Report on recommendations for the uptake of alternative monitoring methods

Water-ForCE

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This document is the draft of the Deliverable 4.4 to be submitted to external experts' review and discussion.

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List of Acronyms

AB	Advisory Board
BLOSM	Boron-based Large-scale Observation of Soil Moisture
CAL/VAL	Calibration and/or Validation
CCVS	Copernicus Cal/Val Solution project
CEOS	Committee on Earth Observation Satellites
CITCLOPS	Citizens' Observatory for Coast and Ocean Optical Monitoring
COINS	Copernicus Observations In Situ Networking and Sustainability
COSMOS	Cosmic-ray soil moisture monitoring network
CSA	Coordination and Support Action
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EC	European Commission
ECSA	European Citizen Science Association
EO	Earth Observation
EOSC	European Open Science Cloud
EU	European Union
GA	Grant Agreement
GCOS-TOPC	Global Climate Observing System - Terrestrial Observation Panel for Climate
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GEWEX	Global Energy and Water Exchanges Project
GLEON	Global Lake Ecological Observatory Network
CTN-H	Global Terrestrial Network on Hydrology
HABs	Harmful Algal Blooms
HWMs	High-Water Marks
ISMN	International Soil Moisture Network
LiDAR	Laser Imaging, Detection, And Ranging
MERIS	Medium Resolution Imaging Spectrometer
MODIS	MODerate resolution Imaging Spectroradiometer
MONOCLE	Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries
MSI	MultiSpectral Instrument
OLCI	Ocean and Land Colour Instrument
OLI	Operational Land Imager
QA/QC	Quality Assurance/Quality Control
R&D	Research and development
RPAS	Remotely Piloted Aircraft System
RS	Remote Sensing
Rrs	Remote Sensing Reflectance
SDGs	Sustainable Development Goals
SfM	Structure from Motion
SIFT	Scale Invariant Feature Transform

SOP	Standard Operating Procedure
SRIX4VEG	Surface Reflectance Intercomparison Exercise for Vegetation
sUAS	small Unmanned Aerial Systems
TIR	Thermal InfraRed
TSS	Total Suspended Solids
TWIGA	Transforming Water, weather, and climate information through In situ observations for Geo-services in Africa
UAS	Unmanned/Unpiloted Aerial System
UAV	Unpiloted or unmanned Aerial Vehicle
VIS-NIR	Visible to Near InfraRed
VHSR	Very High Spatial Resolution
WG	Working Group
WoS	Web of Science
WP	Work Package

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1. Executive summary

This document is the main output of the Task 4.4 of the Horizon **2020 Water scenarios for Copernicus Exploitation** - **Water-ForCE Coordination and Support Action (CSA).** This task aimed to identify innovative methods for data acquisition with the potential to be integrated with satellite remote sensing data streams and in situ networks to complement or validate its products. The document contains the framework inside of the entire project and the responsible Wok Package (WP4), followed by the identification of this potential alternative data sources and the foreseen synergies with satellite Remote Sensing (RS) and hence with the Copernicus Services, identifying when possible what needs or gaps previously identified in Water-ForCE can benefit from this additional data layer. Every alternative or innovative data source has its own section in this document, in which the current knowledge is being summarized or duly referred to other review documents, highlighting the state of the art in data acquisition, limitations and potential uptake in Copernicus Programme. The data management and main recommendations are described in the two last sections, being the recommendations sorted into four different groups: Technology, Data Management, Coordination and Funding.

2. Scope

2.1 Project & Work Package Introduction

The **Horizon 2020** project **Water-ForCE** is developing a Roadmap to better integrate the entire water cycle within the Copernicus Services, thereby addressing needs and requirements from the user community, the current disconnection between remote sensing / in-situ observations and upgrade of the modelling algorithms. The clarity in terms of the needs and expectations of both public and private sectors from the core Copernicus Program and the wider research and business innovation opportunities will be delivered. The Roadmap will then also 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.

The Water-ForCE consortium is led by the University of Tartu (Estonia) and consists of 20 organizations from all over Europe. It will bring together experts on water quality and quantity, in policy, research, engineering, and service sectors. Through close collaborations with these communities, Water-ForCE will among others:

- **Analyse EU and international 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 EU legislations.
- **Specify the technical requirements** for future Copernicus missions in order to make them more suitable for inland and coastal water remote sensing (e.g. adding new spectral bands on Sentinel-2E and onward, improved spatial resolution, hyperspectral sensors).
- **Optimize future exploitation** of Copernicus Services for inland water monitoring, management, legislation implementation, service provision and research & development through enlarged service portfolio and optimized delivery of water related products and services.

The project is divided into eight work packages (WPs), each of them focusing on a specific problem and/or target of the Copernicus service (see Figure 1). The project started 1 January 2021 with a duration of three years.

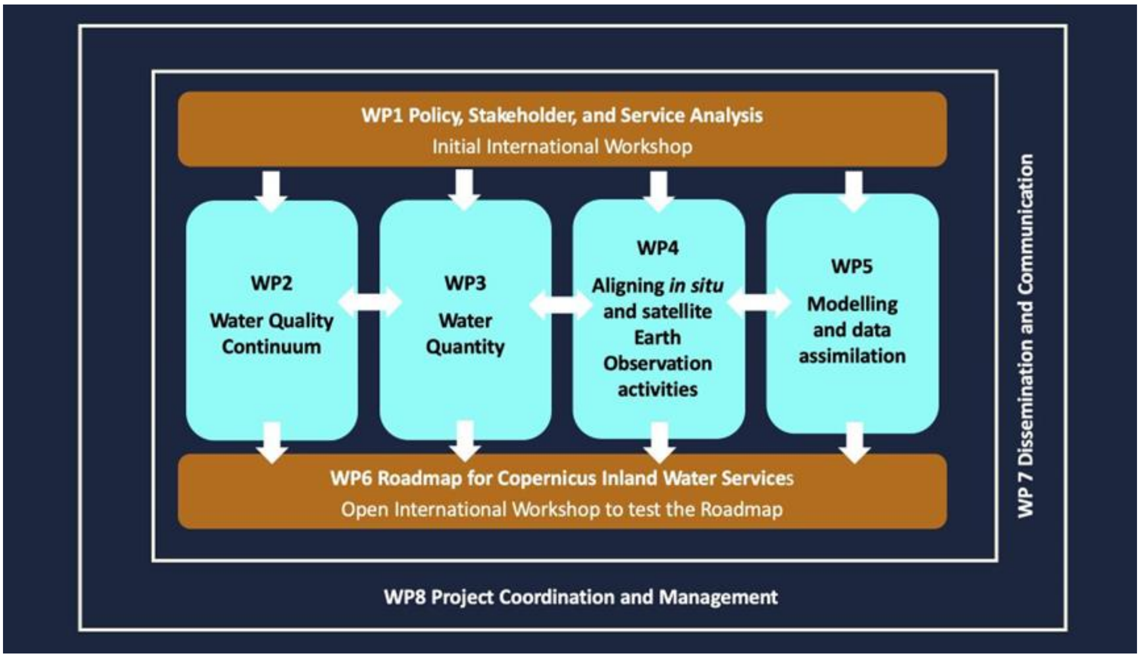

Figure 1.- Organizational structure of the different work packages in the Water-ForCE project

2.2 WP4 overall aim and expected impact

The overall aim of WP4 is to align the **in situ and Earth Observation (EO)** communities to improve products, and to deliver a wide range of water quality and water quantity products to research, industries, policymakers and statutory monitoring bodies. The expected impact is to maximize the interaction with non-satellite EO communities of the inland water domain.

WP4 has six tasks and two milestones, as shown in the table below. The tasks and milestones are closely linked and together provide input to the Roadmap.

Task	Deliverable
T4.1 Identifying in situ networks	D4.1 An international “live” working group for in situ and satellite EO monitoring
T4.2 Strengthening the in situ component of Copernicus for calibration and validation	D4.2 SOPs for the in situ networks and data-intensive monitoring devices

T4.3 Data integration within and between observation networks	D4.3 Report on best practices for combining in situ and earth observation data
T4.4 Integration of alternative data sources	D4.4 Report on recommendations for the uptake of alternative monitoring methods
T4.5 Innovative combinations of existing in situ sensors to provide higher level biogeo-chemical products for lake monitoring, research and management	D4.5 Factsheets outlining the potential new higher-level products
T4.6 Standardization and open science	D4.6 Guidelines to enable interoperability of in situ networks and connection with GEOSS
Milestone 1	MS4.1 - Workshop of in situ data networks for satellite cal/val working group
Milestone 2	MS4.2 - In situ data collection, calibration and validation recommendations for the Roadmap

Table 2.- Overview of WP4 tasks and deliverables

2.3 Objectives and approach of Task 4.4

The Task 4.4 ''Integration of alternative data sources'' aims to identify possible integration between satellite remote sensing data streams and in situ data networks to complement or validate EO-based products. Under this task, we aim to identify and synthesize existing research and technology which can be used to generate data that can be used for the validation of EO-based products related to water quality and quantity. This task also aims to provide recommendations on how to better use these alternative methods of data collection.

We carried out extensive literature/online research to identify alternative sources of water quantity and quality variables as well as radiometric variables for inland waters and evaluated their limitations for EO-based products validation. We provide a list of existing alternative methods and evaluated their usability with the experts involved in the "In situ calibration and validation of satellite products of water quality and hydrology'' (18, 19 and 20 May 2021) and during the "Citizen Science for the CAL/VAL of satellite aquatic products" workshop (11 October 2022). We have identified and engaged with key related projects and international organizations/initiatives to better understand requirements, needs and opportunities with regards to alternative data sources for validation of EO water related products. This information was collected though:

- Water-ForCE workshops and other activities (e.g. webinars) where key international organizations and representatives of global initiatives were invited.
- Engagement with other projects (H2020 Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries - MONOCLE, Copernicus Observations In Situ Networking and Sustainability - COINS, H2020 Copernicus Cal/Val Solution project - CCVS)
- Active engagement (memberships, stream works etc.) with international initiatives and relevant communities (e.g. Global Lake Ecological Observatory Network - GLEON, EU Citizen Science Community).

The outcomes from this task feed directly into WP6, the Roadmap for Copernicus Inland Water Services.

3. Alternative data sources

In this report we will use the term "alternative data sources" as to methods which are not currently being used for getting in situ data for satellite products calibration and/or validation or routinely assimilated to improve or complement RS products.

The requirements for *in situ* data for validation of satellite-based data products relating to water quantity and water quality currently produced across the Copernicus services were recently evaluated in the report "Hydrological In Situ Data Requirements and Availability" (Fry et al. 2019). In this report, availability and limitations of the available in situ data were summarized and the use of alternative methods to collect *in situ* data was highlighted as a possible solution to enlarge the data availability. Here is the list of alternative data sources listed in this report:

- Unpiloted Aerial Vehicles (UAVs)
- Citizen Science
- Real time data from deployed sensors
- The use of National and Regional data

In the same line, a recent report entitled "Lake Water Quality In-Situ Data Requirements and Availability" (Carvalho et al., 2021) showcased the use of Citizen Science for collecting valuable information for satellite products validation. In this report, it was also highlighted the need for using existing data in global networks like the GLEON.

Furthermore, through the workshops and diverse interactions with experts organized along the Water-ForCE project, several user needs related to Copernicus Services for water were identified, that can benefit from the uptake of alternative data sources regarding the main advantages that they can show in synergy with satellite RS.

During the dedicated WP4 and WP2 expert workshop ¨In situ calibration and validation of satellite products of water quality and hydrology¨, the experts were asked about whether some data sources could add value to satellite calibration and validation, including some alternative data sources (Figure 2). Among the alternative sources, Citizen Science and UAV acquired data were considered "extremely or very valuable" above the median value for all the options. More specifically Citizen Science through official programs and UAV with commercial hyperspectral and multispectral sensors or with built-in imaging sensors were the most valued. When these same experts were asked if they would be willing to use the emerging technologies listed in the previous question to carry out in situ monitoring and/or for satellite calibration/validation, 68,75% of the respondents answered to be definitely willing to use them. These results showed a high potential among the experts and research community to uptake these data sources to improve the RS products they are using or developing. Interestingly enough, the most reported reasons for not using these data were the needed funds and the cost of the technology on the one hand and the doubts about data accuracy and lack of Quality Assurance/Quality Control (QA/QC) of the data on the other.

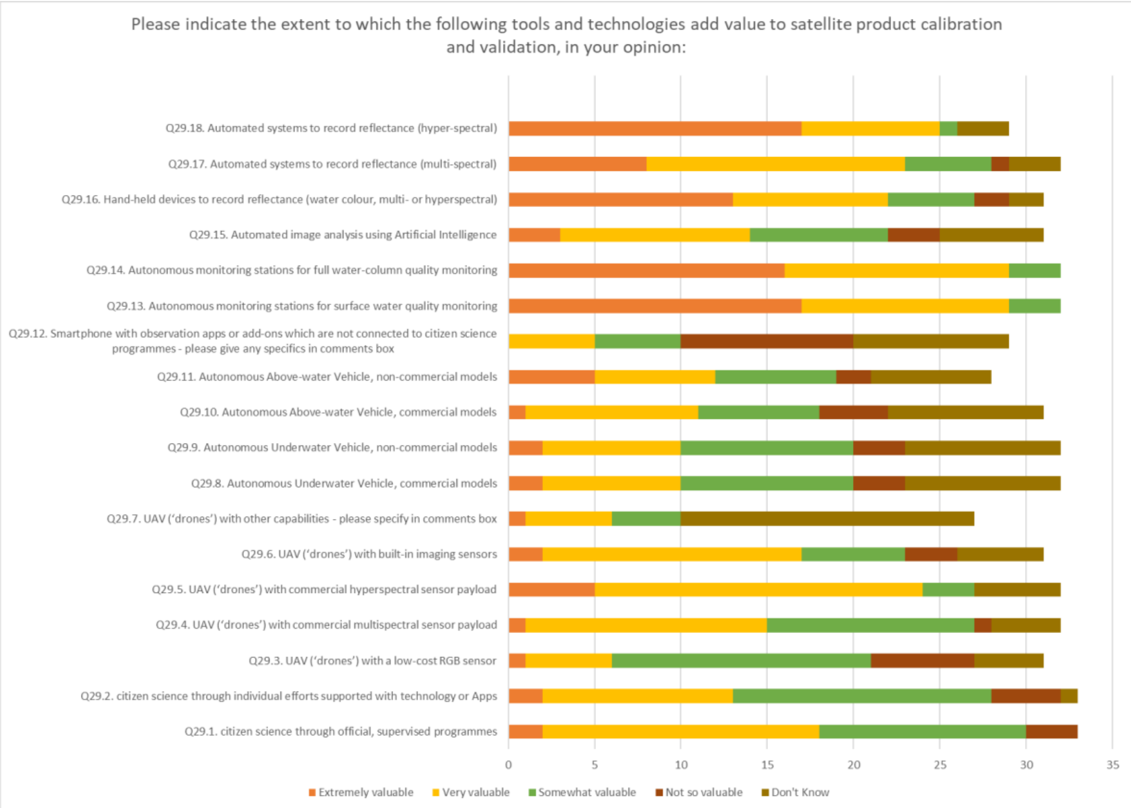

Figure 2. Answers to question 29 of the pre-workshop questionnaire of the workshop ¨In situ calibration and validation of satellite products of water quality and hydrology¨.

3.1 Unpiloted Aerial Vehicles (UAV)

3.1.1 Introduction

"Unpiloted or unmanned Aerial Vehicle" (UAV) and "drone" are the most commonly used terms to refer to a class of aircrafts that can fly without the onboard presence of a pilot. Also known under various other different names and acronyms, "Unmanned/Unpiloted Aerial System" (UAS), ''aerial robots'' or "Remotely Piloted Aircraft System" (RPAS), these systems consist of the aircraft component, the sensor payload and a ground control station. They can fly autonomously controlled by onboard electronics using a pre-planned flight scheme or via direct control from the ground.

One of the most recent classifications of UAVs (Yang & Pei, 2022) divides them into the following categories:

- Based on the wing type: fixed-wing, rotary-wing, flapping-wing UAV.
- Based on the weight: micro (< 1 kg), miniature (1–25 kg), and heavier (> 25 kg) UAV.
- Based on the flight endurance/range: short (< 5 h, < 100 km), medium (5–24 h, 100–400 km), and long/range (> 24 h, > 1500 km).
- Based on the maximum flying height: low altitude (< 1 km), medium altitude (1–10 km), high altitude UAV (> 10 km).

The fast advance of this technology and the miniaturization of the sensors, has enabled the use of UAVs for diverse applications, depending on the selected payload. The initial environmental applications fell in the monitoring of vegetation, including crop health monitoring in agroindustry and forestry but also in geology and species distribution (see Colomina & Molina, 2014 for a comprehensive review) and more recently in water-related applications (eg. Flynn & Chapra, 2014; Su & Chow, 2015; Shang et al, 2017; Becker et a., 2019; Cillero et al., 2020; De Keukelaere et al, 2021; Isgró et al., 2022).

Focusing on water related research and applications, a Web of Science (WoS) literature search based upon different key word combinations matching in, showed that UAV technologies for water applications have raised to a high level, becoming a new and really used data source.

The literature search was based upon the following keyword combinations:

1. (“Drone” or “UAV” or “UAS”) & “water”
2. (“Drone” or “UAV” or “UAS”) & “water” & (“Quantity” or “level”)
3. (“Drone” or “UAV” or “UAS”) & “water” & “Quality”
4. (“Drone” or “UAV” or “UAS”) & “water” & (“Chlorophyll” or “phytoplankton” or “bloom”)
5. (“Drone” or “UAV” or “UAS”) & “water” & (“phycocyanin” or “cyanobacteria” or “HAB”)
6. (“Drone” or “UAV” or “UAS”) & “water” & (“Total Suspended Solids” or “TSS”)

7. (“Drone” or “UAV” or “UAS”) & “water” & “Turbidity”
8. (“Drone” or “UAV” or “UAS”) & “water” & (“Organic matter” or “organic carbon” or “CDOM”)

The first search clearly shows the expected sharp rise in the use of UAV technology for water-related applications, appearing in the beginning of 21st century and acquiring a maturity level as a research technology from 2015 onwards, showing a steep and maintained increase since then, reaching a total number of 3.050 publications up until 2022 (Figure 3).

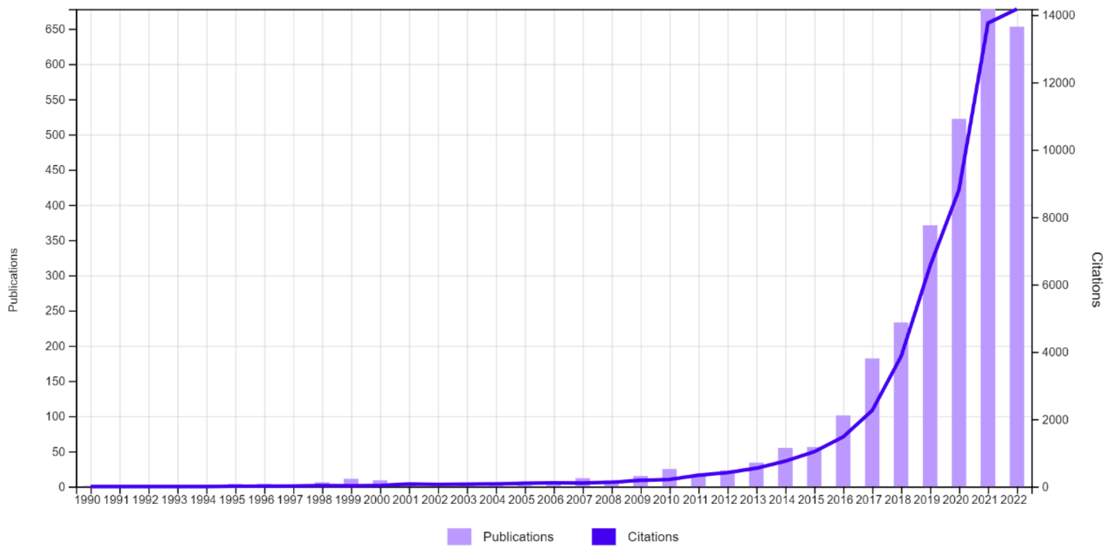

Figure 3. Results for the literature search 1. (“Drone” or “UAV” or “UAS”) & “water”.

Regarding the applications, the publications related to water quantity are more than those dedicated to water quality with a total number of 755 against 567, both starting to increase significantly from 2010 onwards. Inside of this last group, the application with more publications in the field is chlorophyll/phytoplankton detection and monitoring (289).

The main reasons for this sharp increase in their use are mostly related to some important advantages compared to satellite and airborne RS. Two of the main limitations that affect the systematic or periodic monitoring of aquatic ecosystems through optical satellite remote sensing are: on the one hand, the presence of clouds and atmospheric effects, which can leave the managers of water bodies without information for extended time periods, and on the other hand, the spatial resolution of sensors on board satellites, which limit their use for small targets.

Multispectral sensors on board satellites for water applications are mainly designed for ocean water monitoring (e.g., MODerate resolution Imaging Spectroradiometer (MODIS), Medium Resolution Imaging Spectrometer (MERIS) or Ocean and Land Colour Instrument (OLCI)) and their coarse spatial resolution is lower than that required to monitor small systems. It is for this reason that the sensors currently employed for the monitoring of small to medium sized coastal and inland water bodies are sensors initially designed for terrestrial applications as Sentinel 2 MultiSpectral Instrument (MSI) and Landsat 8 Operational Land Imager (OLI).

The main advantages that the UAV technology offers in the field of aquatic RS are: the possibility of overcoming the cloud cover; an increased temporal resolution, offering the flexibility of being deployed almost at any time (except with high wind or rain) and the ability of acquire images at very high spatial resolution (VHSR) (centimetric to millimetric). All these advantages make them an extremely useful tool for water related applications, allowing the monitoring of small water bodies and rivers and being able to capture fast changing and patchy events like Harmful Algal Blooms (HABs).

As with the multispectral sensors on board satellites, the commercial technology currently available for sensors that can be boarded on UAVs is not specifically designed for aquatic but for terrestrial applications, mostly for precision agriculture. Hence, the design of the sensor spectral bands is not ideal, but theoretically they can be used for some aquatic applications (eg. Arango & Nairn, 2020; Cillero et al., 2020, Gray et al., 2022). Hyperspectral sensors, already available as commercial UAV payload, are the future to overcome these limitations while the scientific community is advancing in the integration of hyperspectral Visible to Near InfraRed (VIS-NIR) spectroradiometers on board drones to capture point reflectance - Remote Sensing Reflectance (Rrs) - measurements (Shang, et al., 2017; Becker et al., 2019; Cillero et al., 2022; Li et al.2022) as an alternative data source with the potential to identify certain HABs at species level (Li, et al., 2022), help in the validation of atmospheric correction or monitor extreme events (Cillero, et al., 2022)

3.1.2 UAV data and the Copernicus Services

From the Remote Sensing point of view, the data taken from drones can be considered as RS products on their own or either classified as *in situ* data if they are gathered to be used to complement, calibrate or validate satellite RS data and products.

The Copernicus Services rely on environmental measurements collected from ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data, collectively referred to as *in situ* data, as it is described in the official description of the Copernicus *in situ* Component. These data are used for production and validation of Copernicus products and are also provided to users as observations in their own right.

In situ data are then mostly uptaken, in the framework of the Copernicus Programme, to calibrate, verify and supplement the information provided by satellites, which is essential in order to deliver reliable and consistent data over time. This also includes new and novel sources of *in situ* data, such as from sensors and imagery gathered by UAVs.

As we have pointed out, UAVs carrying different sensors can act as stand-alone solutions and sources of data for many purposes, but in the context of this deliverable we will focus in exploring the synergies that this type of data can have with the Copernicus Programme, which basically means what synergies can or should be found with Satellite RS (calibration, validation or complement of Satellite RS data).

In a review article by Álvarez-Vanhart et al. (2021) about UAV and satellite synergies for optical remote sensing applications, this synergy is considered essential and needed to bridge the gap between the abilities of EO systems and the data needs of different application fields.

The authors consider different strategies to establish synergies between both RS technologies: data comparison, multiscale explanation, model calibration, data fusion and data calibration. The weakest synergy is the data comparison because both data types are not combined or allow to improve the interpretation, while the rest of synergistic approaches either improve the data interpretation or its quality. “Data fusion” is considered by Álvarez-Vanhart et al. (2021) as the strongest synergy because it tries to use the features of each data source fully to create new data, complementing and magnifying the potentials of *in situ* and satellite data.

According to these strategies, three types of roles can be defined for UAV data (Álvarez-Vanhart et al. (2021):

- **Explanation of satellite data.** Provides complementary data (e.g. VHSR or DSM) to reveal inaccessible details or unseen from space or on the ground.

- **Validation of satellite data.** UAV data is used as "ground truth" (or "drone truth"). Relies on UAVs' ability to explain satellite data.
- **Completion of satellite data.** The role of UAV data in this case is to fill gaps in satellite data: fill temporal and spatial gaps in satellite time-series caused by different circumstances, for example cloud cover.

UAVs have been also highlighted as a new data source with a high potential to be used inside of Copernicus Programme in other dedicated projects. Specifically, in the H2020 CCVS, this technology is mentioned inside of the description of their proposed CAL/VAL solution (Deliverable 3.6. Clerc, et al., 2022). In it, an overview of the current organization of the CAL/VAL within the Copernicus project is provided, along with a global assessment of its maturity and a formulation of a number of recommendations.

UAV data is taken into consideration as a data source for CAL/VAL and enters the proposed solution as a cross-mission recommendation. The H2020 CCVS project highlights, inside of the optical component, the need for an operational, hyperspectral, surface reflectance measurement network covering, among other targets, coastal and inland waters. Hyperspectral instruments mounted on UAVs are considered potential technical solutions inside of this network, but still lacking an operational maturity.

It is also mentioned in this deliverable (Deliverable 3.6. Clerc, et al., 2022) inside of the CAL/VAL methods for surface reflectance, that the development of UAV-based reflectance measurements is an opportunity to evaluate the correction methods applied to correct atmospheric, angular anisotropy and adjacency effects, encouraging to support initiatives like the Surface Reflectance Intercomparison Exercise for Vegetation (SRIX4VEG).

UAV-based measurements are considered by Clerc et al. (2022) as a technology that should play a major role in the future of satellite CAL/VAL activities, by complementing automatic measurements *in so far as:*

- *They can provide additional characterization of instrumented sites (e.g. spatial homogeneity) and support intercomparison between sites*
- *They can be used on sites where a systematic instrumentation is not available or not possible.*

Regarding existing platforms and sensors which could be used for validation activities for different type of missions. The CCVS project recommends initiating Research and development (R&D) studies for the different Sentinel parameters addressing:

- *Identification of the most suitable sensors for validation activities*
- *Sensor characterization and calibration protocols*
- *Uncertainty budgets taking into account UAV geometric uncertainty*
- *Satellite-UAV intercomparison methodologies*
- *Comparison between UAVs and ground-based measurements*

3.1.3 State of the art. Data acquisition.

The increasing importance of UAV data acquisition in water-related applications can be derived from the information given in several comprehensive reviews about the role of this new source of data in water science and research; from those focused on fluvial applications (Rhee et al., 2017; Carrivick et al., 2019; Tomsett & Leyland 2019) to algal bloom research (Kislik et al., 2018; Wu et al., 2019) or related to the overall field of hydrology and water resource research (Vélez-Nicolás et a., 2021). This deliverable will not go again through all the information already given in these reviews, but will highlight the uses of this alternative data source which are being currently explored by the research community and have the potential to be integrated in the Copernicus *in situ* component to cover the identified needs in the current Copernicus Services.

Several studies have worked in deriving optical water related parameters using UAV imagery or hyperspectral point measurements using a variety of either multispectral or hyperspectral imagers that measure light at discrete wavebands in the VIS-NIR spectrum. With these technologies, the primary output is Rrs as the main objective or as input data in a workflow to derive higher level water-quality parameters. On the other hand, they can be used to obtain photogrammetric outputs using Structure from Motion (SfM) to derive fluvial/lake morphology or supported by active remote sensing technologies (ie. LiDAR) can be used to derive water quantity related parameters (eg. water level, bathymetry) (See Table 2)

Payload	RS Technology	Data/Variables	References (example)
RGB camera	Passive. Optical	Phytoplankton pigments. Chla.	Su & Chou (2015).

		Submerged vegetation	Flynn & Chapra (2014)
		Bathymetry	Woodget et al (2014); Entwistle et al. (2019)
		Flood event characterization	Forbes et al. (2020)
Multispectral camera	Passive. Optical	Rrs, Chla, turbidity, TSS	Choo et al. (2018); Cillero et al. (2020), Windle & Silsbe, (2021);
		Bathymetry.	Rossi et al (2020)
Hyperspectral camera	Passive. Optical	Rrs, chla, phycocyanin, turbidity	Kwon et al. (2020); Zhang et al. (2020)
		Water depth. Bathymetry.	Gentile et al. (2016)
Hyperspectral radiometer	Passive. Optical	Rrs spectra, chla, turbidity, Phytoplancton species	Shang et al, (2017); Becker, et al., (2019); Li, et al. (2022)
Thermal infrared (TIR) camera	Passive. Optical	Surface water Temp. Skin Temperature.	Lee et al. (2016); Dugdale et al. (2019)
		Thermal Particle Image Velocimetry	Kinzel and Leigleter (2019)
LiDAR	Active	Water depth. Bathymetry River discharge	Mandlburger et al. (2020) Kinzel & Leigleter (2019)

Table 2.- UAVs applications summary.

Water Quality

As the UAV based imagery technologies are increasingly being used, the protocols and methodologies to obtain Rrs data of water bodies are getting refined and advanced, with nowadays studies applying different corrections to increase the accuracy of the data by correcting atmospheric effects (De Keukelaere et al., 2021), skylight, surface reflection and sunglint (Windle & Silsbe, 2021; Gray et al., 2022) and performing uncertainty analysis (Gray et al, 2021). The water quality derived parameters are mainly focused in phytoplankton pigments (mostly chlorophyll-a) turbidity and Total Suspended Solids (TSS).

The recently finished Horizon 2020 project MONOCLE has entailed a step forward in the practical use of drone data to support water quality related parameters, advancing in the definition of Standard Operating Procedures (SOPs) for the acquisition of multispectral data over water targets and including in their main results the development of mapEO water a cloud based processing workflow which transforms raw drone multispectral imagery data into water-leaving reflectance or end products as turbidity or chlorophyll-a. All the related resources are available in the MONOCLE project webpage (www.monocle-h2020.eu):

User guide: Drone data acquisition over water bodies with DJI Phantom 4 pro

User guide: RPAS: Remotely Piloted Aircraft Systems - Deployment and Operation

User guide: Micasense RedEdge-M integrated under DJI Phantom 4 pro

User guide: Drone data upload tool - Field Software

Video: Introduction to MapEO Water workflow process

Webinar: Monitoring water quality with satellites and drones

Webinar: Airborne drone-based monitoring of surface water quality

Water Quantity

The water quantity related data that can be obtained from UAV imagery or active remote sensing data are mostly related to shallow water bathymetry and water level, river discharge or flood characterization.

Regarding shallow water level and bathymetry measurements, one option is the optical modelling (Spectral depth approach or optical-empirical modelling) performed with multispectral sensors. This methodology rests upon the principle that light is absorbed as it passes through the water column and the form of this absorption follows a negative exponential function (i.e., Beer's law). The bathymetry-derived multispectral imagery methodology relates the surface reflectance of shallow coastal waters to the depth of the water, being the basic premises behind related to the difference in penetration of the electromagnetic radiation at visible wavelengths in the water column which can be reflected from the bottom at different depths. The use of passive sensor data in bathymetry is affected by water turbidity and bottom signals (Rossi et al., 2020)

Another option is the Bathymetric LiDAR, a laser-based active remote sensing system that operates in the green and infra-red region of the electromagnetic spectrum. There are several commercial options of UAV bathymetric LiDAR and successful examples in the literature applying this technology to shallow water bathymetry (e.g. Mandleburger et al, 2020) LiDAR Technology is also part of a methodology developed by Kinzel and Leigleter (2019) for computing river discharge based on data collected from small Unmanned Aerial Systems (sUAS). The authors combine a TIR sensor and a scanning polarizing LiDAR in 2 UAVs to obtain river discharge data.

In the field of flood characterization, the peak flood discharge, peak stage (maximum water elevation during the flood), and the extent of inundation (the margin of the inundated area) are the main parameters. Forbes et al. (2020) describe how widespread flood extents are commonly assessed from high-water marks (HWMs) that indicate the highest elevation reached by the water surface during a flood and measurements of the terrain surface that had been inundated; and describe how UAV coupled to RGB cameras can be used to quickly collect photogrammetric data across relatively large affected areas.

Synergies with satellite data

Nevertheless, the synergies with optical satellite remote sensing are still under explored in most of the cases, with very few studies combining both types of data, using most of them a “data comparison” approach (Rossi et al., 2020; Cillero et al., 2020; Gray et al., 2022) which is considered by Álvarez-Vanhart et al. (2021) the weakest synergy as both data types are not combined or allow to improve the interpretation.

This comparison approach can anyway be used for the explanation of satellite data, providing complementary data to reveal inaccessible details or either completion of satellite data by gap filling, temporal and/or spatial.

For validation of satellite data, UAV data should be considered “ground truth”, and for that inter-comparison exercises both with satellite imagery and ground data would be needed.

3.1.4 Limitations

Even though an increasing number of studies are advancing in this field, UAV data acquisition still has some current disadvantages or challenges for future scientific and technological research. The main challenges when using this technology for water-related applications are:

- Difficulty of mosaicking images with only water when using dedicated commercial software based upon Scale Invariant Feature Transform (SIFT) feature detector to create models from a series of overlapping photos

- Smaller swath compared to satellite, which means less surface that can be covered by the sensor
- Limited flight autonomy of the aircraft, related to the battery power supply, thus limiting the efficiency of the sampling.
- Need of dedicated atmospheric correction processors for some optical applications.
- Need of dedicated standard protocols for correcting skylight and sunglint effects.
- UAV flights have to comply with EU and country-based regulations to fly over some targets (populated areas, influence area around airports, distance from ground-based pilot).

3.2 Smartphone solutions

3.2.1 Introduction to Smartphone solutions

The usage of a smartphone, beyond its data logger capacities as an affordable and portable sensor to monitor the aquatic environment has been investigated by different European research projects starting with the European Commission 7th Framework Program (EU FP7) funded project CITCLOPS (Citizens' Observatory for Coast and Ocean Optical Monitoring - www.citclops.eu) and continued with the Horizon 2020 funded project MONOCLE (Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries - https://monocle-h2020.eu/). In Australia, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) further developed one of the CITCLOPS products which is now the Eye on Water Australia (https://research.csiro.au/eyeonwater/) which is now being used as a citizen science tool in Australia.

Additionally, to these research projects, there are some applications and tools from private companies for smartphone devices such as the HydroColor app and the GoSpectro Kit and others.

Considering that smartphones are in our daily use, the development of applications and tools to use them to monitor the environment have been increasing in the last decade. Here some of these mobile data acquisition solutions are presented as alternative methods for satellite products validation.

3.2.2 Smartphone Applications

In this subsection we are only highlighting the applications that are used for data acquisition and/or data storage. Therefore, we are excluding smartphone apps which are based on EO data to inform the population as forecast tools such as the CyanoLakes app (https://www.cyanolakes.com/) and the CyanoAlert app (https://www.cyanoalert.com/). Table 3 summarizes the main features of each selected smartphone application considering the parameters measured by the application, the coverage and the type of data storage.

App	Website	Parameters	Coverage	Data Storage
Bloomin 'Algae	https://www.ceh.ac.uk/our-science/projects/bloomin-algae	Algal bloom	UK	Cloud
Eye on Water	https://www.eyeonwater.org/	Forel-Ule and water clarity	Global	Cloud
Eye on Water Australia	https://research.csiro.au/eyeonwater/	Forel-Ule	Australia	Cloud
HydroColor	http://misclab.umeoce.maine.edu/research/HydroColor.php	Surface water reflectance,	Global	Smartphone
Lake Observer	https://www.lakeobserver.org/	Data storage of water clarity, weather, water quality	Global	Cloud
Secchi	http://www.secchidisk.org/	Water clarity	Global	Cloud

Table 3 - Smartphone application summary

3.2.3 Smartphone Tools

Similarly, to the previous subsection on smartphone applications, there are tools that have been developed for data acquisition which should be coupled to the smartphone. These external tools are able to turn the smartphone in a microscope to a spectrophotometer and can be used for the acquisition of water quality and optical data. Table 4 summarizes the main features of each selected smartphone tool considering the parameters measured by the application, the coverage and the type of data storage.

Tool	Website	Parameters	Coverage	Data Storage
EnLightenment	http://enlightenment.hw.ac.uk/seabeasts/	Microscopic images, plankton count	Global	Smartphone
GoSpectro	https://gospectro.eu/product/gospectro/	Light spectra	Global	Smartphone
iSPEX 2	https://ispex.org/	Aerosol optical thickness, surface water reflectance	Global	Cloud

Table 4 - Smartphone tools summary

3.2.4 Use of these solutions for *in situ* data acquisition

While these tools were developed mainly to be used as a tool for citizen science or educational goal (Table 5)

Smartphone Solution	Scientific Studies
Bloomin' Algae	-
EnLightenment	Wicks et al. (2017)
Eye on Water	Malthus et al. (2020), Burggraaff et al. (2022)
Eye on Water Australia	-

HydroColor	Leeuw and Boss (2018), Malthus et al. (2020), Burggraaff et al. (2022)
Lake Observer	-
Secchi	Seafarers et al. (2017), Kirby et al. (2021),
iSPEX 2	Burggraaff (2022)
GoSpectro	Silva et al. (2022)

Table 5 - Example of studies using each of the smartphone data acquisition solutions

3.2.5 Limitations of the Smartphone Solutions

- Spatial coverage – while having these applications and tools are important for the data acquisition, the acquisition is only possible if these mobile solutions are being used, and unfortunately, the popularization of these tools is still not ideal, and the data is limited to specific regions.
- Temporal coverage – few long-term datasets a few match ups with satellite passages
- Low number of parameters that are currently being measured or added in these mobile applications.
- Quality Control of the data is limited on cloud processing and some apps where data is stored within smartphones there is no quality control.

3.3 Water/Soil Sensors

3.3.1 Soil Moisture

Currently, the data used for the validation of the Soil Moisture product comes from the International Soil Moisture Network (ISMN, https://ismn.geo.tuwien.ac.at/en/) which is a network originated from a combined effort of the Global Energy and Water Exchanges Project (GEWEX), the Committee on Earth Observation Satellites (CEOS), the Global Climate Observing System - Terrestrial Observation Panel for Climate (GCOS-TOPC), the Group of Earth Observation (GEO), and the Global Terrestrial Network on Hydrology (GTN-H). While this is an extremely large dataset which probably contains the majority of useful coordinated soil moisture measurements in the world, it is possible to still use some alternative data sources.

One possible data source described by Fry et al. (2019) is the use of national monitoring programs, such as the National Soil Moisture Network (http://nationalsoilmoisture.com/) in the United States and the cosmic-ray soil moisture monitoring network (COSMOS) in the United Kingdom (https://cosmos.ceh.ac.uk/). Additionally, the European Project H2020 TWIGA (Transforming Water, weather, and climate information through in situ observations for Geo-services in Africa) developed a series of low cost in situ sensors ranging from measuring rainfall with simple rain gauges that can be locally built, smartphone applications with which citizens can take geolocated photos of crops to low-cost GNSS receivers that can monitor atmospheres vapor and provide high-resolution geolocation data (Friesen et al. 2021).

Short Name	Description
TAHMO	Low-cost meteorological stations within the TAHMO network
DISDRO	Low-cost acoustic rainfall disdrometers
GNSS	Low-cost GNSS sensors
UAV	Low-cost UAV platforms with optical and thermal sensors
VegMon	ODK-based monitoring app for vegetation status

Table 6 - Low-cost sensing technologies developed within the H2020 TWIGA Project

Also, from the H2020 TWIGA Project is the development of the Boron-based Large-scale Observation of Soil Moisture (BLOSM) system which uses a low-cost neutron detector. This system does not involve use of toxic or enriched materials, and need for advanced electronics. Instead, it uses the recent developments in silicon-based photomultipliers combined with well-known neutron sensitive materials (van Amelrooij et al., 2022). Thus, BLOSM provides a cost-effective way to measure fast and thermalized neutrons by using low-cost, non–hazardous and accessible materials and equipment. It is based on the measurement of cosmic-ray induced neutrons and on the comparison of the number of fast neutrons with the number of thermal neutrons. Fast neutrons are moderated by hydrogen atoms in the air, organic materials, and especially and primarily by water in the soil, causing the ratio between fast and thermal to be a strong indicator of soil moisture content. Nevertheless, it is important to highlight that BLOSM is still under development and has not been tested in the field.

3.3.2 Water Quality

Automated high-frequency water quality sensors are not alternative sources of water quality monitoring and have been widely used by aquatic researchers in ocean, coastal and inland waters (Laas et al., 2016). However, the use of these sensors for calibration and validation of EO products are not common due to the need of well calibrated systems, non-photochemical quenching and tidal variability corrections. These sensors can be mounted in:

- Buoys
- Underwater vehicles
- Handheld probes
- Unpiloted Boats

3.3.3 Radiometry

One of the key parameters for satellite calibration and/or validation is the remote sensing reflectance (or water leaving reflectance). However, there is a lack of data for calibration and/or validation purposes because most of the data comes from few campaigns within scientific projects (i.e. H2020 EOMORES, BONUS FerryScope, GLOBOLAKES, etc.) or from a few networks of water sites where instruments were deployed to collect data (e.g. AERONET-OC network and HYPERNETS). The Copernicus Land Lake Water Quality product is validated using various in situ datasets from the H2020 EOMORES project and from the Alg@line network through the BONUS FerryScope project (Stelzer et al., 2020).

To fill the gap of the lack of radiometric measurements, the H2020 Multiscale Observation Networks for Optical monitoring of Coastal waters, Lakes and Estuaries (MONOCLE) project developed low-cost sensors and platforms to complement satellite and in situ monitoring of inland and coastal waters. Eight systems are developed in the MONOCLE project, which include: (1) Prosumer Remotely Piloted Airborne Systems (RPAS, or 'drones'), (2) HSP-1 (3) Mini-Secchi disk (4) the Solar-tracking radiometry platform (So-Rad), (5) iSPEX 2, (6) KdUINO, (7) WISP-M, and (8) FreshWater Watch. A short description of each product is available on Table 7.

Product Short Name	Description
Prosumer RPAS drone systems	are imaging sensors to acquire water-leaving reflectance and water quality parameters.
HSP-1	radiometer that provides global and diffuse irradiance.
Mini-Secchi disk	based on the Secchi disk which can be manufactured with marine resistant materials using a 3D printer, and provides water transparency, pH and water colour through a smartphone app
Solar-tracking radiometry platform (So-Rad)	optimizes the measurement geometry of sensors, and provides azimuth viewing angle for high-frequency water-leaving reflectance from non-stationary platforms
iSPEX 2	is an optical add-on device that combination with a smartphone provides aerosol optical thickness and remote sensing reflectance
KdUINO	is a moored instrument and provides diffuse attenuation coefficient
WISP-M	is a portable instrument to provide quality controlled remote sensing reflectance with an interface to the mobile phone to initialize the measurement, send and receive data, and visualise results.
FreshWater Watch	is a citizen science methodology and provides measurements of turbidity, water colour, nitrate and phosphate concentrations and microbial pollutants for the water

Table 7 - Low-cost sensing technologies developed within the H2020 MONOCLE Project

The performance of the developed systems, sensors or platforms developed in MONOCLE project has been quantified through validation against independent field- and/or laboratory-based measurements or by comparison to existing reference instruments. The usability or deployment options of the systems were also evaluated as appropriate and can be used to collect valuable data for satellite products validation.

3.4 Citizen Science

3.4.1 Introduction to Citizen Science

Another alternative data source is citizen science which has been mentioned by previous reports as a possible data source for EO products calibration and/or validation activities (Fry et al, 2019, Carvalho et al. 2021).

Citizen science is a common term used for classifying scientific activities and practices involving the community. However, this general definition makes it open for the interpretation of citizen science to be slightly different. According to Bonney et al. (2006) citizen science is the involvement of citizens in the scientific process, where the degree of involvement varies from data collection to full involvement in research design. Another common term is "crowdsourcing" which is defined by Howe (2006) as the outsourcing of tasks to a crowd that would otherwise be too large to accomplish by a single organization. Despite the different definitions, citizen science is an emerging area of research and practice and the development of citizen science is based on the creation of standards, methodologies, theories and techniques (Haklay et al., 2020).

The involvement of citizen scientists in various water-related research projects is popular, especially in the United States where the participation of citizens in lake's associations is a common activity. This link between humans and their living environment is essential for the success of citizen science programs. One example of a long-term citizen science program is the citizen turbidity monitoring programme of Lake George, New York. This program is ongoing since 1986 was initially meant for targeting better sampling coverage of the whole lake due to limited state budget, and it has been continuously raising public awareness of the water condition and the causes of lake eutrophication (Boyle et al., 2004). However, there are very few global citizen science campaigns delivering relevant water quality data which could be scaled-up and tailored more to deliver useful data for validation of Copernicus water quality products (Carvalho et al., 2021), However, the success of a citizen science program relies on the quality of the collected data. While several studies showed that data accuracy of citizen science can meet the requirements of professional researchers (Aceves-Bueno et al. 2017, Edwards et al. 2018), very few programs have a QA/QC data assessment. The success of Citizen Science programs generally relies on a set of standards and methods to improve data accuracy and reduce data uncertainty. Some other activities can contribute to the success of a program such as: volunteer training and testing, expert verification, replication between volunteers, and statistical modelling of system errors (Kosmala et al., 2016). Another important reference for the success of a citizen science program is to follow the ECSA 10 principles of citizen science ("the 10 principles") as a summary of best practice by the European Citizen Science Association (ECSA, 2015).

3.4.2 Citizen Science Workshop

To understand how Citizen Science could be used for the validation of satellite products for water we organized a workshop entitled "Citizen Science for the CAL/VAL of satellite aquatic products" held on October 11th, 2022 (13:00 - 15:30 CEST) to discuss the following topics:

- Citizen Science Initiatives
- Citizen Science Challenges
- Citizen Science data harmonization, storing and sharing

Before the workshop, a group of experts was invited to answer a pre-workshop survey and they were also invited to participate in the workshop. The answers of the survey by the expert group and the output of the workshop can be found online in the workshop webpage (https://waterforce.eu/workshops/citizen-science) or in Ogashawara and Cillero (2022).

In this workshop we had a total number of 63 people registered and a final number of 43 participants. After the workshop, the questionnaire was opened for the attendants however only 6 participants answered the survey. The answers of the multiple-choice questions are presented below in Figures 4 to 7.

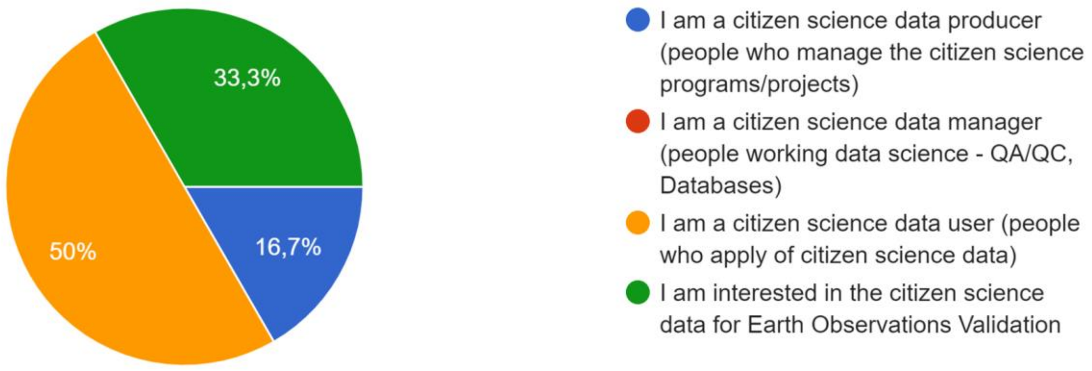

Figure 4 - Answers for the question: “What is your expertise in citizen science?”

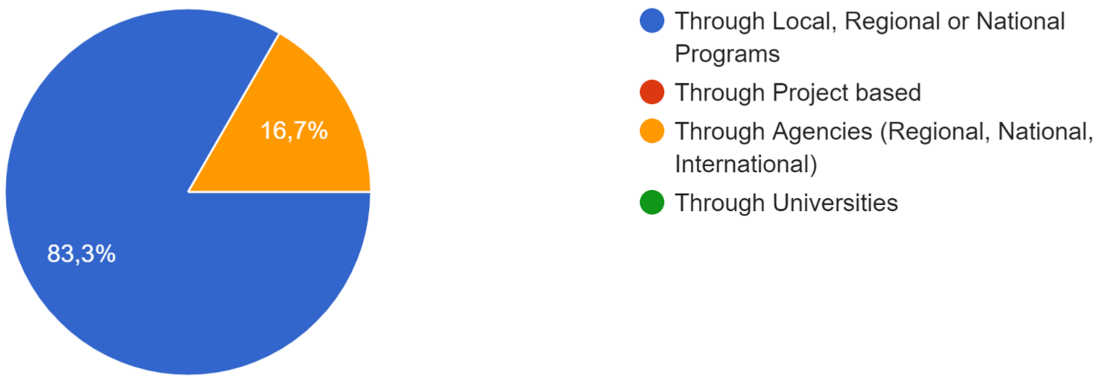

Figure 5 - Answers for the question: “In an ideal case, what is the optimal strategy to fund citizen sciences programs/projects?”

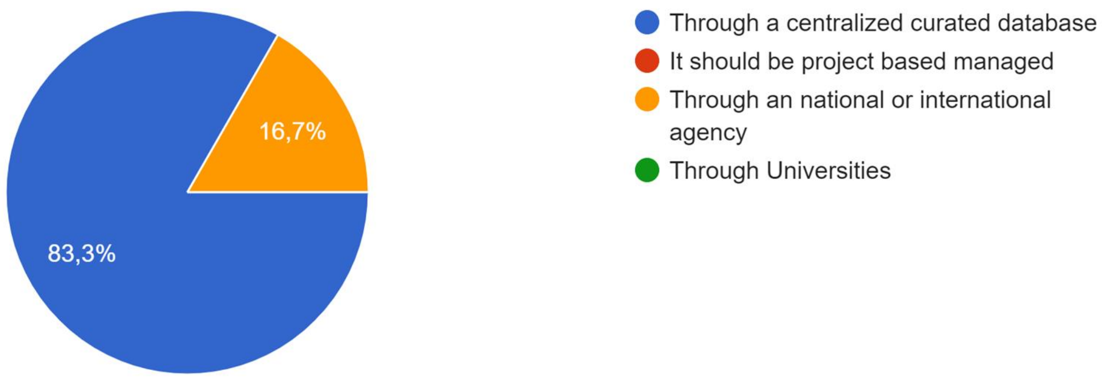

Figure 6 - Answers for the question: “How to best manage citizen science data to make them FAIR?”

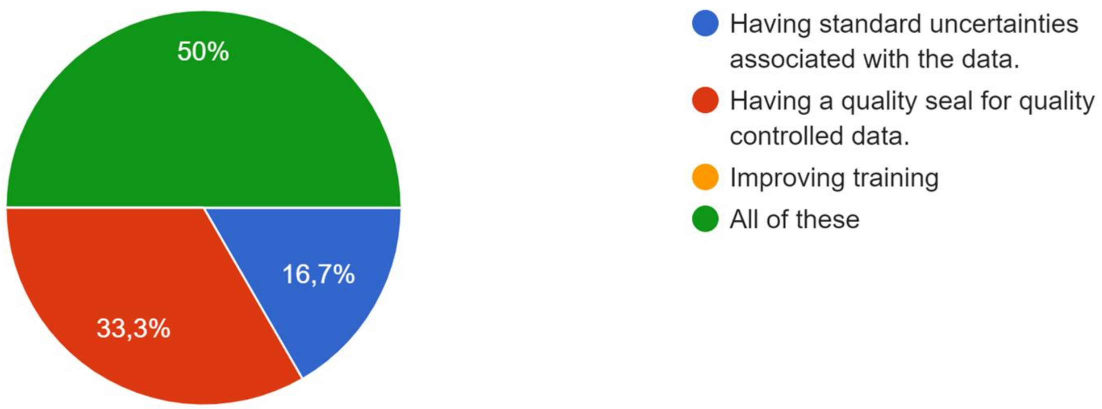

Figure 7 - Answers for the question: “How to make the data reliable?”

3.4.3 Benefits of Citizen Science

- Cost-effectiveness of data acquisition
- High spatial and temporal coverage (depending on the framework)
- Facilitates the observation of otherwise difficult to quantify phenomena
- Public engagement (governance of the commons)
- Promotes education - especially environmental education.

3.4.4 Limitations of Citizen Science

- Long term funding is limited and some initiatives are not prolonged.
- Data does not follow a standard format.
- Limited variability of the parameters monitored by Citizen Science projects which could be used for EO products calibration and/or validation.
- Most citizen science programs do not have a curated database.
- Data generated in citizen science programs are not quality controlled.
- More engagement and promotion are needed to showcase these initiatives.
- Better scientific communication is needed to address the general public.

4 Potential use of alternative Data Source in the Copernicus Program.

The work of other Water-ForCE WPs was also used to identify needs and gaps that could be covered or improved with new data sources. The WP1 (Policy, Stakeholders and Service analysis) had the goal of identifying key users within the different public domains and business sectors and to evaluate whether current operational services can meet policy goals. In the deliverables 1.4 and 1.5 the main end users' needs were identified and the subsequent innovation needs and opportunities both for the upstream and downstream sector. These innovation needs and business opportunities for EO in the water sector, are informed by the emerging user needs described in D1.4 from across the application areas, especially those categorized below as "Evolving needs for new products and services". In WP1 work it was found that the identified needs and opportunities from the EO downstream sector correlated well with the views expressed by industry experts.

The work done inside of the technical WPs of Water-ForCE has also helped to identify other needs, related to Copernicus Services and products that could benefit from the advantages and enhanced capabilities offered by alternative data sources. Below, there is a summary of the needs that could benefit from these new data streams, either identified by WP1 or by the Technical WPs (WP2, 3, 4 and 5) during their interaction with experts and users through workshops, webinars and meetings:

Evolving users' needs: New Copernicus Products/Services

- Regular information on rivers dynamics and especially on river runoff, interfaces with seas/oceans
- Water quality and water levels (quantity) not only on major lakes, but also in smaller reservoirs and rivers at much finer scale
- Better resolution of the algal community structure and plant biomass.
- Monitoring of fast-growing water plants and algae
- Dedicated services for water level, altimetry, bathymetry
- Discrimination of permanent and temporary water bodies
- Monitoring of drinking water quality in reservoirs
- Inland waterways, canals, ditches, culverts

- Chlorophyll-a concentration in lakes and inland waters in general

Likewise, the analysis presented in D1.4 (Report with end-user needs and requirements), also highlights the upstream requirements of the water sector through their synthesis of ‘Sensor requirements and capabilities’, which can be considered the opportunities for the Copernicus Program. Some of the expressed sensor requirements can benefit from alternative data uptake:

Sensor Requirements and Capabilities

- Increased resolution (sub 1m) in order to identify smaller inland water bodies and provide information on hydromorphology of rivers
- Revisit frequency should be as high as possible: daily in reservoirs/dams, weekly on lakes/rivers, monthly on coastal
- Wider collection of hyperspectral radiometry
- Hyperspectral data for water quality, algal blooms, and shallow water

Specifically, in WP2, some more needs were identified related to Atmospheric Correction of satellite optical sensors (Deliverable 2.3):

- Need for more open in situ data and tools to characterize uncertainties in Atmospheric Correction due to algorithm, sensor, water type, observation angle, adjacency effects, atmospheric composition (need high data volume, transects to untangle effects)
- Need for round-robin intercomparison exercises for Atmospheric Correction (including adjacency effect correction validation using in situ data) for different atmosphere and water conditions.

WP1 developed also a framework which allows to have a high-level overview of how the requirements identified within all WP1 tasks (user, missions, Sustainable Development Goals - SDGs) can be met by EO and Copernicus data and services, either alone or with complementary data from drones, in-situ and citizen science, so this deliverable is a complementary source of data for the framework developed by WP1. In the previous sections we have explored some of the alternative methods for in situ data collection and described them regarding their potential as a source of data inside of Copernicus Program. In table 7 we summarized and described this potential by pairing the advantages offered by the alternative data sources to the needs expressed by experts and users and still not met by Copernicus Services.

Identified Need	Alternative Method	Advantage of the alternative data source: Temporal Res.	Spatial Res.	Spectral Res.	Flexibility	Technology readiness: UAV	CS	SPS	S
Evolving users' needs: New Copernicus Products/Services									
Regular information on river's dynamics. River runoff, interfaces with seas/oceans	UAV,CS,S	X	X	X	X	AR	AR		C
Water quality and quantity. Smaller water bodies at much finer scale	UAV,CS,SPS,S	X	X	X	X	C	AR	C	C
Better resolution of the algal community structure and plant biomass.	UAV,CS,S	X	X	X	X	BR	BS		C
Monitoring of fast-growing water plants and algae	UAV,CS,SPS,S	X	X	X	X	AR	AR	C	C
Dedicated services for water level, altimetry, bathymetry	UAV,S	X	X		X	C			C
Discrimination of permanent and temporary water bodies	UAV,CS	X	X		X	C	AR		
Monitoring of drinking water quality in reservoirs	UAV,CS,SPS,S	X	X	X	X	C	AR	C	C
Inland waterways, canals, ditches, culverts	UAV,	X	X		X	C			C
Chlorophyll-a concentration in lakes and inland waters in general	UAV,CS,SPS,C	X	X	X	X	AR	AR	C	C
Sensor Requirements and Capabilities									
Increased resolution (sub 1m) in order to identify smaller inland water bodies and provide information on hydromorphology of rivers	UAV,CS		X		X	C	AR		
Revisit frequency should be as high as possible: daily in reservoirs/dams, weekly on lakes/rivers, monthly on coastal	UAV,CS,SPS,S	X			X	AR	AR	C	C
Wider collection of hyperspectral radiometry	UAV,CS,SPS,S			X	X	BR	BR	C	C
Hyperspectral data for water quality, algal blooms, and shallow water	UAV,CS,SPS,S			X	X	BR	BR	C	C
Atmospheric Correction of satellite optical sensors									
Open in situ data and tools to characterize uncertainties in AC due to algorithm, sensor, water type, observation angle, adjacency effects, atmospheric composition	UAV,SPS,S	X	X	X	X	BR		C	C
Round-robin intercomparison exercises for AC (including adjacency effect correction validation using in situ data) for different atmosphere and water conditions	UAV,S	X	X	X	X	BR			C

Table 7. Summary table on Identified needs inside of Copernicus Programme that can benefit from the uptake of alternative data sources. Res.: resolution. UAV: Unpiloted Aerial Vehicle; CS: Citizen Science; SPS: Smarthphone Solutions; S: Sensors. Technology readiness: BR: Basic Research, AR: Advanced research; C: Commercial.

5 Data Management of these alternative data sources

For the alternative data sources for calibration and validation of EO products, the data management is one of the main issues among all evaluated alternative data sources. Based on the literature, workshops and interviews within the work in the Task 4.4, there is a lack of a centralized curated database for any type of *in situ* data which could be used for EO products calibration and/or validation. For alternative methods this issue is even bigger once there is no infrastructure already established for the data acquisition, data storing and data sharing. For example, the use of UAV for monitoring water quality: 1) just recently an SOP was developed for the data acquisition of multispectral sensors (De Keukelaere et al., 2021); 2) there is not a database for the storage of images collected by UAV which could be used for calibration of satellite data (Clerc et al. 2022); and 3) the UAV data is usually not public shared also caused by the lack of a platform that allow data sharing of UAV imagery.

Within WP4, there are different tasks related to data management of *in situ* data that can be used for EO products calibration and/or validation. One of the tasks is highlighting the need for common standards and interoperability arrangements (see Deliverable 4.2) which is a way to ensure that the data and information coming from different origins and types are comparable and compatible. This is important for all alternative data sources however it is particularly important for smartphone solutions and citizen science programs which have no available SOP yet. Another need is a centralized and curated database for the alternative data sources. While some smartphone solutions have some level of data curation, most of the other data sources do not have a database and data curation. Deliverable 4.3 is highlighting the main features of a database of in situ data for calibration and/or validation purposes. In terms of data sharing, it should be based on commonly accepted principles for data and information management, such as the FAIR principles or the GEOSS Data Management principles, both of which emphasize Findability (or Discovery), Accessibility, Useability, Interoperability and preservation (see Deliverable 4.6 for more information).

The use of these alternative data sources can also lead to larger volumes of data. To ensure that data are open and accessible, and their long-term storage, management and secondary use are not dependent on institutional support, there is a need for open data management and storage services. In Europe, the European Open Science Cloud (EOSC) has aimed to accelerate the deployment and consolidation of an open, trusted, virtual, federated environment in Europe to store, share and reuse research data across borders and scientific disciplines, and to provide access to a wide range of related services. Thus, the use of EOSC services to manage and store data from these alternative data sources is highly recommended and it could be explored in the recently funded Horizon Europe Aqua-INFRA Project (https://aquainfra.eu/).

Recommendations for data management of alternative data sources will follow the recommendations proposed by these other tasks in WP4. But it is important to highlight the need of data management, especially for these non-traditional data sources which are under development. Nevertheless, it is an opportunity to use the current stage of development of these data sources to implement these recommendations for the future use of these data.

6. Recommendations to the Roadmap

Table 9 summarizes the recommendations to the Water-ForCE Road Map. Recommendations are divided by type such as: Technology, Data Management, and Funding.

Type	Recommendation
Technology	Explore the potential of UAV with hyperspectral radiometers as payload to obtain surface reflectance (Rrs) measurement targeting coastal and inland waters.
Technology	Perform inter-comparison exercises between UAV, ground data and satellite data to allow these data to be used for validation.
Technology	Support the development of UAV multispectral sensors designed for water quality parameters retrieval, following the line of ocean color dedicated sensors on board satellites and new capabilities for future sensors (D2.5)
Technology	Support research focused on different synergistic approaches between UAV and satellite remote sensing: Multiscale Explanation, Model Calibration or Data fusion: which either improve the data interpretation or its quality.
Technology	Establish standard protocols for UAV data acquisition. Develop guidelines for the collection of surface reflectance validation data by drones over inland and coastal waters covering different Optical Water Types (OWTs)
Technology	Make use of the already developed low-cost sensors (H2020 TWIGA and H2020 MONOCLE) to create a large network of sensors.
Technology	Intercomparison of water quality probes are needed to access the quality of the data.
Data Management	Create a metadata standard for the different UAV derived data applications.
Data Management	Stimulate open data sharing of the data collected with alternative data sources, especially, UAV imagery and Citizen Science data.
Data Management	Development of a common standards and interoperability

	arrangements for alternative data sources
Data Management	Create a seal of quality for QA/QC data.
Data Management	Need to create a centralized and curated dataset for alternative data sources, including a portal for UAV imagery data sharing.
Data Management	Data uncertainty is needed to highlight the performance of these alternative data sources.
Funding	Need to support long-term citizen science projects.
Funding	Need to support the deployment and maintenance of sensors in areas which can be used as calibration and/or validation sites (especially for inland water).
Coordination	Stimulate the engagement to local communities and stakeholders for the adoption of these alternative data sources.
Coordination	Citizen Science Initiatives should follow the "Ten principles of citizen science" developed by the European Citizen Science Association (ECSA, 2015).

Table 9 - Summary of the recommendations for the Water-ForCE Road Map

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