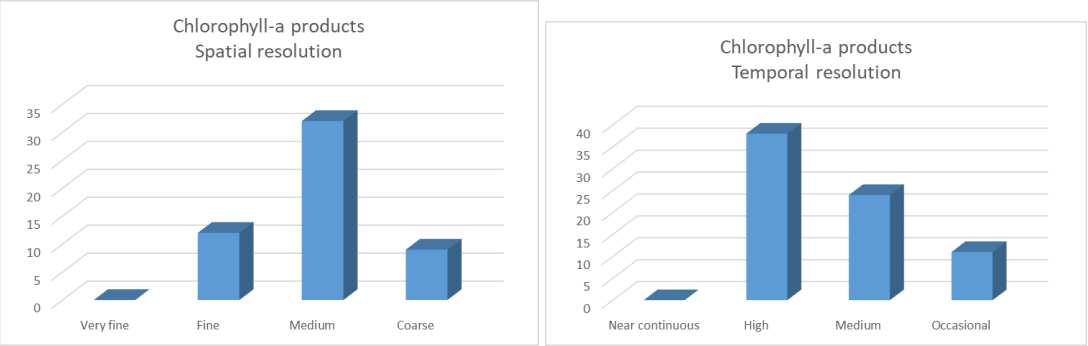

Figure 19.- Spatial and temporal resolutions available at the Copernicus services for the chlorophyll-a products.

Coloured Dissolved Organic Matter (CDM)

There are 13 products in the Marine Service regarding CDM, at regional and global level, although the name of the variable is Absorption coefficient for dissolved and detrital material. They are offered mainly at a daily basis and with 1 km resolution for the regional products and 4 km resolution for the global product, which is also offered at a monthly basis.

		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x

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Mediterranean Sea European North West Shelf Seas	x x
File format	NetCDF
Validation reports	Quality Information Documents
Uncertainty information	Quality indexes, Uncertainty variable (61%)

Table 32.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Coloured Dissolved Organic Matter products.

Thus, the temporal and spatial resolutions for the Coloured Dissolved Organic Matter are shown in Figure 20.

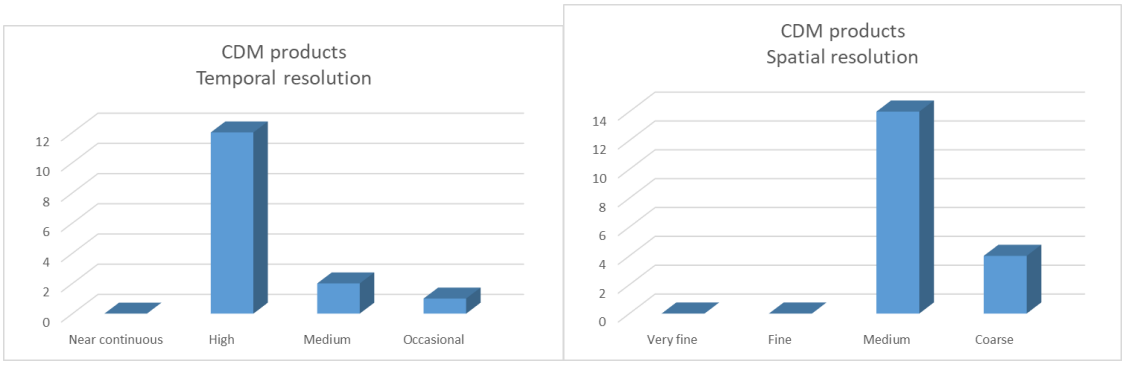

Figure 20.- Spatial and temporal resolutions available at the Copernicus services for the Coloured Dissolved Organic Matter products.

Diffuse attenuation coefficient (K_d)

There are 16 Kd products in the Marine Service, covering the main European sea regions at 1 km resolution as well as the global ocean at 4 km resolution. The variable is offered at a 490 nm wavelength and the name of the variable is Light attenuation (KD490). All of the products are provided daily and monthly, as shown in Table 33. Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Diffuse attenuation coefficient products.

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		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x
	Mediterranean Sea	x
	European North West Shelf Seas	x
File format		NetCDF
Validation reports		Quality Information Documents
Uncertainty information		Quality indexs, Uncertainty variables (50%)

Table 33.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Diffuse attenuation coefficient products.

Figure 21 summarizes the spatial and temporal resolution frequencies for the K_d products.

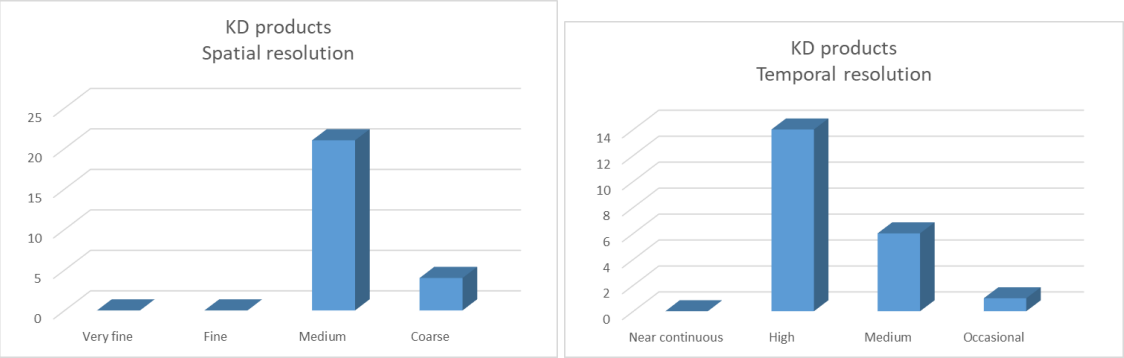

Figure 21.- Spatial and temporal resolutions available at the Copernicus services for the Diffuse attenuation coefficient products.

Lake Surface Water Temperature (LSWT)

Two Lake Surface Water Temperature products are offered by the CGLS, a historical dataset of collection 1km LSWT from 2002 until 2012 generated from the AATSR instrument on Envisat and a NRT dataset of 1km LSWT from the SLSTR instrument on Sentinel-3A from

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November 2016 until present. They all have a global coverage and a temporal resolution of 10 days.

On the other hand, the C3S offers mid-morning daily values for lake surface water temperature generated from the Along Track Scanning Radiometer (ATSR) and Advanced Very High-Resolution Radiometer (AVHRR) sensors between June 1995 to August 2019.

Service	Regions	Temporal coverage	Spatial resolution	Temporal resolution	Validation reports	Uncertainty information
CLMS	Global	May 2002 - Mar 2012	1 km	10 days	Validation report	Uncertainty, standard deviation, quality level
		Nov 2016 - present	1km	10 days	Validation report	Uncertainty, standard deviation, quality level
C3S	Global	Jun 1995 - present	5 km	Daily (with gaps)	Quality assessment report	Bias correction flag, quality levels, total uncertainty

Table 34.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Lake Surface Water Temperature products.

The summary of the spatial and temporal resolutions for the LSWT products is shown in Figure 22.

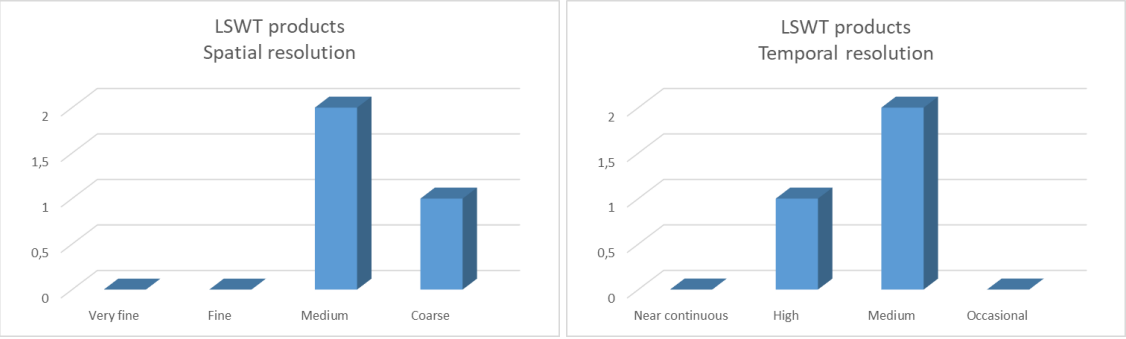

Figure 22.- Spatial and temporal resolutions available at the Copernicus services for the Lake Surface Water Temperature products.

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Particulate Backscattering Coefficient (bbp)

The Copernicus Marine Service offers several products related to Particulate Backscattering Coefficient (called Backscattering coefficient), most of them for the different sea areas in Europe (Arctic Region, Baltic Sea, North West Shelf Region, Iberic Sea, Mediterranean Sea and Black Sea).

On one hand, a 1 km product is offered daily from May 2016 until present for the different coastal regions, while a 4 km product is offered globally on a daily and monthly basis for the same period.

Since May 2021, the Service is also offering daily products and daily and monthly mean products for the European regional coasts at 100 m resolution, and covering from January 2020 until present.

		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x
	Mediterranean Sea	x
	Iberia Biscay Ireland Regional Seas	x
	European North West Shelf Seas	x
File format		NetCDF
Validation reports		Quality Information Documents
Uncertainty information		Quality indexes, Uncertainty variables, Standard deviation, Error (62%)

Table 35.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Particulate Backscattering Coefficient products.

The summary of the spatial and temporal resolutions for the Particulate Backscattering Coefficient is shown in Figure 23.

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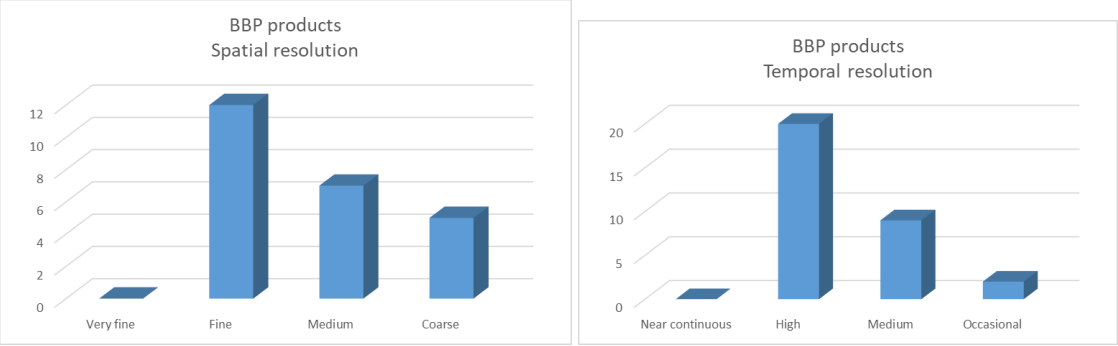

Figure 23.- Spatial and temporal resolutions available at the Copernicus services for the Particulate Backscattering Coefficient products.

Phytoplankton absorption coefficient (a_{Phy})

There are 9 products providing phytoplankton absorption coefficient in the Marine Service. All of them are provided daily and at 1 km and 300 m resolution.

		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x
	Mediterranean Sea	x
	Iberia Biscay Ireland Regional Seas	x
	European North West Shelf Seas	x
File format		NetCDF
Validation reports		Quality Information Documents
Uncertainty information		Quality indexs (44%)

Table 36.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Phytoplankton absorption coefficient products.

The summary of spatial and temporal resolutions of the Phytoplankton absorption coefficient products is shown in Figure 24.

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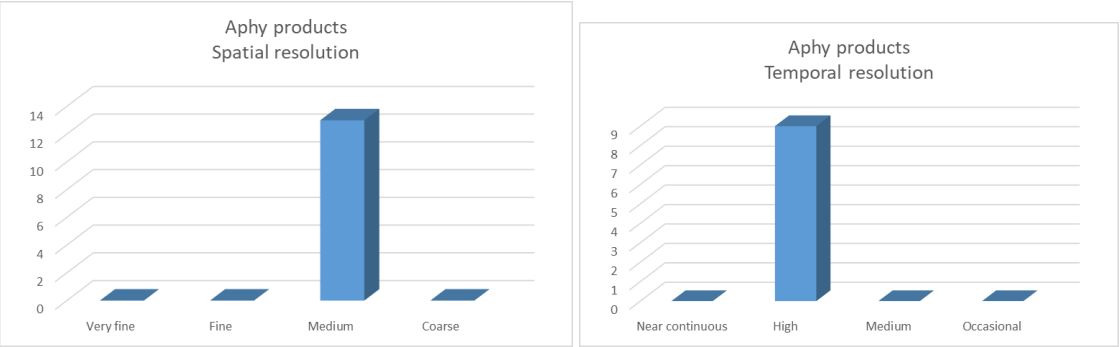

Figure 24.- Spatial and temporal resolutions available at the Copernicus services for the Phytoplankton absorption coefficient products.

Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance (WLR)

The Copernicus Marine Service offers several products related to Remote Sensing Reflectance, most of them for the different sea areas in Europe (Arctic Region, Baltic Sea, North West Shelf Region, Iberic Sea, Mediterranean Sea and Black Sea).

All of them are daily, except one monthly product also for the Global Ocean. Regional products are offered at 1 km 0.3 km and 0.1 km, while global products are provided with 4 km and 0.3 km.

In addition, the C3S provides a global daily estimate of reflectance derived from multiple satellite sensors. The product has global coverage and is available from September 1997 to present at a daily and monthly basis.

On his side, The Global Land Service offers three 10-day Water leaving reflectance products at 100 m (Europe and Africa) and 300 m (Global) resolution. The Lake Water Quality products at 1 km are discontinued.

		CMEMS	C3S	CLMS
Regions	Global	x	x	x
	Europe and Africa			x
	Black Sea	x		
	Arctic Ocean	x		
	Baltic Sea	x		
	Mediterranean Sea	x		

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	Iberia Biscay Ireland Regional Seas European North West Shelf Seas	x x		
File format		NetCDF	NetCDF 4	NetCDF
Validation reports		Quality Information Documents	Validation report	Validation reports
Uncertainty information		RMS, Uncertainty (71%)	RMS, bias and other	Number of observations

Table 37.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Remote Sensing Reflectance and Water Leaving Reflectance (WLR) products.

All this is summarized in Figure 25.

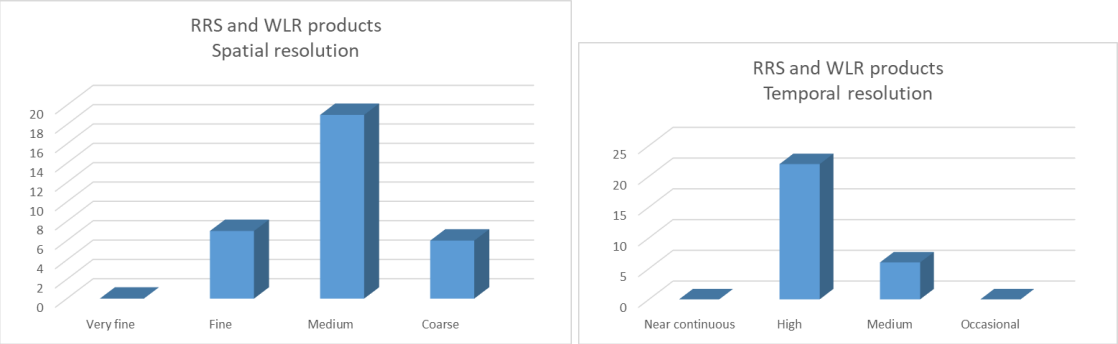

Figure 25.- Spatial and temporal resolutions available at the Copernicus services for the Remote Sensing Reflectance and Water Leaving Reflectance (WLR) products.

Sea Surface Temperature (SST)

There are 23 products in the Marine Service, mainly for the different sea regions in Europe, but also with a global coverage. Most of them are offered daily and with coarse resolution.

		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x
	Mediterranean Sea	x

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European North West Shelf Seas	x
File format	NetCDF, GDS2.0
Validation reports	Quality Information Documents
Uncertainty information	Uncertainty variables, Standard deviation, Quality level (87%)

Table 38.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Sea Surface Temperature products.

The summary of the temporal and spatial resolutions offered is shown in Figure 26.

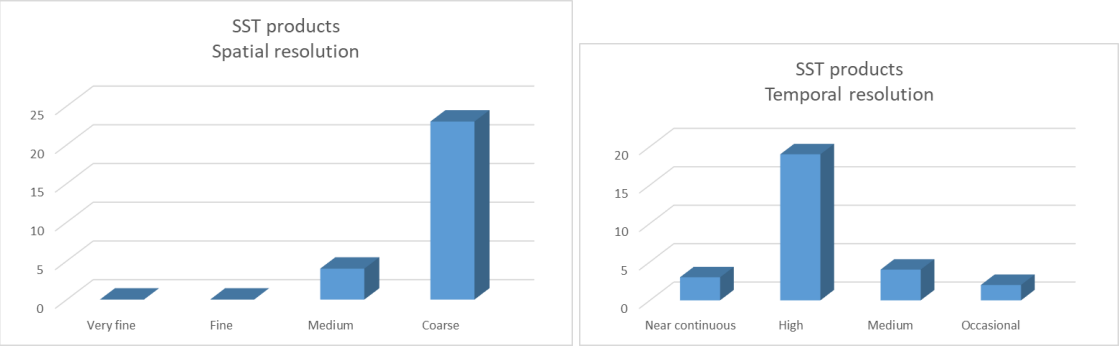

Figure 26.- Spatial and temporal resolutions available at the Copernicus services for the Sea Surface Temperature products.

Secchi Disk Depth (ZSD)

Four products are offered by the Copernicus Marine Service on Secchi Disk Depth. All of them are global and with 4km of spatial resolution. A new product is offered since January 2022 with 300 m resolution. They all are provided on a daily and monthly basis, although a multi-year product is also available.

		CMEMS
Regions	Global Ocean	x
File format		NetCDF 1.4
Validation reports		Quality Information Documents
Uncertainty information		Uncertainty variable (100%)

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Table 39.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Secchi Disk Depth products.

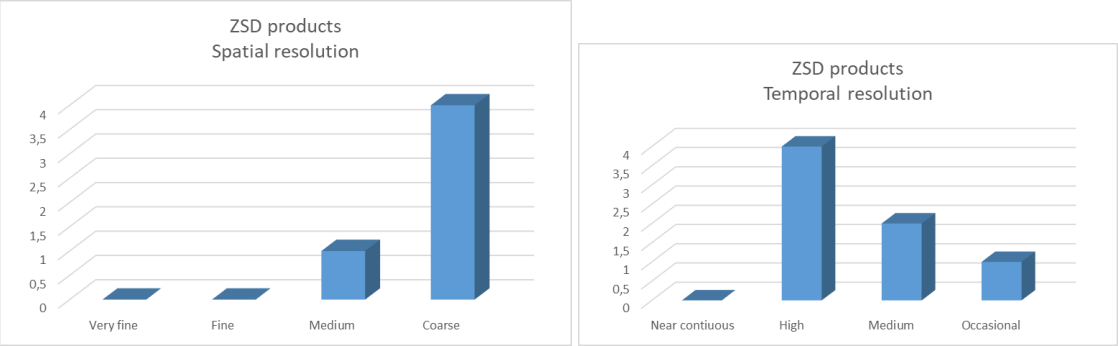

Figure 27.- Spatial and temporal resolutions available at the Copernicus services for the Secchi Disk Depth products.

Suspended Particulate Matter (SPM)

Several products are available in the Marine Service. Since May 2016 until present, a 4 km global product is provided as daily and daily and monthly mean, as well as a daily 1 km product for the Arctic region. Since January 2020, daily and daily and monthly mean products are available at 100 m resolution for the coastal regions in Europe (Arctic Region, Baltic Sea, North West Shelf Region, Iberic Sea, Mediterranean Sea and Black Sea). Since January 2021 and 2022, a 1 km daily product is offered for Arctic and North Atlantic coasts and a 4 km product is offered globally.

		CMEMS
Regions	Global Ocean	x
	Black Sea	x
	Arctic Ocean	x
	Baltic Sea	x
	Iberia Biscay Ireland Regional Seas	x
	Mediterranean Sea	x
	European North West Shelf Seas	x
File format		NetCDF
Validation reports		Quality Information Documents
Uncertainty information		Uncertainty variables, Standard deviation, Quality index (90%)

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Table 40.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Suspended Particulate Matter products.

The summary of temporal and spatial resolutions covered is shown in Figure 28.

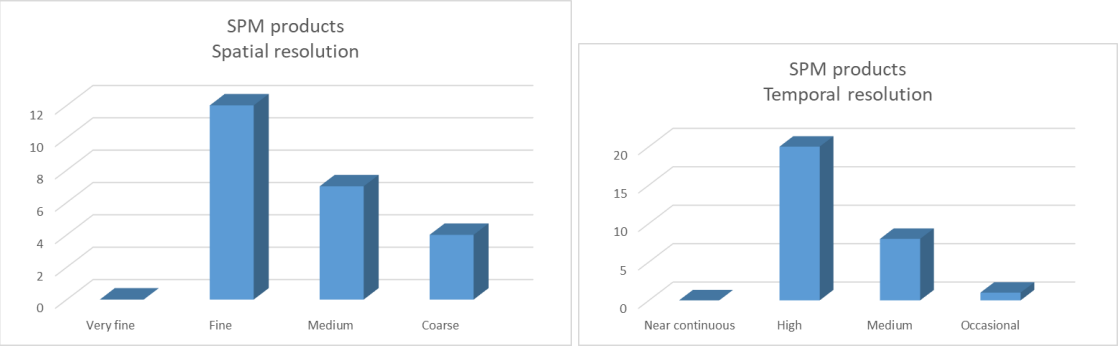

Figure 28.- Spatial and temporal resolutions available at the Copernicus services for the Suspended Particulate Matter products.

Total absorption coefficient (a_{TOT})

There are four products in the Marine Service, for the Arctic and the European North West Shelf Seas regions, offered at 1 km and 300 m (since January 2022) resolution and with a daily temporal resolution.

		CMEMS
Regions	Arctic Ocean	x
	European North West Shelf Seas	x
File format		NetCDF
Validation reports		Quality Information Documents
Uncertainty information		Quality index (50%)

Table 41.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Total absorption coefficient products.

Figure 29 collects the temporal and spatial resolution summary.

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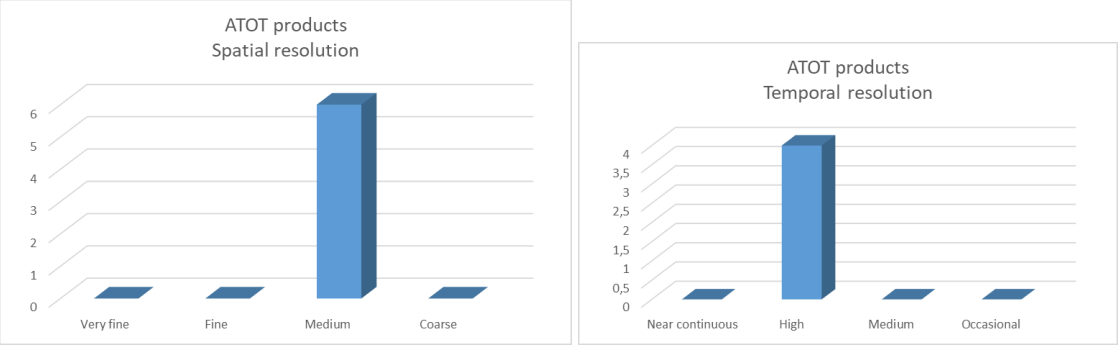

Figure 29.- Spatial and temporal resolutions available at the Copernicus services for the Total absorption coefficient products.

Trophic State Index (TSI)

No products are available in the Marine service for the Trophic State Index (TSI).

The Global Land Service offers two 10-day products at 100 m (Europe and Africa) and 300 m (Global) resolution. The Lake Water Quality products at 1km are discontinued. Trophic State Index (TSI) is derived from phytoplankton biomass by proxy of chlorophyll-a, so it is obtained from chlorophyll-a concentration and just recalculated into TSI before the delivery to users.

			Temporal coverage	Spatial resolution	Temporal resolution	Validation report	Uncertainty information
CLMS	Regions	Europe and Africa	Jan/2019 - Present	100 m	10 days	Validation report	Number of observations
		Global	May/2002 - Mar/2012	300 m	10 days	Validation report	Number of observations
			May/2016 - Present	300 m	10 days	Validation report	Number of observations
			May 2016 - Aug 2018	1 km	10 days	Validation report	Number of observations
			May 2002 - March 2012	1 km	10 days	Validation report	Number of observations

Table 42.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified Trophic state Index products.

The summary of the spatial and temporal resolutions is shown in Figure 30.

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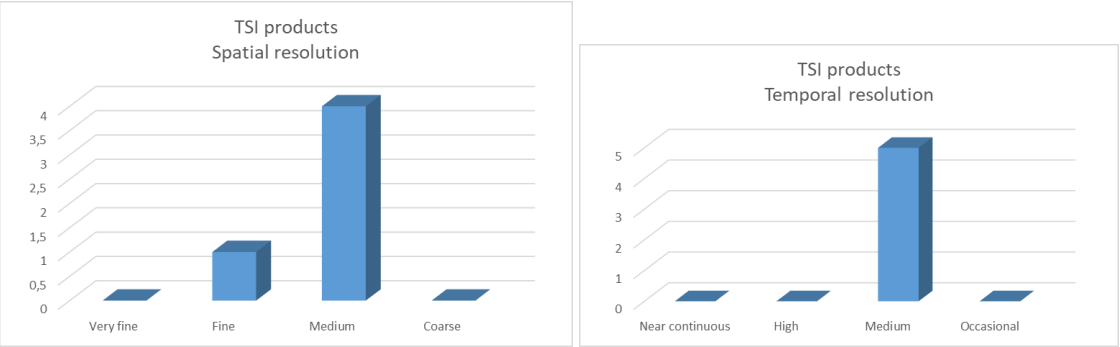

Figure 30.- Spatial and temporal resolutions available at the Copernicus services for the Trophic State Index products.

Turbidity

The variable Turbidity is derived directly or from suspended solids concentration estimates (suspended matter concentration), with algorithms depending on the optical water type. The Global Land Service offers three 10-day products at 100 m (Europe and Africa) and 300 m (Global) resolution. The Lake Water Quality products at 1 km are discontinued.
Since May 2021, the Marine Service is offering daily, daily mean and monthly mean for the regional seas at 100 m resolution, and covering from January 2020 until present.

		CMEMS	CLMS
Regions	Global		X
	Europe and Africa		X
	Black Sea	X	
	Arctic Ocean	X	
	Baltic Sea	X	
	Iberia Biscay Ireland Regional Seas	X	
	Mediterranean Sea	X	
	European North West Shelf Seas	X	
File format		NetCDF	NetCDF
Validation reports		Quality Information Documents	Validation reports
Uncertainty information		Uncertainty variables, Standard deviation, Quality index (90%)	Standard deviation (40%), Number of observations

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Table 43.- Summary of the temporal coverage, spatial resolution and temporal resolution of the identified turbidity products.

The summary of the spatial and temporal resolutions is shown in Figure 31.

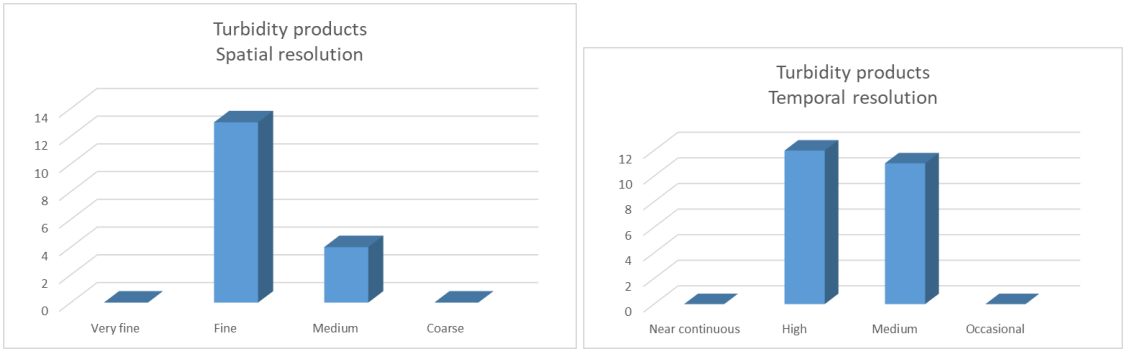

Figure 31.- Spatial and temporal resolutions available at the Copernicus services for the Turbidity products.

4 Relevant existing Water EO products for modelling at non-European agencies

This section shows relevant non-Copernicus Water EO products and services which aims to show some interesting examples of a specific Water Service. This could be relevant because Copernicus prefers a collection of water services distributed at different domain services (C3S, CEMS, CLMS ...) concrete examples of services those water communities are using and how they are grouped in a water single access point.

Droughts:

The United Nations Convention to Combat Desertification (UNCCD) Drought Toolbox: https://knowledge.unccd.int/drought-toolbox provides tools, case studies, and drought monitoring and modelling resources organized into three modules:

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- Monitoring and early warning,
- Vulnerability and risk assessment,
- Risk mitigation measures

The Global SPEI database: https://spei.csic.es/database.html (Vicente-Serrano et al 2010) offers long-time (1901-2020), robust information about drought conditions at the global scale, with a 0.5 degrees spatial resolution and a monthly time resolution with time-scales between 1 and 48 months. The source of primary climate data is https://crudata.uea.ac.uk/cru/data/hrg/ by UK's Natural Environment Research Council (NERC).

Floods

The Japan Aerospace Exploration Agency (JAXA) offers the "Today's Earth" (TE) land surface and river simulation system that distributes and visualizes hydrological products for disaster monitoring and hydrological research. The Map viewer is at https://www.eorc.jaxa.jp/water/map/index.html Flood models are generated by CaMa-Flood (Catchment-based Macro-scale Floodplain) (Yamazaki et al 2011).

Hydrography:

The Global Runoff Data Centre (GRDC) is an international archive of data (https://www.bafg.de/GRDC/EN/03_dtprdcts/dataproducts_node.html) operating under the auspices of WMO. It fosters multinational and global long-term hydrological studies.

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The USGS (United States Geological Survey) together with other US agencies provides, datasets, services and tools for hydrologic modelling, environmental protection, resources management, mapping, emergency response, etc. Two relevant examples are the NHDPlus High Resolution https://www.usgs.gov/national-hydrography/nhdplus-high-resolution and the https://www.epa.gov/waterdata/waters-geoviewer. These services are not global, are dedicated to US, however, their exploration can help to find potential new water Copernicus Services.

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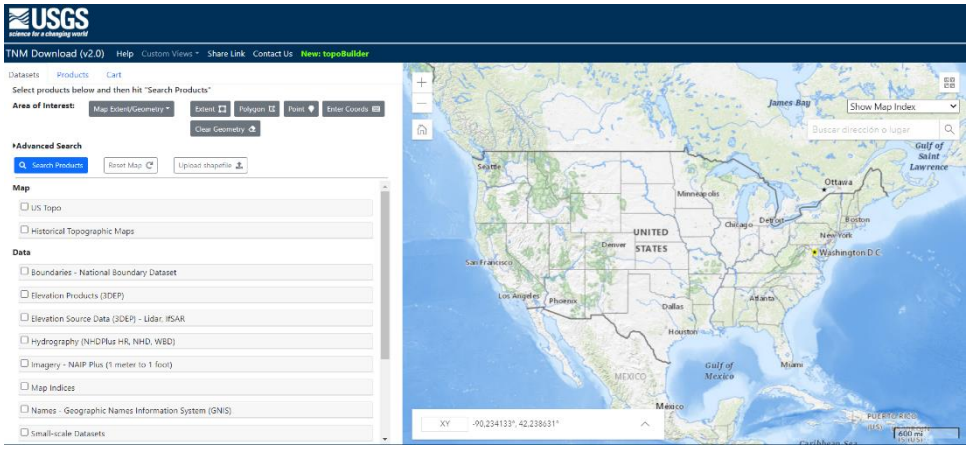

Figure 32.- The National Map Downloader (https://apps.nationalmap.gov/downloader/#/)

Water Quality

The Water Quality Portal https://data.nal.usda.gov/dataset/water-quality-portal (Red et al 2017) is a collaborative service by the United States Geological Survey (USGS), the Environmental Protection Agency (EPA), and the National Water Quality Monitoring Council (NWQMC). A large set of variables are provided: aggregate groundwater use, aggregate surface water use, atmosphere, estuary, facility, glacier, lake, land, ocean, spring, stream, subsurface, well, and wetland. Water quality characteristic groups include physical conditions, chemical and bacteriological water analyses, chemical analyses of fish tissue, taxon abundance data, toxicity data, habitat assessment scores, and biological index scores, among others.

5 Modelling capabilities on Copernicus DIAS

The European Commission has funded (it is operational since June 2018) the deployment of five cloud-based platforms: CreoDIAS (https://creodias.eu), Wekeo (https://www.wekeo.eu), OndaDIAS (https://www.onda-dias.eu), MundiWebServices (https://mundiwebservices.com/) and Sobloo (https://sobloo.eu).

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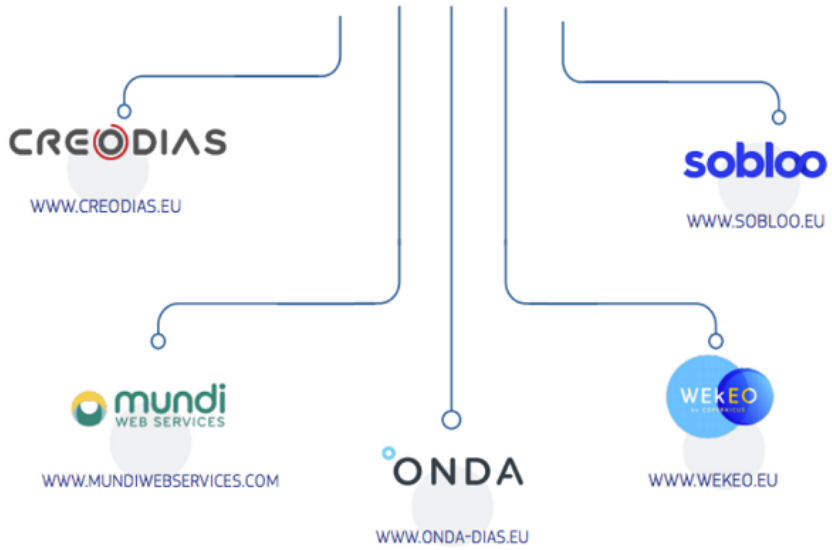

Figure 33.- Schema of the 5 DIAS available in Copernicus. Source: copernicus.eu

They provide centralised access to Copernicus products and information, as well as to processing tools, very useful for modelling purposes. These platforms are known as the DIAS, or Data and Information Access Services with the aim to allowed better Copernicus data and information uptake and be the complement of the Conventional Data Access Hubs Copernicus Open Access Hub, Copernicus Space Component Data Access (CSCDA), Copernicus Online Data Access (CODA) and EUMETCast.

The DIAS back office is the scalable computing environment where users build and run their own services based on Copernicus. The DIAS interface services encompass tools and services that will facilitate to the users to create their own modelling applications.

These tools include, but are not limited to, algorithms and libraries available in SNAP and Orfeo Toolbox, GDAL, GIS environments (i.e., QGIS) and other tools that can support EO and non EO data storage, management (i.e., data cube services), processing/computing (i.e., Jupyter notebook) and publishing (i.e., Geoserver).

Each DIAS solution has specific tools and access to the selected Copernicus Services. Table 44 compares them (source: updated version from EARSC table).

	CAMS	CEMS	CLMS	CMEMS	C3S

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CreoDias	x	x	x	x	x
Mundi		x	x		
Onda	x		x	x	
Sobloo	x	x	x	x	x
Wekeo	x	x	x	x	x

Table 44.- Access relation to the Copernicus Services from each DIAS.

The DIAS architecture enables further extraction of value from Copernicus data and information and increases the ease with which it is handled.

These DIAS provide computing resources for running high demand processing needs. Virtual machines can be rented on an hourly basis whilst programmatic management and backend services can be also provided allowing the development of dedicated applications. In water modelling, these processes can be the previous steps for the generation of specific water products derived from the DIAS available products or, in other cases, we will be able to run the complete water model process-chain, including the full algorithm in the DIAS programming environment. It should be also noted that the way of Integration of external systems/applications with each DIAS may differ considerably (I.e., some DIASes like CREODIAS provide more broad permissions In terms of access to the environment, etc).

6 Characterization of Copernicus available EO products for modelling

In this section, the recommendations obtained in the consultation and review process summarized in D5.1 and those given in the work from the World Bank 2016 introduced in section 2 (World Bank, 2016) regarding the EO needs for water modelling are compared to the analysis about the current Copernicus products and services done in Section 3. Such process should give us a full picture of the existence and availability of suitable products for water modelling in Copernicus. Gaps and limitations in such products for modelling will be made visible so recommendations will be given at the end.

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In the first part of this section (6.1), general conclusions about the characteristics of the Copernicus products for modelling are offered, while in the second part (6.2) a detailed evaluation for each type of modelling is provided.

6.1 Copernicus products general performance

Spatial coverage

Global products are available for nearly all of the variables, offered sometimes by different Services, although they frequently have lower spatial resolution than the equivalent regional products.

In the case of water quantity, the better-covered areas are clearly in Europe, in its different versions: Europe, EEA39, EU countries, Pan-European domain, Greater Europe, Northern Europe. Other zones - Africa, Arctic, North America, Mediterranean, West/East domain, Eastern partnership countries, Northern hemisphere - are less covered.

In the case of water quality, since most of the products are offered by the Marine Service, the better-covered areas (in addition to the global ocean) are: Arctic Ocean, Baltic Sea, Black Sea, European North West Shelf Seas, Iberia Biscay Ireland Regional Seas, Mediterranean Sea, North/South Atlantic Ocean, North/South Pacific Ocean. Other zones like Europe and Africa are less covered.

No detailed regional products (only global products) are available in the case of Inland water temperature, Land surface temperature, Air temperature, Lake Surface Water Temperature, Secchi Disk Depth or Water levels in lakes and rivers.

On the contrary, the DEM product is available only for the EEA39 region and the groundwater recharge only for greater Europe. Total absorption coefficient is available only for Arctic Ocean and European North West Shelf Seas.

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Data access

In terms of data access, good availability is provided for most of the products, since they are available in most cases both for data download as well as via web map servers as WMS. Product portals and web services also offer the possibility to download the data for a given region. FTP access is also offered in some cases.

Despite of that, a great difference is found between Services regarding the facility and easy of access to the information about the products and to the product itself. While the Land Service has a clear portfolio and unique product pages describing the variables and characteristics of the products, other Services such as C3S or CAMS have a large amount of pages describing the same products and many times with contradictory information on each of it, resulting in a confusion for the user about the characteristics of the product. User can get lost and not to know which product is suitable for his/her work. Information is not well structured and pages are not up to date. The Marine Service has recently invested in a new portal and a more structured information, which has resulted in a more comfortable search portal, although some of the information in the products pages does not correspond with the information described in the product user manuals or with the catalog.

File format

Some products are offered in different file formats, but the most common format for all the variables is NetCDF, in its different versions. Other usual formats are GRIB and GeoTIFF. Some Services offer also GeoJSON, XML, GDS2.0, ENVI, HDF5 or Shapefile (for vector data).

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Validation reports

One important thing when using remote sensing derived products is knowing the validity of the product and its performance in real applications. Copernicus Services are continuously developing new products which are in different stages of development and validation. In order to assess the level of maturity of the products analysed, the existence of

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some kind of validation or quality assessment reports have been checked. Details on the type of validation for each product are available in the corresponding product tables in Section 3.

Some validation procedures are more robust than others, going from known issues, strengths and weaknesses or external validation (in journal papers) to dedicated validation reports or quality information documents. As a summary, Table 45 shows the level of validation of the listed Copernicus products, considering the following degrees of validation. The idea is to show the level of confidence that the products can have for the user, depending on the kind of validation provided for the products.

Low level of validation	• Known issues • Strengths and weaknesses • External validation • Bias adjustment
Medium level of validation	• Evaluation and Quality Control • Product gap analysis • Evaluation products
High level of validation	• Validation reports • Quality information documents • Quality assessment reports • EQA reports
Not validated	• No validation

Table 45.- Classification of the existing types of validation for the Copernicus products into different levels.

WATER QUANTITY PRODUCTS		WATER QUALITY PRODUCTS	
Parameter	**Degree of validation**	**Parameter**	**Degree of validation**
Precipitation	Low (54%)	Chlorophyll-a	High
Soil moisture	Medium (78%)	Coloured Dissolved Organic Matter	High

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Surface run-off	Low	Diffuse attenuation coefficient	High
River discharge	Medium (67%)	Lake Surface Water Temperature	High
Flood extent	Medium	Particulate Backscattering Coefficient	High
Inland water temperature	High	Phytoplankton absorption coefficient	High
LU/LC and Vegetation products	High (73%)	Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance	High
Land surface temperature	High	Sea surface temperature	High
Air temperature	Low	Secchi Disk Depth	High
DEM and DTM	High	Suspended Particulate Matter	High
Water levels in lakes and rivers	High	Total absorption coefficient	High
Drought	Low (60%)	Trophic State Index	High
Groundwater	Low	Turbidity	High
Lake ice cover	Medium (46%)		
Snowmelt	Medium (55%)		
Total water storage	Low		

Table 46.- Level of maturity of the identified Copernicus products according to the degree of product validation offered.

Uncertainty information

Uncertainty information refers to the availability or not of levels of confidence in the data values, that is, an uncertainty or error information provided on the values that the product is offering. The problem when using remote sensing products is not that much data quality (or product quality), but uncertainty. In many cases the Copernicus products are not properly validated or not properly validated for a particular lake or region. This is why users don't trust

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them. If modellers know the uncertainty, then they can decide whether to use the Copernicus product or not.

In that sense, the availability of uncertainty information has been evaluated for the identified products by means of the existence of uncertainty variables, standard deviation or some kind of quality indexes and flags. Details on the type of validation for each product are available in the corresponding product tables in Section 3.

As a summary, Table 47 shows the percentage of listed Copernicus products providing uncertainty information for each of the variable.

WATER QUANTITY PRODUCTS		WATER QUALITY PRODUCTS	
Parameter	**% of products with uncertainty information**	**Parameter**	**% of products with uncertainty information**
Precipitation	80%	Chlorophyll-a	47%
Soil moisture	22%	Coloured Dissolved Organic Matter	61%
Surface run-off	74%	Diffuse attenuation coefficient	50%
River discharge	-	Lake Surface Water Temperature	100%
Flood extent	3%	Particulate Backscattering Coefficient	62%
Inland water temperature	100%	Phytoplankton absorption coefficient	44%
LU/LC and Vegetation products	49%	Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance	72%
Land surface temperature	100%	Sea surface temperature	87%
Air temperature	100%	Secchi Disk Depth	100%
DEM and DTM	100%	Suspended Particulate Matter	90%
Water levels in lakes and rivers	100%	Total absorption coefficient	50%
Drought	-	Trophic State Index	-

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Groundwater	100%	Turbidity	40%
Lake ice cover	77% (23% ongoing)		
Snowmelt	55%		
Total water storage	-		

Table 47.- Percentage of identified Copernicus products providing some kind of uncertainty information along with the data values for the Identified variables.

Spatial resolution

The spatial resolution of the identified products has been analysed in Section 2 for each of the variables. Table 48 provides a summary of the main spatial resolutions for each of the variables, according to the classification and the graphics in Section 2.

WATER QUANTITY PRODUCTS		WATER QUALITY PRODUCTS	
Parameter	**Most common spatial resolution**	**Parameter**	**Most common spatial resolution**
Precipitation	Coarse	Chlorophyll-a	Fine to Coarse
Soil moisture	Coarse	Coloured Dissolved Organic Matter	Medium to Coarse
Surface run-off	Coarse	Diffuse attenuation coefficient	Medium to Coarse
River discharge	Coarse	Lake Surface Water Temperature	Medium to Coarse
Flood extent	Coarse	Particulate Backscattering Coefficient	Fine to Coarse
Inland water temperature	Medium-Coarse	Phytoplankton absorption coefficient	Medium
LU/LC and Vegetation products	Very fine to Coarse	Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance	Fine to Coarse

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Land surface temperature	Coarse	Sea surface temperature	Medium to Coarse
Air temperature	Coarse	Secchi Disk Depth	Medium to Coarse
DEM and DTM	Fine	Suspended Particulate Matter	Fine to Coarse
Water levels in lakes and rivers	-	Total absorption coefficient	Medium
Drought	Very fine-Fine and Coarse	Trophic State Index	Fine to Medium
Groundwater	Coarse	Turbidity	Fine to Medium
Lake ice cover	Fine to Coarse		
Snowmelt	Coarse		
Total water storage	Coarse		

Table 48.- Most common spatial resolutions found In the Copernicus products for each of the Identified variables.

Temporal resolution

The temporal resolution of the identified products has been analysed in Section 2 for each of the variables. Table 49 provides a summary of the main temporal resolutions for each of the variables, according to the classification and the graphics in Section 2.

WATER QUANTITY PRODUCTS		WATER QUALITY PRODUCTS	
Parameter	**Most common temporal resolution**	**Parameter**	**Most common temporal resolution**
Precipitation	Near continuous to Medium	Chlorophyll-a	High to Occasional
Soil moisture	Near continuous to Medium	Coloured Dissolved Organic Matter	High to Occasional

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Surface run-off	Near continuous to Medium	Diffuse attenuation coefficient	High to Occasional
River discharge	High to Occasional	Lake Surface Water Temperature	High to Medium
Flood extent	High to Medium	Particulate Backscattering Coefficient	High to Occasional
Inland water temperature	High to Medium	Phytoplankton absorption coefficient	High
LU/LC and Vegetation products	Near continuous to Occasional	Remote Sensing Reflectance (R_{RS}) and Water Leaving Reflectance	High to Medium
Land surface temperature	Near continuous and Medium	Sea surface temperature	Near continuous to Occasional
Air temperature	Medium	Secchi Disk Depth	High to Occasional
DEM and DTM	Occasional	Suspended Particulate Matter	High to Occasional
Water levels in lakes and rivers	Medium	Total absorption coefficient	High
Drought	High to Occasional	Trophic State Index	Medium
Groundwater	Occasional	Turbidity	High to Medium
Lake ice cover	Near continuous to Occasional		
Snowmelt	Near continuous to Occasional		
Total water storage	Medium		

Table 49.- Most common temporal resolutions found in the Copernicus products for each of the identified variables.

6.2 Copernicus products for modelling

Biogeochemical models

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Biogeochemical models are strongly related with monitoring and predicting water quality in dams and reservoirs. As indicated in World Bank, 2016, depending on the size of the reservoirs, high spatial resolution (very fine to medium) may be required. Generally, slow water dynamics mean that a moderate frequency is likely to be required. The main required variables will be those related to surface water and to water quality. As derived from section 3.1 in this deliverable, Copernicus provide the following products:

	Spatial resolution	Temporal resolution
Surface runoff	Coarse	Near continuous to Medium
River discharge	Coarse	High to Occasional
Water quality	Fine and Medium	High to Occasional

In order to let for the identification and monitoring of small dams and reservoirs, spatial resolution of surface water variables such as surface runoff or river discharge should be improved to less than 1km. For the river discharge and the water quality variables, also the temporal resolution could be improved for monitoring water quality, since some of the changes require less than 1 month of temporal resolution.

Hydrodynamic models

Hydrodynamic models are crucial in predicting the extent of floods, since hydrodynamic models can simulate water flows and flood extent. Required information include DEM, weather forecasts, antecedent rainfall and soil moisture conditions. It is also useful to know the previously flooded areas and the recurrence times.

As indicated by the World Bank report, useful variables will then be precipitation, soil moisture, surface water and DEM. For such models, fine to medium spatial resolution is required for surface water while coarse resolution can be suitable for precipitation or soil moisture. Temporal resolution needs to be high or near continuous for that variables and high to medium for surface water.

The provided Copernicus products, according to Section 2 are:

	Spatial resolution	Temporal resolution

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Precipitation	Coarse	Near continuous to Medium
Soil moisture	Coarse	Near continuous to Medium
Surface runoff	Coarse	Near continuous to Medium
River discharge	Coarse	High to Occasional
DEM	Fine	Occasional
Flood extent	Coarse	High to Medium

Again, surface water variables (such as surface runoff and river discharge or flood extent) would work better with a higher spatial resolution for predicting extent of floods. But good temporal resolutions are provided in Copernicus for such type of modelling.

River models

River models are used for assessing water use efficiency, monitoring rates of irrigation water use, monitoring rates of groundwater extraction, monitoring river flow or conducting integrated assessment of water availability under climate change scenarios.

As indicated in World Bank (2016), the key variable to monitor in assessing water use efficiency by crops or rates of irrigation water use is evapotranspiration, which should have high and medium spatial resolutions and high- and medium-frequency revisit times. Other useful variables are land cover, at the same spatial resolution and at least once during the growing cycle (medium), and precipitation and soil moisture, typically at coarse spatial resolution, but perhaps daily or more frequently.

River flows can also be estimated with river models by using precipitation, soil moisture, evapotranspiration, snow and ice extent or groundwater. Finally, for an integrated assessment of water availability, almost all of the variables mentioned can be useful.

As indicated in Section 2, no evapotranspiration products are available in Copernicus for river models. For the rest of the variables, available products include:

	Spatial resolution	Temporal resolution
Evapotranspiration	-	-
LU/LC	Very fine to coarse	Near continuous to occasional
Precipitation	Coarse	Near continuous to medium
Soil moisture	Coarse	Near continuous to medium

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Snowmelt	Coarse	Near continuous to Occasional
Groundwater	Coarse	Occasional

According to the requirements, most of the available products in Copernicus would be appropriate for river modelling. For snowmelt, spatial resolution should be higher (<1000 m) and for groundwater the temporal resolution should higher (<24 h). But the key issue here is the lack of an evapotranspiration product for some of the models.

Crop or pasture growth models

These types of models are addressed to estimate crop production and food security. Crop growth models or pasture growth models can be parameterized with EO data. The main required variables are vegetation indexes, normally at high and medium spatial and temporal resolutions. Remotely sensed precipitation and evapotranspiration can be useful too.

According to this, the following products are available in Copernicus for vegetation growth models:

	Spatial resolution	Temporal resolution
Vegetation	Very fine to Coarse	Near continuous to Occasional
Precipitation	Coarse	Near continuous to medium
Evapotranspiration	-	-

Both the vegetation and precipitation products in Copernicus are adequate for modelling crop or pasture growth, but again an evapotranspiration product is missing for such type of modelling.

Landscape water balance models

Landscape water balance models are aimed at monitoring and forecasting drought, monitoring river flow and conducting integrated assessment of water availability under climate change scenarios. For monitoring and forecasting drought, usually the vegetation

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indices and precipitation are used, but other useful variables are evapotranspiration, soil moisture, groundwater, and snow and ice.

River flows can also be estimated with landscape and river models by using precipitation, soil moisture, evapotranspiration, snow and ice extent or groundwater. Finally, for an integrated assessment of water availability, almost all of the variables mentioned can be useful.

According to this, the related available products in Copernicus are:

	Spatial resolution	Temporal resolution
Vegetation	Very fine to Coarse	Near continuous to Occasional
Precipitation	Coarse	Near continuous to medium
Evapotranspiration	-	-
Soil moisture	Coarse	Near continuous to medium
Groundwater	Coarse	Occasional
Snowmelt	Coarse	Near continuous to Occasional
Lake ice cover	Fine to Coarse	Near continuous to Occasional

With such products, only groundwater temporal resolution should be improved (<24 h), as well as the spatial resolution of snowmelt products (<1000 m). And, of course, again evapotranspiration is missing.

7 Conclusions and technical recommendations

In this document, an analysis of the parameters and their characteristics required in inland water modelling has been done, based on the needs assessment performed in Task 5.1 of the Water-ForCE project and the specifications collected in the literature, the (World Bank, 2016) is the main reference, where the key types of variables and their minimum spatial and

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temporal resolution requirements are evaluated for each water resource management issue.

All the requirements have been contrasted to the existence of available products in Copernicus services covering those requirements and an analytical approach has been applied in previous Section to evaluate the suitability of the Copernicus portfolio for water modelling. In this section, we summarize and present the main conclusions extracted from the analytical process.

In conclusion, the following recommendations can be derived regarding the availability of Copernicus water products for modelling:

- A **bathymetry** product is required for water modelling. It seems that there are plans to derive Copernicus satellite derived bathymetry product in the Marine Service. For the moment, EMODNET bathymetry, developed jointly by EMODNET and the Marine Service, is being used.

- For **Chlorophyll-a**, the 1 km products are not suitable for coastal zones. This resolution is too coarse for most coastal waters. The accuracy of the Chl-a product is questionable for open parts of the seas (e.g. R^2=0.24 or basically hopeless in the Baltic Sea) and it performs much worse than that in coastal waters.

- Regarding **remote sensing and water leaving reflectances**, there is the issue that marine (coastal) and lake reflectances are not calculated in the same way. Thus, there is no water continuum. Studying water properties from lakes to coastal waters cannot be done as the atmospheric corrections are different. For example, in the coastal lagoons two different sets of reflectance can be obtained for the same region. This situation also happens for products like Chl-a. Three different marine, coastal and inland water Chl-a values for certain areas can be obtained.

- Users also asked in D5.1 for new products related to **water quality**: Water primary production (WPP), Total Nitrogen (TN), Total Phosphorus (TP), Dissolved Organic Carbon (DOC), and Partial pressure of CO2 or CO2 concentration (pCO2).

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- For **soil moisture** products, there is a demand from various user communities for higher spatial resolution datasets at kilometre scale ((Peng et al 2021). The current and future missions provide opportunities to develop high spatial resolution soil moisture products and with moderate (e.g., daily) temporal resolution.

- No detailed **regional products** (only global products) are available in the case of Inland water temperature, Land surface temperature, Air temperature, Lake Surface Water Temperature, Secchi Disk Depth or Water levels in lakes and rivers. This can difficult the high resolution modelling in the case of detailed or regional hydrodynamic, river or water balance models.

- Better-structured information is needed when accessing data in product platforms and websites, avoiding the existence of contradictory information in different places describing the product. Unique description pages are desirable for each product.

- Although NetCDF is an appropriate common format for all the products, recommendations can be done to provide products in **Cloud Optimized GeoTIFF** (COG) in the near future. COG is a format prepared to work in the cloud so that different formats are not required for cloud and not cloud applications.

- Although the water quality related products have all a high level of validation in terms of the existence of related validation reports and information, in the case of water quantity parameters the situation is very different: only 5 parameters have high level of validated products, 5 parameters have medium level of validation and 5 more have low levels of validation. The case of precipitation is remarkable, being one of the most used parameter in modelling and having a 54% of the products with a low level of validation. Products for surface run-off have all also low levels of validation. This situation introduces uncertainty and lack of confidence in the models.

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- **Uncertainty information** is not provided for any of the River discharge, Drought, Total water storage or Trophic state index products, and is only provided in 3% of the flood extent products and in 22% of the soil moisture.

- In order to enable the identification and monitoring of small dams and reservoirs, spatial resolution of **surface water** variables such as surface runoff or river discharge should be improved to less than 1km.

- For the **river discharge** and the **water quality** variables, the temporal resolution could be improved for monitoring water quality, since some of the changes require less than 1 month of temporal resolution to be detected.

- **Surface water** variables (such as surface runoff and river discharge or flood extent) would work better with a higher spatial resolution in predicting extent of floods. It is also a demand that came from users in D5.1.

- For river models and landscape water balance models, spatial resolution of **snowmelt** products should be higher (<1000 m) and temporal resolution of **groundwater** products should be higher also (<24 h).

- An **evapotranspiration** product is missing for water resources modelling, crop or pasture growth modelling and landscape water balance models. This is a great issue widely demanded by users and they demand in finest spatial resolution as possible (Guzinskia et al 2019). Evapotranspiration estimates are key variables regarding the use of water in agriculture for the production of indicators required by the Common Agricultural Policy. According to 2019 Copernicus user consultation there is a need from the community for seasonal maps based on daily to weekly information and a 5-20 m pixel resolution to go for 1 ha minimum mapping unit.

- Major needs are continuous and consistent long-term archives of **vegetation** biophysical parameters coupled with **land cover** information for the qualitative assessment of crop development and growth monitoring. Thus, existing Copernicus

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vegetation products are indeed a good resource; yet reference land-use should be also up-to-date (annually instead of every 6 years).

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