Copernicus Cal/Val Solution

D4.1 - Roadmap and Sustainability Analysis

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Table of Content

1 Introduction

1.1 Scope of the document

This document analyses funding and schedule aspects of the Copernicus Cal/Val Solution.

1.2 Structure of the document

The document addresses successively:

- Existing funding sources and potential sustainability issues
- Recommendations regarding sustainability
- A possible implementation roadmap
- Conclusion

2 Current funding sources

2.1 Introduction

In this chapter we describe the sources of funding for activities relevant to Cal/Val activities, the type of activities they support, and their level of commitment to the Copernicus program.

2.2 Copernicus program

2.2.1 Cal/Val operations

The Copernicus program, funded by the European Union (DG-DEFIS), covers the main activities related to the operations of Sentinel missions. This concerns in particular:

- Sensor characterization and on-ground calibration for recurrent models
- Commissioning activities for recurrent models
- Routine Calibration, Validation and Quality Control of Sentinel core products
- Evolutions of Sentinel products and associated validation of the data reprocessings.

2.2.2 Fiducial Reference Measurements

Calibration and validation rely on the availability of and access to so-called in-situ data, including a subset called Fiducial Reference Measurements (FRM).

In-situ data are collected from in-situ infrastructures, deployed either through research programmes or Copernicus Participating States, which are usually numerous and organized in the form of networks. In-situ data are usually numerous, not always very precise and more generally used for user level data validation after calibration has been made with FRM points of reference.

FRMs are specific in-situ measurements characterised in terms of accuracy and uncertainty to act as a long-term reference, and traceable to standards and/or community best practices. They are of particular importance to provide the reference on which the calibration results can be anchored and enable delivering to users the required confidence in user level data, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission.

An in-situ data (in general terms) can be considered as an FRM, ready for operational use by Copernicus, when it meets the following criteria:

- required to determine the in-orbit uncertainty characteristics of satellite geophysical measurements via independent validation activities;
- independent from the satellite geophysical retrieval process;

- characterised by an uncertainty level which is stable and maintained in the long run;
- described by protocols, procedures and published community management practices;
- documented via SI traceability using metrology standards and/or community recognised best practices;
- accessible to other researchers allowing independent verification of processing systems.

The Copernicus programme support two very different types of FRM-related activities:

- Tailoring: Short-term development projects for measurement protocols, guidelines and processing tools, such as some "FRM4" projects led by ESA and EUMETSAT. The funding may also cover data distribution activities, e.g. for the ESA LAW and ST3ART projects, the EUMETSAT OC-DB project.
- Operations: Long-term support for operational calibration and validation infrastructures, e.g., SAR calibration transponders for Sentinel-1, Sentinel-3 calibration transponder, and funding of future central processing facilities for atmospheric composition FRM data.

The FRM activities are currently managed by ESA and EUMETSAT.

Note that not all FRM projects are covered by Copernicus funding. Some are entirely funded by ESA: e.g., FRM4AVEG, FRM4DOAS, FRM4GHG, FRM4STS, PANDONIA FRM.

2.2.3 Contribution from Copernicus Services

Other Cal/Val activities performed by the Copernicus Services are funded by Copernicus. The activities concern the evaluation and/or validation of the products generated by the services. Some of these activities can indirectly contribute to the Cal/Val of Sentinel missions. For instance, land product validation data collected by the GBOV service for the needs of the Copernicus Land Monitoring Service is also used to validate Sentinel-3 L2 products. Similarly, collection of fast-delivery ground-based data organized for and funded by CAMS also benefits the operational validation of Sentinel-5P, and reciprocally: e.g., instrumental developments in FRM4GHG will benefit CAMS and C3S.

2.2.4 Sustainability

Product data quality is recognized as a high priority for the programme. However some issues affect the sustainability of Copernicus funding for Cal/Val and other data-quality. First, these activities are competing for resources with ever expanding activities (new Sentinel missions, new products, new instrumentation and standards). Brexit is also putting a new risk on funding sources for the programme.

2.3 Other EU program

R&D activities funded by European programs have significantly contributed to the improvement of the Cal/Val of Sentinel missions. For example:

- Development of in-situ instrumentation technology in such H2020 projects as Hypernets, E-AIMS, Scarbo, etc.

- Development of methodologies for Cal/Val activities: FP7 project QA4ECV for Land and Atmosphere products, H2020 programs GAIA-CLIM, Fiduceo, etc.

- Project dedicated to improve and harmonize data quality and coordinate data collection, in particular the European Research Infrastructures (RI) like ACTRIS, ICOS, EuroArgo, JERICO, etc. can provide reference in-situ measurements for Cal/Val activities.

- Other EU programs contribution: for instance, the EMODNET project funded by DG-MARE collects several types of in-situ measurements.

There is generally a very close coordination between Copernicus and other European programmes, which provides a good visibility on the sustainability of these activities. However, the CVVS project recommends a more systematic and formalized collaboration agreement between European Research Infrastructures (RI) and Cal/Val activities.

2.4 Space agencies

2.4.1 Mission development

In the current Copernicus framework, mission development activities are funded by ESA (ground segment preparation and satellite prototype), with preparatory activities for routine operations Cal/Val funded in some cases by ESA (e.g., Sentinel-5P) or EUMETSAT (e.g., CO2M). From the point of view of Cal/Val activities, this concerns:

- Sensor pre-flight characterization and calibration
- Commissioning activities
- Development of ground processors
- Elaboration of mission and product requirements and Cal/Val plans

2.4.2 Other Cal/Val activities

The Cal/Val of Sentinel missions benefits significantly by efforts funded by European and National Space Agencies:

- R&D on ground-based instrumentation
- R&D on Cal/Val methods and software development
- Field and aerial campaigns
- Parallel Cal/Val activities led by e.g. CNES and inter-comparison with operational Cal/Val results

- Inter-comparisons with other (non-Copernicus) sensors

- Maintenance of alternative processing chains and inter-comparisons with operational processing (e.g., BIRA-IASB, CNES, DLR...)

It should be highlighted that in most cases these activities are critical for the Copernicus mission. For several Sentinel variables, the validation relies essentially or exclusively on campaigns funded by European or National Agencies (S3 OTCI, S3 FRP, S2 L2A…). Comparisons with alternative processing chains are essential to detect and correct processing anomalies, as shown by several recent examples. Inter-comparisons with other sensors are also an integral part of Calibration and Validation activities.

2.5 Member states funding

Reference data used for the validation of many Sentinel variables are directly or indirectly funded by Member States through research programs, which are not necessarily space-related (e.g. operational European Research Infrastructures like ICOS and ACTRIS). Since there is no formal commitment from member states to the Copernicus programme, the risk on long-term sustainability of these data sources is relatively high. Moreover, there is no concerted effort to close existing data gaps.

Brexit and other geopolitical circumstances may also impact the provision of reference measurements. An example is the contribution of Atlantic Meridional Transect (AMT) cruises to the validation of Sentinel-3 marine data products.

2.6 Private funding

It is worth mentioning that R&D funding from commercial companies also contribute to the improvement of the Cal/Val of Sentinel missions:

- R&D on Cal/Val methods / software development

- R&D on instrumentation/calibration technology

There is a reasonably good perspective on the sustainability of such fundings as long as private companies can expect a return on investment through future contracts on Cal/Val activities funding by Agencies. The Copernicus programme can encourage such investments by promoting inter-comparisons exercises which help improve the overall quality of methods and software. In recent years, “Cal/Val as a Service“ has emerged as a possible business model whereby technical specifications of the Cal/Val activities are left to responsibility of the contractor while only the results from Cal/Val activities are provided. This model can be applied to Copernicus activities only if traceability, interoperability and open data policies are ensured.

In the context of the New Space industry, private companies are launching and operating their own Earth Observation satellites, e.g., the GHGSat company with currently a fleet of 6 satellites in operation aiming at contributing global emissions monitoring to key markets like Oil and Gas, Coal Mining, and Waste Management. Funding perspectives for this emerging market of emissions monitoring look encouraging. Some form of collaboration with a selection of these New Space companies could benefit the Cal/Val of the Copernicus satellites, e.g., by enhancing satellite-to-satellite comparisons and by providing complementary views at higher geographical resolution than achieved with the Copernicus satellites. Nevertheless, a prerequisite is that these satellites operated by the private sector do adopt similar standards of quality, traceability and operability as in use by institutional space agencies.

2.7 International contributions

Collaboration with non-European partners has an essential role for the Copernicus programme.

- Parallel Cal/Val activities on Sentinel sensors performed by other agencies (e.g., JAXA, NASA, USGS) and inter-comparison exercises
- R&D on Cal/Val methods, elaboration of standards and guidelines
- Provision of In-situ and other reference measurements

Collaborations are managed trough different channels:

- The CEOS Working Group on Cal/Val for generic Cal/Val activities
- Specific international thematic groups such as IOOCP, IOCCG, OSTS, GOOS, etc.
- Formal collaborations agreements with the Copernicus programme are in place to secure long-term contributions from some countries for in-situ data provision.

The situation is less satisfactory for some international measurement networks which are often less sustainable (e.g. FLUXNET). Maintenance and operations of the measurement sites is rarely directly funded and must be covered by grants or research projects from various sources without long-term visibility. The lack of formal commitment also means that timely provision of data is not guaranteed, as laboratories may have conflicting priorities affecting the maintenance and servicing of the instruments.

3 Recommendations on sustainability

3.1 Subsidiarity principle and in-situ data collection in Europe

In the European Union, the principle of subsidiarity requires that decisions are retained by Member States if the intervention of the European Union is not necessary. The collection of in-situ data being a local activity, it is under the responsibility of the member states according to the subsidiarity principle. More precisely, existing in-situ data collected by member states are provided as in-kind contribution to the Copernicus programme, see Space Regulation article 27:

"(1) Member States which participate in the Programme shall contribute with their technical competence, know-how and assistance, in particular in the field of safety and security, or, where appropriate and possible, by making available to the Union the data, information, services and infrastructure in their possession or located on their territory, including by ensuring an efficient and obstacle free access and use of Copernicus in-situ data and cooperating with the Commission to improve the availability of Copernicus in-situ data required by the Programme, taking into account applicable licences and obligations."

"(7) The Member States and the Commission shall cooperate in order to develop the in-situ component of Copernicus and ground calibration services necessary for the uptake of space systems and to facilitate the use of Copernicus in-situ data and reference data sets to their full potential, building on existing capacities."

However, the collection of Cal/Val data for the Copernicus programme requires more than collecting data from existing sites:

- Measurement shall be acquired with a geographical sampling mesh optimized for Cal/Val needs
- Measurement protocols and processing should be harmonized
- Calibration consistency shall be ensured throughout the network
- Data processing, formatting, archiving and distribution should be harmonized and preferably centralized.

Moreover, initial characterization and maintenance of sensors are activities that would be more efficiently handled if performed at network level rather than at station level.

There is a striking contrast with other continent-wide environment monitoring programs like NEON[1] in the United States or TERN in Australia. These measurement networks are designed from a top-down approach, with a relatively low number of carefully selected sites sampling all the biomes of the area.

1 See NEON Science Strategy document “Enabling contiental-scale ecological forecasting” https://www.neonscience.org/sites/default/files/NEON_Strategy_2011u2_0.pdf

This dual approach can be noticed within atmospheric monitoring networks, e.g., NASA and NOAA adopting a combined top-down and bottom-up approach to the network they contribute to, while stations managed by European partners follow mainly a bottom-up approach.

The European Research Infrastructures provide a useful coordination framework because they are centrally coordinated in order to provide fully standardized data collection and centralized QA/QC and processing of the data. However, the setup and maintenance of local measurement sites remains dependent on the participation of member states. This leads to some shortcomings, for instance the spatial coverage depends on the individual participation of the member states and leads to a current under-sampling of some areas (c.f. the scarcity of ICOS ecosystem monitoring sites in the Mediterranean area, the Carpathian Mountains or the coast of the Black Sea). This has a potential impact on its usefulness for the validation the Copernicus data as some biomes are under-represented. In addition, the overall cost of the site network at European level is not optimized, as many measurements are collected on similar biomes.

A (top-down + bottom-up) coordinated ground-based observation program for the monitoring of the European environment and ecosystems, involving the Research Infrastructures and Copernicus, would increase the scientific value of collected measurements and reduce costs through optimizations and synergies.

3.2 FRM data funding

The Cal/Val strategy defined by ESA and EUMETSAT for Sentinel data products strongly relies on Fiducial Reference Measurements (FRM). Currently, FRMs are available for a limited number of variables (mostly for imaging radar and altimeters measurements). The availability of FRMs for other variables is limited by a lack of commonly agreed measurement protocols and uncertainty analysis, but also by the low operational maturity of data providers.

To support the transition to operational FRM provision, the Copernicus programme has funded some development activities such as: FRM4SOC phase 2, OC-SVC, ST3ART, TRUSTED. These activities aimed at consolidating measurement protocols and uncertainty analyses, demonstrate the collection of FRMs, develop community processors, and/or prototype data distribution services. Similar studies have been funded by ESA for other variables (e.g. FRM4DOAS, FRM4VEG, etc.).

In the future, it is expected that the funding effort for such development activities should decrease, while support for operational data collection should increase. Indeed, some support of data providers is needed to ensure the long-term, operational provision of FRMs, to cover operations, monitoring, calibration and maintenance of instruments and services. This could be done by implementing data provision service contracts with operational requirements (timeliness, availability, etc.). The contract could be issued and managed by Cal/Val entities (ESA MPCs or EUMETSAT Cal/Val teams). The data should be collected and archived in the relevant aggregating data distribution services (such as GBOV, EVDC, CMES In-situ TAC, etc.)

The Copernicus programme should transition to the support of operational provision of reference data. This requires implementing new FRM data provision contracts which could be managed by space agencies or other European entities (JRC/EEA). For some variables, European Research Infrastructures could be tasked with the provision of the relevant FRMs.

4 Implementation roadmap

4.1 Introduction

The main project recommendations are described from a technical point of view of D3.6 “Copernicus Cal/Val Solution”. The implementation scenario for these recommendations is provided in D4.2 “Reference Scenario for Implementation”. The latter document provides a synthesis table with numbered recommendations which are used in the present chapter.

4.2 Short-term high-priority actions

In this section we identify short-term actions which can be readily implemented with limited technical risk, and which are expected to have a high impact.

- **Consolidate Sentinel product data quality**: this involves the definition and implementation of global plan to provide per measurement prognostic uncertainties (R-GEN_3, R-GEN_4) and uniform time series (R-GEN_9), as well as more minor actions.

- **Consolidate calibration and characterization activities:** these actions can be readily implemented (no technical blocking point) and should provide a high return on data quality (R-GEN_5, R-OPT_22, R-ALTI_33).

- **Consolidate reference data acquisition and distribution**: this concerns both quality of the data (R-GEN_10, R-GEN_13; R-ATM_68) and operational readiness (R-OPT_25, R-GEN_71, R-GEN_10). For the latter activities, a more central role of the Copernicus In-Situ Component is recommended. This could be done by upgrading the current Copernicus In-Situ Observations Working Group. The working group could be mandated to ensure that reference data is available for all Sentinel data, elaborate a joint inter-agency action plan and monitor its implementation. To be efficient, the Working Group could be subdivided in different component (Optical, Altimetry, SAR and Atmospheric composition) and involve the relevant Cal/Val experts. Some specific cross-agencies activities could be handled directly by the Copernicus In-Situ Component under EEA leadership, for instance provision of cross-network travelling standards. Finally, the proposed international effort to certify FRM (R-GEN_11, R-GEN_12) will also help consolidating reference data provision.

- **Support current good practices**: these recommendations highlight the importance of current practices for which there is a risk regarding sustainability: R-GEN_6, R-ALTI_32, R-ALTI_45, R-ATM_74. The activities could benefit from a reinforced support from Copernicus.

- **Close reference data gaps for current** (R-OPT_23, R-OPT_24, R-ALTI_41, R-ALTI-42, R-ALTI_43, R-ALTI_53, R-SAR_56, R-ATM_66) **and future** (ALTI_36, R-ALTI-40, R-SAR_58, R-ATM_67) **Sentinel products**.

4.3 Long-term high-priority improvements

A number of recommendations aim at improving the quality of validation activities through R&D activities. A level of technical risk is involved in these actions.

High-priority actions are expected to have a major impact on the maturity of the Cal/Val processes, by addressing either **gaps in Cal/Val procedures** (R-OPT_27, R-OPT_31, R-OPT_48, R-ATM_63-65, R-ATM_54, R-ATM_72), or **low-maturity validation levels** for some important variables or performance metrics (R-OPT_30, R-ALTI_49, R-ALTI_51, R-SAR_5). These actions rely on improvement of methods and algorithms used to process calibration or validation data, or on novel instrumentation approaches.

4.4 Other activities

The reference scenario calls for other important actions, although with a lower criticality.

They concern:

- Various improvements of Copernicus data quality management processes
- R&D activities to progress on Cal/Val methods, either generic or specific to some products
- Lower priority efforts on reference data acquisition (data gaps)

4.5 Risk assessment

The main identified risks on the scenario are as follows:

- **Lack of coordination between the different stakeholders**. A critical aspect of Cal/Val activities in the Copernicus programme is that similar activities are performed by different groups (ESA, EUMETSAT, National Agencies, Copernicus Services), sometimes using the same reference data, while gaps remain uncovered. Some redundancy can be beneficial especially if results can be inter-compared in the framework of Sentinel Validation Team meetings or other ad-hoc inter-comparison exercises. However coordination is required to avoid inefficiencies (for instance duplication of reference data archiving and distribution services) and inconsistencies (if different protocols, methods or metrics are used). As a direct outcome of the CCVS project, some coordination activities have been initiated, e.g.: 3-way discussions between GBOV, ESA and the ICOS research infrastructure – Discussions with Copernicus Services about product uncertainty management. Such activities should continue in the future.

- **Impact of Brexit**. Brexit may result in a loss of expertise on Cal/Val for some data products and potentially in access to reference data.

- **Complexity**. The proposed Cal/Val solution is based on metrology principles and centered around the notion of measurement uncertainties. However, the Copernicus observation system is very complex; for most data products, the measurement equation involves many error sources and intricate correlations. This complexity may limit the ability to really achieve the goal of characterizing measurement uncertainties in a way that is effective and meaningful for data users. This complexity raises also the question of the propagation of quality information along the data production chain, from Level-0 binary units at the sensor level to higher-level information produced in a useful form for users of the Copernicus services.

5 Conclusion

The CCVS project has proposed a consistent solution to improve the quality of Copernicus data, based on observed gaps in the current status. This solution has been developed into a set of actionable recommendations with identified priorities.

The proposed implementation roadmap tries to focus on short-term and long-term high-priority actions, as well as lower-priority but still useful actions.

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