GAIA-CLIM Report

Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring:

Final review of and update to the GAID from the perspective of WP5

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Table of Contents

Introduction

The GAIA-CLIM project aims to assess and improve global capabilities to use ground-based, balloon-borne, and aircraft measurements (termed non-satellite measurements henceforth) to characterise space-borne satellite measurement systems. The work under GAIA-CLIM encompasses the following tasks:

1. Defining and mapping existing non-satellite measurement capabilities;
2. Improving the metrological characterisation of a subset of non-satellite (reference) observational techniques;
3. Better accounting for co-location mismatches between satellite observations and non-satellite (reference) observations;
4. Exploring the role of data assimilation as an integrator of information;
5. Creation of a 'Virtual Observatory' bringing together all comparison data, including their uncertainties, and providing public access to the information they contain;
6. Identifying and prioritizing gaps in knowledge and capabilities. Under its work package 6, GAIA-CLIM performs an assessment of gaps in capabilities or knowledge relevant to the use of non-satellite data to characterise satellite measurements.

It is recognized that GAIA-CLIM shall provide progress in these application areas, but not necessarily close out all potential issues and challenges. Hence, in each of the project tasks outlined above, presently unfulfilled user needs ('gaps') have been identified through an iterative process throughout the project's lifetime. This gaps assessment exercise exclusively considers gaps identified as relevant to these GAIA-CLIM project aims. The identified key user communities for whom the impact of the identified gaps would be most relevant include:

- Service providers (e.g. ECMWF for NWP, CAMS and C3S)
- Users and providers of ECV climate data records (e.g. space agencies and satellite data user communities)
- Users of reference observations
- Users of baseline network observations
- Users of the 'Virtual Observatory'

The Gaps Assessment and Impacts Document (GAID) is a living document that summarises the outcome of this collection of gaps and their proposed remedies. It further describes the gap identification process, as well as the way these findings are presented and made accessible to users, stakeholders and actors. The current set of gaps and remedies captured under the living GAID document v4 provides a firm basis for providing costed and prioritised recommendations for future work to improve our ability to use non-satellite data to characterise satellite measurements. The first draft of recommendations document[1] builds upon this careful and meticulous collection and cataloguing process to produce a set of eleven overarching recommendations for future work to close the most critical gaps identified through the life of the project

This document provides a snapshot of the gaps status as per December 2017 in relation to work package 5. It provides a third, and final, formal delivery of WP5 input to the process. The on-line 'Catalogue of Gaps' provides the latest version of the full content of the gaps and their proposed remedies. The catalogue is available from: http://www.gaia-clim.eu/page/gap-reference-list .

[1] http://www.gaia-clim.eu/page/recommendations

Input from external parties continues to be invited through the GAID website. A designated e-mail address[2] and a specific template for gap reporting is provided at the website. Further user engagement shall be achieved through a series of visits to key stakeholders through the end of 2017. This user feedback will be important in refining the GAID and ensuring its usefulness to the broader scientific and policymaker communities, as well as space agencies, international organisations, and funding bodies.

[2] Email address for GAID feedback: gaid@gaia-clim.eu

1. Summary of existing gaps for WP5

Table 1.1. Overview of the gaps identified under work package 5 under GAID V4 and their identified remedies

Gap reference/ ownership	Gap title	Remedies
G5.01	Vast number of data portals serving data under distinct data policies in multiple formats for fiducial reference-quality data inhibits their discovery, access and usage for applications, such as satellite Cal/Val	• (R1) Successful implementation of the Copernicus Climate Change Service activity on baseline and reference network data access via the Climate Data Store • (R2) Operationalisation and extension of the GAIA-CLIM Virtual Observatory facility
G5.06	Extraction, analysis, and visualization tools to exploit the potential of fiducial reference measurements are currently only rudimentary	• (R1) Operationalisation of a satellite – non-satellite matchups facility with appropriate discovery and user tools
G5.07	Incomplete development and/or application and/or documentation of an unbroken traceability chain of data manipulations for atmospheric ECV validation systems	• (R1) Propagation and adoption of metrological best practices in sustained validation activities
G5.09	Need to propagate various fiducial reference quality geophysical measurements and uncertainties to TOA radiances and uncertainties to enable characterisation of satellite FCDRs	• (R1) Implement means to provide the community with a forward radiative transfer capability or results of computations • (R2) Improved characterisation of error covariances in GRUAN measurements
G5.11	Non-operational provision of fiducial reference-measurement data and some satellite-derived products reduces their utility for monitoring and applications	• (R1) Operationalise processing and delivery for non-satellite reference measurements and satellite CDR Interim L2 products

2. Detailed update on traces for the gaps arising from WP5

G5.01:"Vast number of data portals serving data under distinct data policies in multiple formats for fiducial reference-quality data inhibits their discovery, access, and usage for applications, such as satellite Cal/Val"

No substantial changes, only a new benefit was added under Part II table: "This system would for the first time consider the full uncertainty budget involved in such a data comparison at the operational level." to the third benefit. Also removed the reference to H2020 funding as the gap is about operationalisation, which shall not be funded by research. The first remedy title has been edited to make it more self-descriptive to GAID users.

G5.06: "Extraction, analysis, and visualization tools to exploit the potential of fiducial reference measurements are currently only rudimentary "

Adapted status of gap at end of GAIA-CLIM, as well as its remedy, so they are more in line with the given timelines. As for G5.01, the reference to H2020 funding was removed as the gap remedy has no research component.

G5.07: "Incomplete development and/or application and/or documentation of an unbroken traceability chain of data manipulations for atmospheric ECV validation systems "

No substantial changes besides some textual editing to make the gap trace easier to read.

G5.09: "Need to propagate various fiducial reference quality geophysical measurements and uncertainties to TOA radiances and uncertainties to enable characterisation of satellite FCDRs"

Adapted status of gap at end of GAIA-CLIM, as well as its remedy, so they are more in line with given timelines.

Textual editing to update and adapt several sections to better describe the gap and to include current GAIA-CLIM results, such as extended the group addressed by the gap from "research" to "operational" because the evaluation of FCDRs is done by both. Also added lidar and passive microwave radiometers to the non-satellites instruments involved, because they have the potential to be used in the same way as radiosondes.

Changes to remedy title and subsequent sections, following the expanded title and text from online capability to a service that can deliver forward-calculation results. The user may not need a Graphical User Interface (GUI) to do radiative-transfer calculations online, but might be interested in the results and the collocations, which could be fetched from a data base without a GUI.

G5.11:" Non-operational provision of fiducial reference-measurement data and some satellite-derived products reduces their utility for monitoring and applications"

No substantial changes were made. The gap title was altered to be made more intuitive to the reader. Adapted status of gap at end of GAIA-CLIM, as well as its remedy, so they are more in line with given timelines. Remedy type: Changed order to “technical” and second “governance”, because this remedy describes mostly technical items;

3. Conclusions

The final review of the GAID from the perspective of WP5 has only led to marginal updates that revised the statements on the status of the GAIA-CLIM project at its end. Only for G5.09 on the need to propagate various reference quality geophysical measurements and uncertainties to TOA radiances and uncertainties to enable robust characterisation of satellite FCDRs, the remedy has been extended. As an alternative to the GUI of the Virtual Observatory that enables online radiative transfer calculations, the provision of a service that would provide results of forward radiative transfer computations for non-satellite reference measurements co-located to satellite measurements in a routine way, has been proposed. This has the advantage that this remedy would potentially be less expensive and easier to implement.

4. Annex I Updated GAIA-CLIM Catalogue of gaps for WP5

Within this section, gaps that were detailed in section 1 are here expanded to give full trace of the current understanding of the gaps including a revision of its impacts and potential remedies

G5.01 Vast number of data portals serving data under distinct data policies in multiple formats for fiducial reference-quality data inhibits their discovery, access, and usage for applications, such as satellite Cal/Val

Gap abstract:

Presently, access to high-quality reference network data and satellite data is obtained through a variety of portals, using a broad range of access protocols, and the data files are available in an array of native data formats that lack interoperability (see Gap 1.06). There also exists a broad range of data policies from open access through delayed mode restricted access. To make effective usage of the full range of reference-quality measurements, e.g., for the characterisation of satellite data, therefore presently requires substantial investment of time and resources to instigate and maintain a large number of data-access protocols and data read/write routines, as well as to fully understand and adhere to a broad range of data policies and timeliness. This is a substantial impediment to the effective usage of data for applications, such as the GAIA-CLIM Virtual Observatory or similar application areas.

Part I: Gap description

Primary gap type:

- Technical (missing tools, formats etc.)

Secondary gap type:

- Parameter (missing auxiliary data etc.)
- Governance (missing documentation, cooperation etc.)

ECVs impacted:

Temperature, Water vapour, Ozone, Aerosols, Carbon Dioxide, Methane

User category/Application area impacted:

- Operational services and service development (meteorological services, environmental services, Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), operational data assimilation development, etc.)
- International (collaborative) frameworks and bodies (SDGs, space agencies, EU institutions, WMO programmes/frameworks etc.)
- Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)

Non-satellite instrument techniques involved:

Independent of instrument technique

Related gaps:

- G1.06 Currently heterogeneous metadata standards hinder data discoverability and usability

Gap 1.06 pertains to unifying metadata format and discovery metadata, which would naturally form a component of resolving the current gap. This critical dependent gap should be addressed with this gap.

Detailed description:

The task of characterizing satellite measurements by means of comparison to reference measurements needs consistent and reliable access to data and documentation of various “fiducial” reference measurements for the analysis of the quality of satellite measurements and/or derived geophysical data products. This task can be massively complicated and time-consuming arising from the need to collect data from multiple locations also often offering the data on various types of user interfaces with which a user needs to become familiar. In many cases, data downloads do not follow specific data exchange standards, which makes it difficult to automate access to them. In addition, the available bandwidth at the provider side might be too small to serve many customers, which can result in extended waiting times for the data. This applies even more when co-located ground based and satellite data are to be offered to the user. The range of data policies that a user needs to adhere to further complicates the issue. These include timeliness of the data exchange.

A common source that integrates several reference-data networks with satellite data considering traceable uncertainty does not exist but is needed according to the GAIA-CLIM user survey. A key first step to this is consistent access to reference quality measurement systems in a harmonised data format that contains requisite discovery metadata and for which the data usage policy and restrictions are clearly articulated. Many of the existing data policies can be very different, e.g.,

- Completely open access for all users including commercial users;
- Open access for research purposes only;
- Open access after a set time delay;
- Access only upon request to PI.

Several sources for co-located data sets exist, but most of them are specialized to very particular use cases. Most are not fully utilizing the potentially available information on uncertainty or including uncertainty arising from spatiotemporal mismatch of the compared data streams. Some of the existing datasets are publically available via the internet, while others are run internally to organizations like space agencies to monitor data quality in real time. While many validation activities are performed, they do not use the available uncertainty information in an optimal way, which has resulting impacts on the quality of the research and the robustness of any conclusions drawn from such validation exercises.

In summary, the issues over data discovery and access are pervasive and inhibit their effective usage in a broad range of application areas, including satellite Cal/Val activities. The recently instigated Copernicus Climate Change Service contract C3S311a Lot3 which is concerned with access to data from baseline and reference networks may go a considerable length towards addressing this gap for non-satellite reference measurements and is discussed under remedy G5.01(R1).

Operational space missions or space instruments impacted:

Independent of specific space mission or space instruments

Validation aspects addressed:

- Radiance (Level 1 product)
- Geophysical product (Level 2 product)
- Gridded product (Level 3)
- Assimilated product (Level 4)
- Time series and trends
- Representativity (spatial, temporal)
- Calibration (relative, absolute)

Gap status after GAIA-CLIM:

GAIA-CLIM explored and demonstrated potential solutions to close this gap in the future

Some of the work within GAIA-CLIM provided unified access to a range of reference quality data products via the Virtual Observatory facility. However, this access shall not be operational and substantive further work would be required. It also will not permit universal access for other applications to integrated holdings.

Part II: Benefits to resolution and risks to non-resolution

Identified Benefit	User category/Application area benefitted	Probability of benefit being realised	Impacts
Access to reference measurements organised via a brokering system service as envisioned by Copernicus makes discovery and access easier.	All users and application areas will benefit from it	High to Medium	The one-stop-shop for the described data would become the central platform where several scientific and service oriented communities would search for such data. This can lead to significant cost reductions for research and development activities that count on the availability of such data.
Access to reference measurements co-located to satellite measurements through the GAIA-CLIM Virtual Observatory in operational mode, in particular at level 1, could boost satellite-retrieval development and	International (collaboration) frameworks (SDGs, space agency, EU institutions, WMO programmes/frameworks etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	Medium	Individual satellite retrieval developers, international retrieval round robin activities for retrieval analysis and selection, as well as climate data record quality assessments, as performed by WCRP, would save significant effort in setting

comparison.			up data bases like the ones contained in the Virtual Observatory.
An operational Virtual Observatory could be exploited as real-time Cal/Val facility for new satellite instruments at space agencies.	International (collaboration) frameworks (SDGs, space agency, EU institutions, WMO programmes/frameworks etc.)	Medium	The Virtual Observatory may provide a basic structure for real-time satellite data Cal/Val that can be reused and further developed with new programmes. This system would for the first time consider the full uncertainty budget involved in such a data comparison at the operational level.
Identified risk	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
The use of multiple locations with different set ups for data access continues to complicate work on data comparison and increases cost to delivery and analysis / exploitation of data.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	High	The limited number of users who are able to fully exploit available observations to undertake activities, such as satellite Cal/Val, reduces the intrinsic value of these data and related investments into infrastructure.
Non-satellite reference measurements will have limited value for the characterisation of satellite measurements.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High	Negative impacts on funding support for non-satellite measurements. Poorer quality assessments of satellite measurement programs.

Part III: Gap remedies

Gap remedies:

Remedy 1: Successful implementation of the Copernicus Climate Change Service activity on baseline and reference network data access via the Climate Data Store

Primary gap remedy type:

Deployment

Secondary gap remedy type:

- Technical
- Governance

Proposed remedy description:

The C3S 311a Lot 3 contract, concerned with access to baseline and reference network data, shall make considerable strides in making harmonised access to reference- and baseline-network data available under a common data model and with clear articulation of data policies that enables appropriate and seamless usage. Work is envisaged to cover aspects of data access brokering, data harmonisation, and data provision and builds upon aspects of work within GAIA-CLIM. Data shall be served via the Climate Data Store (CDS) facility of C3S. However, it is limited to accessing data from a subset of atmospheric networks and ECVs, so in the longer-term, extension to remaining atmospheric ECVs and oceanic and terrestrial ECVs would be required were these to be used for satellite cal/val.

Relevance:

The remedy would provide single point of access to harmonised data products served under a common data model. Note that rapid access, e.g. for satellite validation in the commissioning phase, is not being addressed through this remedy.

Measurable outcome of success:

Data available via the CDS and used in applications such as the GAIA-CLIM Virtual Observatory

Expected viability for the outcome of success:

High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

Copernicus funding

Remedy 2: Operationalisation and extension of the Virtual Observatory facility developed within GAIA-CLIM

Primary gap remedy type:

Deployment

Secondary gap remedy type:

Technical

Proposed remedy description:

The diverse sources of reference-quality data could be integrated with data made available through operational exploitation platforms, which could be developed for different user communities. GAIA-CLIM provides this as part of the Virtual Observatory for a set of atmospheric ECVs and the specific application of characterising satellite measurements. As a major part of the Virtual Observatory, a co-location database has been developed. The first step is to identify all pertinent satellite and non-satellite reference datasets that are of interest for a comparison to a given satellite sensor data. This could either be via a forward modelling approach to derive an estimate of the satellite-sensor data or a comparison to geophysical variables derived from the satellite data or both. The provided data need to be complemented by as complete as possible metadata and traceable uncertainty information, including comparison mismatch uncertainties that need to be derived from the comparison setting and the variability of the geophysical variable to be compared.

The Virtual Observatory has been developed to demonstrate the use of non-satellite reference data and NWP model data for the characterisation of satellite data. The Virtual Observatory integrates the different measurements, their metadata, quantified uncertainty for the measurements, and the uncertainty arising from the comparison process. Many other ECV reference measurements – satellite data combinations, e.g., for terrestrial and oceanic ECVs, are outside the scope of the GAIA-CLIM project and have not been addressed by this project. But these could be accommodated via operationalisation and extension of the service in the future. Such an operational service should involve unified access to the underlying reference quality non-satellite measurements used benefitting from proposed Remedy 1 to this gap.

Relevance:

An operational and extended Virtual Observatory facility would provide unified access to non-satellite reference-quality measurements and specific co-located data under its purview via the Copernicus CDS.

Measurable outcome of success:

Operational access to relevant measurements and colocations

Expected viability for the outcome of success:

High

Scale of work:

- Single institution
- Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- ESA, EUMETSAT or other space agency

G5.06 Extraction, analysis, and visualization tools to exploit the potential of fiducial reference measurements are currently only rudimentary

Gap abstract:

Climate research and services have an increasing need to consider a large amount of observational data and model outputs simultaneously in applications. Because the data volumes provided by satellite observations and ensemble model runs have increased to levels that prevent easy download to local compute environments, there is an enhanced need for tools that provide functionality for data extraction, analysis, and visualisation at source or on cloud compute resources. At the same time, "fiducial" reference measurements are needed to provide evidence for the quality of satellite observations and models, but the aforementioned tools to exploit the potential of such reference measurements are currently only rudimentary. This in particular includes tools to analyse and display uncertainty of comparison results due to differences caused by mismatches in space and time of data used in comparisons.

Part I: Gap description

Primary gap type:

Technical (missing tools, formats etc.)

Secondary gap type:

- Knowledge of uncertainty budget and calibration
- Uncertainty in relation to comparator measures

ECVs impacted:

Temperature, Water vapour, Ozone, Aerosols, Carbon Dioxide, Methane

User category/Application area impacted:

- Operational services and service development (meteorological services, environmental services, Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), operational data assimilation development, etc.)
- International (collaborative) frameworks (SDGs, space agency, EU institutions, WMO programmes/frameworks etc.)
- Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)

Non-satellite instrument techniques involved:

Independent of instrument technique

Related gaps:

- G5.07 Incomplete development and/or application and/or documentation of an unbroken traceability chain of data manipulations for atmospheric ECV validation systems

The tools to be developed to address this gap in the context of validation work should be based on the traceability principles and Cal/Val best practices referred to in G5.07. Hence G5.07 should be addressed before G5.06 as it represents a contribution to the latter.

Detailed description:

Services that provide data extraction, analysis, and visualization tools exist for comparisons of gridded data, but are currently only rudimentary for comparisons of satellite and non-satellite fiducial reference measurements based on data co-locations, which are needed for the validation of satellite measurements and derived products. In particular, analysis capabilities that for instance allow analysis at different time or spatial scales are missing. While measurement uncertainties are at least displayed by some existing services, e.g., the FP7 NORS project, the visualisation of uncertainty arising from differences in spatiotemporal sampling is generally not included, but is needed to fully understand the uncertainty budget of a specific comparison.

The user survey undertaken by GAIA-CLIM indicated a clear need for such a capability to be developed. But challenges remain, because whatever analysis / visualisation tool can be provided, it will not necessarily match all individual needs. The GAIA-CLIM user survey also indicated that the analysis of the co-locations provided by the Virtual Observatory may not solely be used to evaluate satellite measurements but also vice-versa, the satellite measurements may be used to evaluate the quality of the reference measurements, e.g., their temporal consistency. Such a flexible tool does not exist to date.

Operational space missions or pace instruments impacted:

Independent of specific space mission or space instruments

Validation aspects addressed:

- Radiance (Level 1 product)
- Geophysical product (Level 2 product)
- Gridded product (Level 3)
- Assimilated product (Level 4)
- Representativity (spatial, temporal)

Gap status after GAIA-CLIM:

GAIA-CLIM explored and demonstrated potential solutions to close this gap in the future:

GAIA-CLIM WP5 has developed a Virtual Observatory that addresses this gap partly for a limited set of ECVs and with several limitations concerning the representation of the mismatch errors. At the end of the GAIA-CLIM project, there will be a prototype tool that can be developed further in the future.

Part II: Benefits to resolution and risks to non-resolution

Identified benefit	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
The existence of the GAIA-CLIM Virtual Observatory allows quality assessment for satellite data and derived products with a high potential to be made operational. It can also be extended to more GCOS ECVs.	All users and application areas will benefit from it	High	The GAIA-CLIM Virtual Observatory can be used in different contexts such as validation tool for products contained in the C3S CDS, as baseline for satellite-retrieval studies and comparisons, and as a satellite Cal/Val tool in space agencies that have the capability to deal with many different sensors. These usages increase the visibility of the value of non-satellite reference measurements and make sustained funding more viable.
The data extraction capability of the Virtual Observatory allows the export of data from the Virtual Observatory in user-friendly formats.	All users and application areas will benefit from it	High	The provision of a data extraction and visualisation capability considering the uncertainty aspects of data comparison can make further developments of retrieval schemes for considered variables easier. This usage increases the visibility of the value of non-satellite reference measurements and makes sustained funding more viable.
Identified risk	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
Lack of the described tools prevents optimal use of reference measurements leading to potential issues with the justification of the measurements in the future.	All users and application areas will suffer from it.	High	Derived global products from satellite may suffer in quality from inadequate evaluation of the measurements and retrieval schemes used to generate them. This can hamper applications supporting decision and policymaking.

Part III: Gap remedies

Gap remedies:

Remedy 1: Operationalisation of a satellite – non-satellite match-ups facility with appropriate discovery and user tools

Primary gap remedy type:

Technical

Secondary gap remedy type:

- Research
- Education/Training
- Governance

Proposed remedy description:

The Virtual Observatory contains a still rudimentary data extraction capability that allows the export of co-located data from it in user-friendly, self-descriptive NetCDF format. The format also allows comparison data being amended by meta-data of the comparison, e.g., the used co-location criteria, etc., but this has not been realised within the lifetime of the GAIA-CLIM project. Such a format also supports analysis of the data in ways that may not be enabled, at least initially, in the final demonstrator version of the Virtual Observatory. Data extraction tools also are capable of sub-setting each data source contained in the co-location data base by ECV, time and location, observing system, and other boundary conditions such as surface type.

To exploit the co-location data base proposed as remedy 2 for gap G5.01, analysis tools must be developed to provide statistics and various indicators for a comparison that meet user needs as indicated by the GAIA-CLIM user survey outcomes. These analysis tools must have some flexibility, such as interchanging the reference in a comparison and the ability to perform analysis at different time and eventually space scales.

Visualisation tools need to be capable of displaying multiple co-located parameters to circumvent the complexity of comparing datasets of varying type and geometries, e.g. time series and instantaneous, spatially localised and large spatial extent observations, column-integrated observations, and vertical profiles, etc. Special attention must be paid to the specification of graphical representation of individual parameters and various uncertainty measures, including the smoothing uncertainty.

Tool development should look to benefit from existing elements and capabilities whenever possible. All developed tools need to be accessible via a GUI that also needs to be developed. GAIA-CLIM has developed a demonstrator facility with a limited number of static examples. Further development and operationalisation of the facility would be required to enable reliable near-real-time and delayed mode exploitation for a broader range of satellite instruments and ECVs.

Relevance:

The GAIA-CLIM Virtual Observatory could serve as the basis for the development of an operational tool for the Evaluation and Quality Control pillar of the C3S, if being made available after the end of the GAIA-CLIM project. Such an implementation represents an important step towards an easily accessible comparison tool that considers all kinds of uncertainty relevant for data comparisons.

Measurable outcome of success:

Developed tools for data extraction and display for co-located satellite and non-satellite measurements being accessible via an operational graphical user interface.

Expected viability for the outcome of success:

- Medium
- High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- Copernicus
- ESA, EUMETSAT or other space agency
- SMEs/industry

G5.07 Incomplete development and/or application and/or documentation of an unbroken traceability chain of data manipulations for atmospheric ECV validation systems

Gap abstract:

Recently established quality assurance and validation guidelines and systems are not sufficiently well recognised or understood in the global community, where validation purposes, methodologies, and results can differ significantly from one report to another. Harmonised practices should now be advertised and applied more universally across the community to avoid (1) missing quality indicators, (2) incoherent results between different validation exercises, and (3) unreliable results or additional methodological uncertainties due to sub-optimal data manipulations. Moreover, there is room for further improvement in validation methodologies, taking advantage of the ever-increasing breadth of measurement, modelling, and data analysis techniques.

Part I: Gap description

Primary gap type:

Technical (missing tools, formats etc.)

Secondary gap type:

- Uncertainty in relation to comparator measures
- Governance (missing documentation, cooperation etc.)

ECVs impacted:

Temperature, Water vapour, Ozone, Aerosols, Carbon Dioxide, Methane

User category/application area impacted:

- Operational services and service development (meteorological services, environmental services, Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), operational data assimilation development, etc.)
- International (collaborative) frameworks and bodies (SDGs, space agencies, EU institutions, WMO programmes/frameworks etc.)

Non-satellite instrument techniques involved:

Independent of instrument technique

Related gaps:

- G5.06 Extraction, analysis, and visualization tools to exploit the potential of fiducial reference measurements are currently only rudimentary

The tools to be developed to address G5.06 in the context of validation work should be based on the traceability principles and Cal/Val best practices referred to in G5.07. In this sense, G5.06 should be addressed first, as it represents a contribution to the remedy for G5.07 (see G5.07 gap remedy #1).

Detailed description:

In the context of sustainable Earth Observation data services, such as those in development for the Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), Quality Assurance (QA) and geophysical validation play a key role in enabling users to assess the fitness of available data sets for their purpose. User requirements, e.g., those formulated for the Global Climate Observing System (GCOS), have to be identified and translated into QA and validation requirements. In turn, QA and validation results must be formulated in the form of appropriate Quality Indicators (QI) to check and document the compliance of the data with the user requirements. Metrology practices recommend the development and implementation of traceable end-to-end QA chains, based on the Système International d'Unités (SI) and community-agreed standards (as identified for instance in the GEO-CEOS QA4EO framework).

Generic guidelines for such QA systems applicable virtually to all atmospheric and land ECVs are being developed within the EU FP7 QA4ECV project (2014-2018), while more specific guidelines developed in projects like ESA's Climate Change Initiative (CCI) and dedicated to atmospheric ECVs are being published. Generic and specific QA systems and guidelines established in those recent projects are not sufficiently well recognized or understood in the global community, where validation purposes, methodologies, and results can differ significantly from one report to another. Harmonised practices should now be advertised and applied more universally across the community.

The impacts of not adopting a traceable end-to-end validation approach are diverse. Firstly, important quality indicators may be missing in the analysis, e.g. information on spatio-temporal coverage, resolution, dependences of the data quality on particular physical parameters (e.g. solar zenith angle, cloud cover, thermal contrast, etc.). Secondly, results may be incoherent between several validation exercises on the same data set and the origin of the discrepancies be unclear due to insufficient traceability. Thirdly, methodological uncertainties in, e.g., geographical mapping, in the use of vertically averaging kernels, or in unit conversions using auxiliary data, may lead to unreliable results. Finally, all this may imply sub-optimal use of the true validation capabilities of the ground-based reference network, which means that the full potential value is not being extracted from these measurement system assets.

Operational space missions or space instruments impacted:

Independent of specific space mission or space instruments

Validation aspects addressed:

- Radiance (Level 1 product)
- Geophysical product (Level 2 product)
- Gridded product (Level 3)
- Assimilated product (Level 4)
- Time series and trends
- Representativity (spatial, temporal)
- Calibration (relative, absolute)

- Spectroscopy
- Auxiliary parameters (clouds, lightpath, surface albedo, emissivity)

Gap status after GAIA-CLIM:

GAIA-CLIM explored and demonstrated potential solutions to close this gap in the future:

The GAIA-CLIM project adds to other EU projects with respect to more ECVs and disseminates results via the "Virtual Observatory" facility but does not close the gap.

Part II: Benefits to resolution and risks to non-resolution

Identified benefit	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
Completeness of the QA and validation reports, addressing all Quality Indicators relevant for the envisaged use.	All users and application areas will benefit from it	High	Users will have access to more and better information on which to judge the fitness-for-purpose of a particular product for their application.
Homogeneity in adopted Quality Indicators and processing chains allows intercomparison of different validation studies and their results.	All users and application areas will benefit from it	High	Users can easily compare different products based on their performance in validation exercises that were performed along the same principles and with comparable metrics.
Improved reliability and minimal methodological uncertainties related to the Cal/Val processing chain.	All users and application areas will benefit from it	High	Optimal use of the reference data to gauge the quality of the satellite data sets, without unnecessary additional methodological uncertainties; Improved feedback on satellite data production, with greater detail and differentiation.
Identified risk	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
Difficulty to judge the fitness-for-purpose of satellite data products because of missing or poorly-defined Quality Indicators.	All users and application areas will suffer from it.	Medium	Users of satellite data products may refrain from using these products when they are not sufficiently characterised. This constitutes sub-optimal use of the EO system and may lead to non-realised performance of

			the services.
Difficulty to compare different validation exercises, e.g. of different products for a particular ECV.	All users and application areas will suffer from it.	High	Users are often faced with the question "which is the best data set for my application?". Without comparable validation methods and Quality Indicators applied to all candidate data sets, no reliable, informed choice can be made. This leads to sub-optimal use of the EO system and impacts negatively the application(s) envisaged by the user.

Part III: Gap remedies

Gap remedies:

Remedy 1: Propagation and adoption of metrological best practices in sustained validation activities

Primary gap remedy type:

Governance

Secondary gap remedy type:

- Technical
- Research
- Education/Training

Proposed remedy description:

The remedy proposed here consists in the composition of expert consortia under the umbrella of (and potentially with funding by) overarching bodies and initiatives (WMO, EC, space agencies). These consortia should look into the following highly related aspects of the gap:

- The development of (new) best-practice validation protocols and the corresponding documentation framework;
- The application of these protocols and guidelines in (operational) validation platforms;
- The advertising (including peer-reviewed papers, handbooks, training and courses) to validation teams and service providers.

Some efforts are already ongoing in this direction, for instance in the EC FP7 project QA4ECV (definition of a traceable validation chain and application in the "Atmosphere Validation Server" for a few ECVs), in ESA's CCI, and in ad-hoc initiatives such as the recent ISSI team "EO validation across scales" (which included GAIA-CLIM and CEOS representatives). Still, these only partially address the gap, and a much wider effort (in terms of ECVs, methods, platforms, and outreach) is required to extend, implement, and operationalise these QA4EO-compliant practices.

Relevance:

The integrated concept of the proposed remedy (including research, technical developments, education, and governance) ensures that the gap is broadly addressed. For optimal acceptance by the scientific community and the major stakeholders, the composition of the expert teams is key.

Measurable outcome of success:

Published protocols and guidelines, endorsed by the large stakeholders, and referred to in the scientific literature. Implementation of these protocols in the validation platforms supported by the space agencies, the Copernicus programme, etc.

Expected viability for the outcome of success:

- Medium
- High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Potential actors:

- EU H2020 funding
- Copernicus funding
- WMO
- ESA, EUMETSAT or other space agency

G5.09 Need to propagate various fiducial reference quality geophysical measurements and uncertainties to TOA radiances and uncertainties to enable characterisation of satellite FCDRs

Gap abstract:

Presently, the evaluation of the quality of Fundamental Climate Data Records (FCDR) (observations at radiance level that serve as key inputs for model-based reanalyses and retrievals of GCOS ECVs) is based mainly on isolated activities by individual research groups. Given the importance of FCDRs for all downstream data records, there is an important and evolving requirement to improve the assessment of FCDRs by utilising non-satellite reference measurements and model fields, among other means, for validation. The utilisation of non-satellite reference measurements for this purpose requires the use of observation operators (often in the form of radiative transfer models) to transfer the reference measurements into the measurement space of the satellite instrument. There is currently no readily accessible, maintained, online tool (except for the 'GRUAN processor' as part of GAIA-CLIM) that would enable the broader scientific and operational communities to contribute to the quality evaluation of FCDRs.

Part I: Gap description

Primary gap type:

Technical (missing tools, formats etc.)

Secondary gap type:

Uncertainty in relation to comparator measures

ECVs impacted:

- Temperature
- Water vapour

User category/Application area impacted:

- Operational services and service development (meteorological services, environmental services, Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), operational data assimilation development, etc.)
- International (collaborative) frameworks and bodies (SDGs, space agencies, EU institutions, WMO programmes/frameworks etc.)
- Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)

Non-satellite instrument techniques involved:

- Radiosonde
- Microwave radiometer
- Lidar

Detailed description:

The GAIA-CLIM user survey highlighted the need for a readily accessible radiative-transfer capability available as part of the Virtual Observatory to allow the transfer of reference measurements into the measurement space of satellite instruments. Such a tool would enable a more direct characterisation of the satellite measurements. The validation of satellite measurements in terms of the measured radiance is more straightforward than a validation of retrieved (or analysed) quantities. This is because the forward calculation from the geophysical profile is unique, whereas solutions to the inverse problem are non-unique in that several distinct geophysical profiles can be consistent with a given radiance measurement. As part of this, the uncertainty information in reference measurements needs to be appropriately transformed in the mapping (e.g. from reference measurements to top-of-atmosphere (TOA) brightness temperatures). In turn, this requires knowledge of the vertical and / or horizontal correlation structures present in the reference measurement.

The GAIA-CLIM project realised the development and demonstration of a GRUAN-processor, which is able to monitor Numerical Weather Prediction (NWP) model temperature and humidity fields relative to GRUAN radiosonde observations, and to monitor the differences in computed TOA radiances for a wide range of meteorological satellite sensors from both measured (GRUAN) and modelled (NWP) state estimates. The GRUAN-processor is built around several core capabilities that are likely to be supported longer-term by EUMETSAT (the fast RT modelling capability [RTTOV] and the flexible interface to NWP model fields [the Radiance Simulator]), nevertheless there is a foreseen governance gap beyond the term of GAIA-CLIM regarding the ongoing development priorities and support for the GRUAN-processor.

The key stakeholders include: satellite agencies (engaged in assessing the quality of long term satellite datasets and implementing Cal/Val plans for forthcoming missions); NWP centres (with an interest in determining traceable uncertainties in model fields); GRUAN governance groups and site operators (with an interest in assessing the value of NWP for cross–checking GRUAN-data quality); and the wider climate-research community (also with an interest in assessing the quality of long term satellite datasets). The future governance of the processor would ideally take account of the priorities of this group of stakeholders.

Associated with this top-level requirement for a flexible observation operator is a specific requirement, related to the need for comprehensive information on the error characteristics of reference measurements. In the context of reference radiosonde measurements, this includes estimates of the error correlations between measurements. Other ground-based data sources such as microwave radiometers and Lidar systems could be developed into reference measurements, including the full assessment of uncertainty.

GRUAN was established with the goal of creating a network of sites around the world where reference measurements of atmospheric vertical profiles are performed (Seidel et al., 2009). Data processing for GRUAN sondes attempts to account for all known sources of systematic and random error affecting the temperature and humidity sensors (Dirksen et al., 2014). However, although vertically resolved best-estimate uncertainties are available, the error correlation structure (i.e. between vertical levels) in the sonde measurements is not presently available, constituting a current gap.

Many applications of reference radiosonde measurements require an estimate of error correlations. For example, as part of the comparison of reference-sonde measurements and NWP fields in terms of TOA brightness temperatures, it is necessary to have realistic estimates of these error covariances. Only then is it possible to estimate realistically, using a radiative-transfer model, the uncertainty in TOA brightness temperature that propagates from sonde profile uncertainty.

Calbet et al. (2017) performed a study into the calibration-traceability chain for forward modelling of the Infrared Atmospheric Sounding Interferometer (IASI), using collocated GRUAN sondes and the LBLRTM radiative transfer model. They found the propagation of uncertainties from sonde profiles was hampered by the lack of covariance information between levels. They resorted to analysing two extreme cases: where the level-by-level sonde profile uncertainties are perfectly correlated or perfectly uncorrelated. The uncertainty in modelled TOA radiances was assumed to lie between the two extremes.

The vertical error correlation structure in GRUAN-sonde profiles is the subject of current research. Such uncertainties are envisaged to be reported in the version 3 GRUAN product (correlated, partially correlated and random terms) being developed by the GRUAN Lead Centre.

A tractable means of representing vertical error covariances is by parametrisation. If the measurement variance at each vertical level is known, the correlated errors between levels can be represented by Gaussian statistics assuming a characteristic correlation length (see e.g. Haefele and Kämpfer, 2010). The correlations should be based on physical constraints where these are known.

Operational space missions or space instruments impacted:

- Meteosat First, Generation (MFG)
- Meteosat Second Generation (MSG)
- Meteosat Third Generation (MTG)
- MetOp and MetOp-SG
- Other agencies comparable missions in polar and geostationary orbit

Validation aspects addressed:

- Radiance (Level 1 product)
- Spectroscopy

Gap status after GAIA-CLIM

GAIA-CLIM has partly closed this gap.

The GAIA-CLIM Virtual Observatory has partly closed this gap at the conceptual demonstrator level by addressing the ECVs upper-air temperature and humidity for the HIRS satellite instruments measuring in the infrared spectral ranges. The Virtual Observatory contains results obtained by an offline forward modelling capability to transfer GRUAN radiosonde measurements into the measurement space of the satellite instruments using a radiative transfer model that is sustained in operational mode within the EUMETSAT Numerical Weather Prediction Satellite Application Facility.

The gap is only partly closed, because more GCOS ECVs and associated satellite instruments need to be considered in the future and because the capability is not available online and operationally, which would require additional funding. In addition, more sophisticated radiative transfer models could be coupled with the Virtual Observatory to address eventual shortcomings of the operational fast model and more reference measurement techniques could be added.

With respect to the requirement for comprehensive knowledge of the error characteristics of reference data (specifically, error correlations for GRUAN data), initial estimates have been generated and tested within the timeframe of GAIA-CLIM, but it is expected that this activity will need to continue beyond the end of the GAIA-CLIM project in part because further information is expected from GRUAN ,but not yet available on the specific correlation structures apparent in the radiosonde profiles.

Part II: Benefits to resolution and risks to non-resolution

Identified benefit	User category/Application area benefitted	Probability of benefit being realised	Impacts
Integration of a forward radiative transfer capability into the GAIA-CLIM Virtual Observatory enables direct comparison of satellite radiances to non-satellite reference measurements.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	Medium	The realisation will lead to the use of the GAIA-CLIM Virtual Observatory for the validation of Fundamental Climate Data Records forming the basis for GCOS ECV climate data records via the use of FCDRs in NWP-model based reanalysis and retrieval schemes.
The forward radiative transfer capability in the Virtual Observatory provides the potential for a further development of the Virtual Observatory into a general satellite Cal/Val facility.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	Medium Low	The quality of satellite data is monitored in real time using various, often mission specific, tools. Non-satellite reference data play only a marginal role. The Level-1 capability of the GAIA-CLIM Virtual Observatory makes it viable to be considered to become part of a real time monitoring system.
Identified risk	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
Limited uptake of Virtual Observatory as comparisons not possible at level-1b radiance space.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	Medium	Value of reference-quality measurements for satellite-data characterisation not realised with the consequence that the Virtual Observatory has no potential for satellite Cal/Val activities. On the long term, justification for non-satellite reference measurements may fade.
Lack of penetration and	Operational services and	High	Sub-optimal (slower !)

acceptance of proposed methodology (NWP, coupled to GRUAN, for the validation of meteorological EO data) into wider user community.	service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)		evolution of the community's understanding of the quality of key measured datasets.

Part III: Gap remedies

Gap remedies:

Remedy 1: Implement means to provide the community with a forward radiative transfer capability or results of computations

Primary gap remedy type:

Technical

Secondary gap remedy type:

Deployment

Proposed remedy description:

GAIA-CLIM has developed the GRUAN processor that is able to simulate measurements for many satellite instruments operating in the infrared and microwave spectral ranges consistent with GRUAN-profile measures and their uncertainties. Here, it is proposed to integrate the GRUAN processor into the Virtual Observatory and make it accessible online to create simulated measurements for any satellite instrument for which co-locations with the GRUAN-reference measurements exist in the Virtual Observatory database. This could then provide a working model that would enable development of similar operators for measurements arising from other non-satellite reference quality measurements. In particular, many of the modules in the GRUAN processor could be extended to enable the use of additional measurements in future.

Alternatively, potentially at lower cost, a service could provide online results of radiative transfer calculations for ground-based reference measurements that can form an element of match-up data bases and GUI such as the Virtual Observatory.

Relevance:

Implementing the proposed remedy would help to satisfy a clear user need expressed by the GAIA-CLIM user survey. The remedy presents an important step forward towards the validation of Fundamental Climate Data Records that can be evaluated for many instruments using non-satellite reference measurements available within the GAIA-CLIM VO.

Measurable outcome of success:

The measurable outcome of success for the specific remedy proposed is the accessible online radiative transfer capability, available as part of the Virtual Observatory, and provision for the long-term maintenance and development of the capability, in accordance with the evolving requirements of stakeholders.

Expected viability for the outcome of success:

High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes, in case a service is established that provides results from forward calculations or co-located data.

Potential actors:

- EU H2020 funding
- Copernicus funding
- ESA, EUMETSAT or other space agency

Remedy 2: Improved characterisation of error covariances in GRUAN measurements.

Primary gap remedy type:

Technical

Proposed remedy description:

Uncertainty-covariance information needs to be made available and used appropriately within applications that convert from geophysical-profile data to TOA radiances. Firstly, the profile information needs to contain the uncertainty and the correlation structure in a usable format. Within GAIA-CLIM, simple parametrised versions of the vertical error covariances have been developed and tested as part of the significance testing in the GRUAN processor. Further work could refine approaches to more robustly utilising the uncertainty covariance information available.

Alternative approaches based on methods (Desroziers et al, 2005) routinely used to characterise errors in data assimilation systems should also be tested. This method requires that observations are actively assimilated. Initial estimates could be obtained from sub-selecting from the larger set of GUAN data currently assimilated in operational NWP systems, where the selection is based on those GUAN stations exhibiting gross-error characteristics similar to those of GRUAN measurements.

Relevance:

The solution proposed here is fully aligned with the requirement (to establish traceable uncertainties for NWP fields and radiances calculated from them).

Measurable outcome of success:

Parametrised error covariances, developed and tested in consultation with experts from the GRUAN community.

Expected viability for the outcome of success:

High

Scale of work:

- Single institution
- Consortium

Time bound to remedy:

Less than 3 years

Indicative cost estimate (investment):

Low cost (< 1 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- EU H2020 funding
- National Meteorological services

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G5.11 Non-operational provision of fiducial reference-measurement data and some satellite-derived products reduces their utility for monitoring and applications

Gap abstract:

Copernicus Services, including the Climate Change Service (C3S), will provide information in close to real time using global and regional reanalysis outputs, as well as satellite L2 products. These outputs are not always consistent with their own climatology, because input data are not produced with the same quality at real-time as they are in elaborated climate data records. The availability of so-called "Climate Data Record Interim Products" would remedy this problem by producing products with as high as possible consistency with the climatology, being based on automated satellite inter-calibration and careful quality control. These types of data records are emerging from operational satellite agencies, but lacks optimal means for validation due to non-availability of many non-satellite reference measurements in close to real-time.

Part I: Gap description

Primary gap type:

Governance (missing documentation, cooperation etc.)

Secondary gap type:

Technical (missing tools, formats etc.)

ECVs impacted:

Temperature, Water vapour, Ozone, Aerosols, Carbon Dioxide, Methane

User category/Application area impacted:

- Operational services and service development (meteorological services, environmental services, Copernicus Climate Change Service (C3S) and Atmospheric Monitoring Service (CAMS), operational data assimilation development, etc.)
- International (collaborative) frameworks and bodies (SDGs, space agencies, EU institutions, WMO programmes/frameworks etc.)
- Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)

Non-satellite instrument techniques involved:

Independent of instrument technique

Related gaps:

- G1.10 Relative paucity and geographical concentration of reference-quality measurements, with limited understanding of uncertainty in remaining measurements, limits ability to formally close satellite to non-satellite comparisons

Gap 1.10 where the remedy of it would enable the networks of reference measurements with better geographical distribution that can become candidate for operational quality control and data dissemination.
The remedies of Gap 1.10 and this gap can be realised in parallel.

Detailed description:

Copernicus Services, including the Climate Change Service, will provide information in close to real-time using global and regional reanalysis outputs, as well as satellite-derived products. For the validation of these products, both delivered with high timeliness, it is essential to have non-satellite reference measurements available for use in near-real-time, which is rarely the case today. There is a need to operationalise quality control and delivery of such data in the future to realise the potential benefits that fiducial reference measurements with characterised uncertainty offer.

Currently, many reference measurements are provided with specific delays due to requirements for certain quality-control measures to be applied. But in many other cases, delayed mode provision relates solely to network data policies and / or to data transmission protocols. The usage scenario for a Virtual Observatory within a Copernicus Service would likely need a close to real time availability of reference quality data streams to enable the assessment of very recent satellite-data products and the close to real time performed reanalysis. If the quality analysis and data provision for non-satellite fiducial reference measurements cannot be operationalised, leading to faster delivery, quality assessments of Copernicus products at short time scales shall remain of limited nature, reducing the value of the data for applications.

In addition, the timely operational delivery of satellite Climate Data Record Interim Level 2 products that are consistent with their long-term climatology also needs to be fostered to improve close to real-time reanalysis products and their validation. The validation of the Interim products could enhance the needs for non-satellite reference measurements as part of an operational validation set up.

Operational space missions or space instruments impacted:

Independent of specific space mission or space instruments
The gap addresses the timeliness of validation that is needed for close to real-time outputs of Copernicus Services.

Gap status after GAIA-CLIM:

After GAIA-CLIM this gap remains unaddressed

The GAIA-CLIM project is not addressing this gap and it is likely to remain after the end of the project.

Part II: Benefits to resolution and risks to non-resolution

Identified benefit	User category/Application	Probability of benefit being	Impacts

	area benefitted	realised	
Operational quality control and delivery of non-satellite reference measurements would allow for better characterisation of satellite and reanalysis products offered in close to real time. This would most likely generate a higher demand for operationally produced reference measurements where the operational delivery requires also a sustained funding of the needed measurement devices and associated data services.	All users and application areas will benefit from it	Medium	Quality analysis for time-critical services of Copernicus could be significantly increased by providing reference measurements closer to real time.
Operational production of L2 Climate Data Record Interim satellite products would allow for more consistent reanalysis outputs and its validation.	All users and application areas will benefit from it	Medium	Quality analysis for time-critical services of Copernicus could be significantly increased by providing CDR Interim L2 products for assimilation and validation of reanalysis. The validation of such products requires the first benefit to be realised.
Identified risk	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
If the remedy on non-satellite reference measurements is not started, the use of non-satellite reference measurements remains limited.	All users and application areas will suffer from it.	Medium	Reference measurements may play only a minor role in the validation of Copernicus service outputs with potential long-term consequences for the network maintenance. This also applies to their use in the validation of emerging CDR Interim L2 products.
If the remedy on the satellite CDR Interim is not started, reanalysis outputs and other Copernicus satellite-based products suffer from temporal inconsistencies.	All users and application areas will suffer from it.	Medium	Quality assurance for CDR Interim L2 products would be far from optimal and financial support of reference-measurement systems may fade also endangering the validation of long-term data records.

Part III: Gap remedies

Gap remedies:

Remedy 1: Operationalise processing and delivery for non-satellite reference measurements and satellite CDR Interim L2 products.

Primary gap remedy type:

Technical

Secondary gap remedy type:

Governance

Proposed remedy description:

A first step would be to assess the current procedures for quality control and delivery mechanism for non-satellite reference measurements, and to work out a proposal to further automate them. Depending on the needs, specific projects could be established to operationalise the processes and associated software. The dissemination of such data could be included into operational dissemination mechanisms used for operational data provisions such as over the WMO Information System.

In addition, entities producing GCOS ECV climate data records from satellite measurements should be encouraged to develop a mechanism that continues the data processing by keeping high consistency with the produced CDR. This involves automated inter-satellite calibration for input data to retrieval schemes and a strongly automated quality control, using non-satellite reference measurements that produces statistics in particular related to the temporal consistency with the long term CDR, e.g., stability and trend estimates with uncertainty. Such data shall be disseminated with high timeliness (~2-3 days delay).

Relevance:

The remedy has the potential to significantly increase the use of non-satellite fiducial reference data in Copernicus Services. The operational character of quality control and delivery mechanism for such data and their subsequent operational use would potentially lead to a funding of measurement systems from operational sources that would sustain the measurement systems and associated data services rather long-term. This could be realised in conjunction with the already emerging generation of CDR Interim L2 products that need reliable reference measurements for their validation, which may increase the chance for funding.

Measurable outcome of success:

Close to real-time availability of non-satellite reference measurements and their use in the continuation of GCOS ECV climate data records with high timeliness to Copernicus Services.

Expected viability for the outcome of success:

- Medium
- High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 10 years

Indicative cost estimate (investment):

Very high cost (> 10 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- Copernicus funding
- National funding agencies
- National Meteorological Services
- ESA, EUMETSAT or other space agency
- SMEs/industry