GAIA-CLIM Report / Deliverable D1.4

Gap Analysis for Integrated Atmospheric ECV Climate Monitoring:

Update for GAIA-CLIM Gap Analysis and Impacts Document from WP1

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Executive Summary

This deliverable constitutes further input from WP1 (Geographical capabilities mapping) to the drafting of the living Gaps Assessment and Impacts Document (GAID) of WP6, led by KNMI. The purpose of the GAID is to collate and document gaps directly relevant to the aims of the GAIA-CLIM project. The GAIA-CLIM project is concerned with increasing the utility, use and value of non-satellite observations to characterise satellite observations. Further project details are available at www.gaia-clim.eu.

This deliverable refers to the second official release of the GAID (D6.4) and builds upon the gaps identified therein. In addition, it arises any new gaps that have been identified in relation to the Work Package (WP) activities.

The goal of this GAIA-CLIM WP is to identify the geographical capabilities and gaps in the existing surface-based and sub-orbital observing systems at both the European and the global scales for the characterization of EO measurement performance. WP1 activities include the mapping and visualization of the existing capability based upon objective assessment criteria by ECV and by measurement fundamental characteristics. It also considers the scientific understanding of the impacts of spatial capabilities gaps upon our ability to characterise EO sensor performance on a sustained basis. These activities directly support the creation of a ‘virtual observatory’ under GAIA-CLIM WP5.

This deliverable further expands upon the gaps identified in the initial work package input, relevant gaps sourced externally, and any new gaps that have been identified by participants. The gaps discussed herein are exclusively those related to the WP aims and remit (see prior paragraph). A key focus of the current iteration is to make the gaps and their remedies more SMART (Specific, Measurable, Actionable, Relevant and Timebound) with realistic cost estimates and assessments of the risk / cost of leaving the gap unremedied. In year 3 the GAID shall inform the development of a list of prioritised recommendations and this shift in emphasis is expected to help inform such an exercise.

1. Document rationale and broader context

The purpose of this document is to provide input to the Gap Analysis and Impacts Document (GAID) of the GAIA-CLIM project arising from WP1. This WP is concerned with the identification of the existing data capabilities at the global-scale for the core ECVs identified by the GAIA-CLIM project for each layer in a 'system of systems' approach to enable rigorous EO data characterization (Tasks 1.1 and 1.2). This information will be made available through a "Virtual Observatory" of ground based and satellite data, which will be able to visualize in 3D the current surface-based observing capabilities (Task 1.3). Rigorous scientific assessment of geographical gaps will be provided through the implementation of advanced geo-statistical approaches, as well as using existing global chemistry models and weather reanalysis techniques (Tasks 1.4 and 1.5).

The review of the existing observing non-satellite capabilities at the global scale under Task 1.2 has allowed us to identify 56 networks currently operating regionally or globally, on different spatial domains, and measuring different ECVs through the use of one or more measurement techniques. For most of these at least one measurement maturity matrix assessment (Task 1.1, D1.3) is also available, and statistics are also available for each layer of the system of systems (i.e. Reference, Baseline and Comprehensive networks). A suite of metadata formats for the collection of both discovery and observational metadata have been identified and also inter-compared to provide the 'Virtual Observatory' with the most efficient solutions to be implemented. First results on the modelling activities to assess existing gaps in the observation system using chemistry and weather models has been also achieved and are discussed within D1.5. These first results have allowed WP1 partners also to provide additional information about geographical gaps in the current observation system, but also gaps in the current use of metadata across the international programs and agencies.

The GAID has now gone through 2 iterations. The first iteration was based upon a combination of the user survey and individual inputs from this and the four remaining underlying Work Packages. The second iteration built upon this by incorporating feedback from the first user workshop and additional informal input delivered from this and other Work Packages. The third version shall build upon the second by considering input arising from this current set of deliverables. That version shall be discussed at the second user workshop to be held in Brussels in November 2016 and the input received shall lead to a further iteration, which shall form the initial basis for a set of prioritised recommendations arising from Task 6.3.

Feedback from the science advisory panel, the first General Assembly, and the review pointed collectively to the need to evolve the GAID to go beyond characterising the gaps to considering in more detail implications, potential SMART remedies, costs, and the benefits of resolving them. This then shall help allow external and internal users to more fully explore and appreciate the gaps identified prior to work by Task 6.3 to collate a set of prioritised recommendations.

2. Summary of gaps from GAID v2 relevant to the current WP

The gaps identified in GAID that shall be considered in further detail in Section 4 are summarised below. This is a direct subset of relevant entries from Table 2.2 of the version 2 release of the GAID. These gaps arose from either the initial Deliverable from this WP (D1.1) or from subsequent external input. All gaps are assigned an owner within GAIA-CLIM, even if they arose from an external source. Some of the gap titles herein are modified from those in the corresponding table in version 2 of the GAID to reflect suggestions of the WP1 participants. Further, some gaps which were superseded have been removed.

Gap Identifier	**Gap Type**	**ECV(s)**	**Gap Short Description**	Trace
G1.02	Technical	H_2O, O_3, T, CO_2, CH_4, aerosols	Unknown suitability of measurement maturity assessment	D1.3
G1.03	Coverage Governance	H_2O, O_3, T, CO_2, CH_4, aerosols	Missing evaluation criteria for assessing existing observing capabilities	D1.1
G1.04	Coverage Governance	H_2O, O_3, T, CO_2, CH_4, aerosols	Lack of a comprehensive review of current non-satellite observing capabilities for all the study of ECVs in atmospheric, ocean and land domains	D1.4, D1.6, D1.8
G1.05	Technical	H_2O, O_3, T, CO_2, CH_4, aerosols	Lack of unified tools showing all the existing observing capabilities for measuring ECVs with respect to satellite spatial coverage	D1.4, D1.6, D1.8
G1.06	Technical	H_2O, O_3, T, CO_2, CH_4, aerosols	Lack of a common effort in metadata harmonization	D1.4, D1.6, D1.8
G1.07	Coverage	H2O, O3, T, CO2, CH4, aerosols	Need for a scientific approach to the assessment of gaps in the existing networks measuring ECVs	D1.9
G1.08	Coverage	H2O, O3, T, CO2, CH4, aerosols	Evaluation of the effect of missing data or missing in temporal coverage of fully traceability data provided by ground-based networks	D1.9 Whiteman et al., 2011
G1.09	Coverage Vert. resolution	CO	Limited availability of quantitative profiles; Insufficient verification of vertical information in satellite products	D1.2
G.1.13	Coverage	H_2O	Uncoordinated lidar and microwave	D1.1, D2.1

	Governance		radiometer water vapor measurements	
G1.14	Coverage Governance	H_2O, O_3, T, *wind*	Currently limited aircraft measurements in Eastern Europe	n/a
G1.15	Coverage Governance	O_3 (total column)	Northern Hemisphere bias in NDACC and PANDORA network sites distribution	D1.1, D1.10 D2.1

3. New gaps identified by WP participants to date

Subsequent to the first official input to the GAID (D1.1), substantial work has been undertaken upon the Work Package in the following respects:

- Definition of a system of systems approach to assess the measurement quality provided by the existing networks at the global scale (Task 1.1, D1.3);
- Definition of common metadata format for both the discovery and observational metadata (Task 1.2);
- Collection of observational metadata for 56 networks at the global scale (Task 1.2);
- First results available from the model-based assessment of geographical gaps (Task 1.5).

These activities, in addition to advancing the aims of the GAIA-CLIM project, have given cause to reflect further on potential gaps in our collective knowledge and capabilities. This has led to changes and updates to the gaps already identified, including their titles. Note that G1.01 although in the GAID v2 table had been amalgamated with G1.03 in the GAIDv2 text. We therefore shall not consider G1.01 further in this current work and it has been removed from our table in Section 2 above. Moreover, gaps G1.10, G1.11 have been moved to the Deliverable D2.2 while G1.12 has been moved to the Deliverable D4.3, submitted concurrent with the present report. This has the purpose to avoid redundancy and conflicts among the input provided to the Gap Analysis and Impacts Document in the frame of the different WPs. Finally, in these various revisions no new gaps were identified by participants that pertain to WP1.

4. Detailed update on traces for the gaps arising from this Work Package for inclusion in the GAID

Within this section gaps that were detailed in Section 2 are expanded to give a full trace of our current understanding of the gap, its impacts and its potential remedies. We take as the starting point the corresponding text arising from the GAID (v2, Section 3) text and / or the initial deliverable text as we deem most appropriate. This is then expanded upon here in an attempt to better delineate the gap, its impacts, its potential remedies (including indicative costs and timelines) and the scientific impact of (non-)resolution. Gaps are ordered numerically per the Table in Section 2 and each given a specific subsection.

4.1 G1.02 Unknown suitability of measurement maturity assessment

Gap detailed description

Ensure that the measurement maturity assessment prepared by GAIA-CLIM is readily applicable to all reference, baseline and comprehensive networks, and is beneficial to identify shortcomings in the practices applied by network operators. The maturity assessment involves assessing against 7 major strands such as metadata, uncertainty quantification and sustainability, as outlined in D1.3. This assessment, in the context of Task 1.2, has now been carried out for a number of target GAIA-CLIM networks and ECVs , but it should be applied more broadly to other ECVs and measurement domains if it is to extend its utility. Testing needs to be performed and may result in a subsequent need for revision of D1.3 accordingly either within or after the project.

Activities within GAIA-CLIM related to this gap

Task 1.2 has undertaken an assessment of the measurement maturity matrix for in excess of 50 measurement networks of relevance to GAIA-CLIM. These analyses are in the process of being analysed by Task 1.2 participants and shall be the subject of a deliverable due in M18 of the project.

Gap remedy(s)

Remedy

Specific remedy proposed

Application of the measurement maturity matrix exercise to a number of networks and domains to assess suitability for purpose and gain broader buy-in to the concept and its scientific value.

Measurable outcome of success

Feedback received from assessors leading to one or more of:

- Revised versions of guidance to address perceived shortcomings
- Demonstrated usage of the approach yielding improved observations usage / improved observations capabilities based upon lessons learnt
- Citation of approach in the literature

Achievable outcomes

Technological / organizational viability: High

Indicative cost estimate: low (<1 million)

Relevance

The adoption of the tiered approach and assessment of maturity within that framework would help to ensure better use of observations across application areas as detailed in D1.3. A number of case studies shall help gain broader buy-in.

Timebound

Internal to GAIA-CLIM the Task 1.2 assessment and feedback shall be completed by M18. A summary paper shall be produced outlining both the approach taken and the results achieved. The approach will also be used in the new BG09 H2020 project INTAROS for the Arctic domain and across atmospheric, oceanic and terrestrial domains (NUIM task lead). Further usage and feedback beyond GAIA-CLIM cannot be given a specific timescale.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
The guidance and assessment criteria are not fit for purpose and not adopted	Medium	Benefits of taking a tiered network of networks approach not fully realised

4.2 G1.03 Missing evaluation criteria for assessing existing observing capabilities

Gap detailed description

No effort has been made to define and broadly agree amongst global stakeholders the measurement and network characteristics underlying a system of systems approach to Earth Observation. As a result this potentially inhibits realisation of the full benefits of an explicitly system of systems architecture (trickle down, calibration, characterisation etc.). It also places the burden of appropriate use of data squarely on the user, which is an unrealistic expectation in the majority of cases. Different domain areas use specific, but overlapping naming conventions, but often mean very different things. The unwary user is faced with an unenviable task as a result, and this yields sub-optimal and / or incorrect usage of available observational records in many cases.

Activities within GAIA-CLIM related to this gap

Task 1.1 created a guidance to support the designation of non-satellite observational capabilities into a structured system of systems observing architecture, also included under D1.3. This report proposed a specific system of systems approach to observing system design and arose potential approaches to their assessment. Task 1.2 is in the process of undertaking an assessment for a subset of the atmospheric domain that may plausibly contribute to the VO with a deliverable due in M18 (Sept 2016).

Gap remedy(s)

Remedy

<u>Specific remedy proposed</u>

Adoption of the GAIA-CLIM approach or of similar approaches established by globally responsible entities, such as the Global Climate Observing System (GCOS) or WMO Integrated Global Observing System (WIGOS) and / or in subsequent relevant scientific projects. GAIA-CLIM has developed D1.3 which provides a potential framework to initiate discussions. But this is the limit of how far GAIA-CLIM alone can proceed on this gap. WIGOS or GCOS are likely the appropriate bodies to get broader buy-in and enhanced coordination amongst global stakeholders. The adoption of such an approach is currently articulated in the draft version of the third GCOS Implementation Plan. GAIA-CLIM shall also write-up a version of D1.3 for peer-review to gain greater exposure and buy-in (submission foreseen Q4 2016).

<u>Measurable outcome of success</u>

Successful implementation of the system of systems approach and maturity assessment shall be achieved through adoption by WIGOS and /or GCOS (likely modified). Promoting its use to instigate a system of systems approach across atmospheric, oceanic and terrestrial domains and that approach yields demonstrable scientific, technological and financial benefits. In the interim, uptake in other projects would be a demonstrable outcome.

INTAROS shall utilize the approach for the Arctic and across terrestrial, oceanic and atmospheric domain areas.

Achievable outcomes

Technological / organizational viability: Medium.

Technologically this is entirely feasible. However, there is a relative lack of buy-in to the concept outside of GAIA-CLIM that is required to be overcome. Although some actors see it as potentially useful, it is not seen as sufficiently relevant within e.g. WIGOS at this time.

Indicative cost estimate: low (<1 million)

Relevance

The adoption of the tiered approach and assessment of maturity within that framework would help to ensure better use of observations across application areas as detailed in D1.3.

Timebound

Currently, potentially to be included as an action for GCOS to consider in their next Implementation Plan spanning 2016-2021. Any adoption as part of WIGOS would next be possible at CG18 in 2019.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Continued use of inappropriate data in applications	High	Impact depends upon the specific role of the data. Examples such as the Ozone hole or tropospheric temperatures suggest potentially large issues.
Continued within and across domain confusion in naming conventions and data quality assessments	High	Confusion to end-users on what different data streams constitute.
Inefficiencies in network design arising from imperfect knowledge of capabilities	High	Economically wasteful use of resources, synergies between observing capabilities not realised leading to degraded assessments of

		observational change

4.3 G1.04 Lack of a comprehensive review of current non-satellite observing capabilities for the study of ECVs in atmospheric, ocean and land domains

Gap detailed description

Non-satellite observations support an increasingly wide range of applications in monitoring and forecasting of the atmosphere, and of the oceans and land surfaces, at different time scales (including near-real-time and delayed mode applications). These activities support an increasing range of services with high socio-economic benefits. User requirements have become more stringent and new requirements have increasingly appeared with respect to these applications (and undoubtedly shall continue to do so). These observation systems provide the products in one or more of real-time, near-real-time and non-real-time (those that provide a mix may apply different processing to different timescale releases with, in general, greater quality assurance for delayed mode products). In order to allow EO providers and users to maximize the value of existing observations and implement a user-friendly mapping facility, a comprehensive review of the current observing capabilities at European and global scale is needed for all the ECVs. This will also facilitate an identification of the existing geographical gaps in the global observing system. While a comprehensive review of space-based missions and needs has been put together within official documents of the international community (e.g. the CEOS Handbook and the "Satellite Supplement" to the 2nd GCOS Implementation Plan), in contrast the mapping of current non-satellite observing capabilities is piecemeal and poorly documented. It is based on the information provided voluntarily by each network or station to some international data portals in an uncoordinated way, often on an ECV by ECV basis. Extensive reviews have been provided by WMO, GEOSS, GCOS, but they are limited to those networks and ECVs relevant for their institutional mission, and often disagree with one another.

Activities within GAIA-CLIM related to this gap

GAIA-CLIM task 1.2 will make considerable efforts to identify possible options to remedy this gap as detailed in the Gap remedy text below. These will be documented in GAIA-CLIM task 1.2, deliverable D1.6: Report on data capabilities by ECV and by system of systems layer for ECVs measurable from space. (CNR; M18)

Gap remedy(s)

Remedy

GAIA-CLIM will make considerable efforts in putting together an extensive review of the existing non-satellite measurement capabilities for several techniques and networks, concentrating on the priority ECVs within the GAIA-CLIM project. Results will be delivered in September 2016 (deliverable D1.6). This assessment will include an assessment of their measurement maturity. Discussion on how to establish over the long -term the service offered under this task in the framework of the C3S program is ongoing. Current C3S call for tender Lot 3 may provide the needed funding support to sustain this activity.

<u>Specific remedy proposed</u>

GAIA-CLIM will make considerable efforts in putting together one of the most extensive reviews of the measurement maturity against assessable measurement properties for existing capabilities and for the measurement of a multitude of ECVs, focussing primarily upon the priority ECVs within the GAIA-CLIM project. Discussion on how to establish over the long-term the service offered under this task including the delivery of different measurement maturity data streams to end-users to enable their easy use and application in the frame C3S program is ongoing. The current C3S call for tender may provide the needed funding support to sustain this activity.

It has been recognized by the consortium that the review would be significantly reinforced by a sustained exchange of rich measurement metadata information resulting from an enhanced coordination amongst global stakeholders, like the WMO Commission on Basic Systems, GCOS, GEOSS, GAW, and the various federated networks reporting to these programs. Such rich metadata exchange under e.g. enhanced WIGOS metadata standards would greatly aid an assessment as to which tier different observing networks may fall within and ensure their appropriate usage. Ambiguity around current practices, instrumentation etc. complicates an assessment for many of the networks that might be assessable under Task 1.2. Currently, this looks quite uncertain and requires further plans and a cost assessment.

Measurable outcome of success

Use of the collected geographical metadata in the 'Virtual Observatory', and hence downstream applications. The timeline for the assessment and quantification of these datasets can be quantified in the first two years after the end of the project, to allow the full development of the 'Virtual Observatory', which will make these results and metadata available to all the potential GAIA-CLIM users. At that stage, the users level of satisfaction will be quantifiable.

Achievable outcomes

Technological / organizational viability: High

Indicative cost estimate: medium (>1million), bigger investments may depend on the size of the service requested and offered to the end-users

Relevance

The GAIA-CLIM work provides one of the first attempt to remove the fragmentation already experienced in the past creating a metadaset with the discovery metadata for a large number of networks at the global scale.

Timebound

First results will be delivered in September 2016 (deliverable D1.6) and they will be improved over the duration of GAIA-CLIM project. In order to have a long-term impact, this metadata service must be supported and sustained in the frame of C3S or other funding programs.

Gap risks to non-resolution

Identified future risk / impact	Probability of occurrence if gap not remedied	Downstream impacts on ability to deliver high quality services to science / industry / society
Fragmentation of metadata among international bodies and measurements programs.	High	Minimize the value of existing observations and the capability of the users to simultaneously use products for a multitude of ECVs and from varying data sources.

4.4 G1.05 Lack of unified tools showing all the existing observing capabilities for measuring ECVs with respect to satellite spatial coverage

Gap detailed description

A unified tool able to visualize all the sub-orbital observing capabilities for measuring ECVs at the global scale with respect to spatial and temporal coverage of space-based sensors has never been provided in the past by international bodies and agencies. Several tools have been implemented for specific networks of the global observing system, but all of them are designed on the basis of very specific needs, using different criteria / tools, and typically including just one ECV and only one or a small subset of the networks at the global scale.

One of the most apposite examples is represented by the OSCAR (Observing Systems Capability Analysis and Review Tool) system of the WMO (http://www.wmo sat.info/oscar/) and in particular for the surface based capabilities[1] still under development. At its present state this tool is, focused on the WMO mission and does not include all the ECVs and all the existing networks. Moreover, satellite observing capabilities are collected separately and a unified tool able to show simultaneously all the existing non-satellite capabilities, along with the field of view of the satellite-based instruments can strongly help end-users in the design of new validation strategies and in the full exploitation of both ground-based and satellite data. This shall in turn help inform users on the available ECVs measurements within different domains (atmosphere, land, ocean) through a facilitated analysis of the geographical distribution of the system of networks at the global scale.

Activities within GAIA-CLIM related to this gap

GAIA-CLIM task 1.3 will provide a demonstrator mapping facility, which shall allow users to explore the data in the context of available non-satellite and satellite capabilities taken together. This is the proposed GAIA-CLIM solution to implement in the EO programme to (at least partially) remedy this gap.

GAIA-CLIM task 1.3, deliverable D1.8 – Provision of a 3D tool for the online visualization of existing measurements (CNR; M24)

Gap remedy(s)

Remedy

Specific remedy proposed

GAIA-CLIM will provide a mapping capability to address this gap through Task 1.3. The software will be able to evaluate each network (taking advantage of the metadata collected through GAIA-CLIM Task 1.2) using the maturity matrix approach elaborated within Task 1.1. This software (to be delivered by February 2017) might be established as a permanent operational service. This work might be offered to the community also to encourage a joint effort amongst global stakeholders like GCOS, GEOSS, GAW to foster the design of further relevant tools.

[1] https://oscar.meteoswiss.ch/OSCAR/index.html

Measurable outcome of success

The adoption of the proposed open source platform for metadata visualization by C3S or other agencies established as a long term service is a measure of the success of this activity after the end of GAIA-CLIM.

Achievable outcomes

Technological / organizational viability: High

Indicative cost estimate: low (<1 million)

Relevance

The synergic approach based on metadata collection and its visualization provides the basis to identify geographical gaps and, therefore, the starting point for any other scientific assessment within the GAIA-CLIM project (e.g. G1.09, 1.15, etc).

Timebound

The proposed platform may remedy the described gap in an efficient and offer a long term approach if sustained by funding programs. The initial mapping facility shall be available prior to the end of GAIA-CLIM and integrated within the Virtual Observatory facility.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Lack of tools to drive future investments for the EO	Medium	Lack of services in the frame of the EO programs enabling users to quickly access and assess the suitability of a number of fully traceable reference measurements for a given application to satellite characterisation.

4.5 G1.06 Lack of a common effort in metadata harmonization

Gap detailed description

Metadata is an increasingly central tool in the current web environment, enabling large-scale, distributed management of resources. Recent years have seen a growth in interaction between previously relatively isolated communities, driven by a need for cross-domain collaboration and exchange. However, metadata standards have not been able to meet the needs of interoperability between independent standardization communities. Observations without metadata are of very limited use: it is only when accompanied by adequate metadata (data describing the data) that the full potential of the observations can be realized. Several efforts have been undertaken to improve the harmonization of metadata across the networks and international programs, but this is still not sufficient. Harmonization effort in the atmospheric science community is related to the WIGOS (https://www.wmo.int/wigos) standard, currently under development and subsequent implementation at the WMO, and by the ESA Climate Change Initiative (CCI [2]).

Activities within GAIA-CLIM related to this gap

An attempt to address this gap within GAIA-CLIM will be undertaken as part of Task 1.2 whereby metadata will be collected and then delivered in a useable set of formats for a selected set of networks which may plausibly contribute to the Virtual Observatory activity.

GAIA-CLIM task 1.2, deliverable D1.7 – Report on the collection of metadata from existing network and on the proposed protocol for a common metadata format (CNR; M18).

Gap remedy(s)

Remedy

Specific remedy proposed

Within GAIA-CLIM Task 1.2 / WP5 and, in synergy with WIGOS and ESA-CCI representatives, we will provide a unified metadata format (UMDF) that will aim to extend and integrate additional important elements into the WIGOS format (while keeping the various formats interoperable). After selecting relevant initial candidate metadata formats (ISO, WIGOS, ESA-CCI), the UMDF will be developed. The UMDF shall hold relevant parameters common to all original data formats. In addition, it will preserve the «original MD» as an additional field «original xml» at the end of each database document in a MD collection, thus preserving the ability to export in the original data formats upon request if needed.

Measurable outcome of success

Use of the proposed UMDF within GAIA-CLIM and by downstream users of the Virtual Observatory.

[2] http://cci.esa.int/sites/default/files/CCI_Data_Requirements_Iss1.2_Mar2015.pdf

Achievable outcomes

Technological / organizational viability: medium, this is a demonstration activity but not extremely challenging to be implemented in an efficient way.

Indicative cost estimate: low (<1 million)

Relevance

The proposed UMDF is a significant attempt to improve the metadata harmonization at the international level and its benefit may be expected to be large and affecting many (primarily expert) data users.

Timebound

This UMDF will be defined by September 2016 (deliverable D1.7) and finalized by end of the project within WP5. It will build up from the dialogue established with WIGOS and ESA-CCI (making use of CF convention). The GAIA-CLIM metadata will be used for all the reviewed networks, but also for the all the data records that will be available on the GAIA-CLIM virtual observatory (WP5).

A final version of the UMDF will be finally released and implemented by the end of the GAIA-CLIM project (Feb. 2018).

Gap risks to non-resolution.

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Missing interoperability between independent metadata standardization communities	Medium	Limited cross-domain collaboration and exchange for the users. Limits the ability to appropriately use and derive value from the data

4.6 G1.07 Need for a scientific approach to the assessment of gaps in the existing networks measuring ECVs.

Gap detailed description

Significant gaps in our observing capabilities limit our ability to provide a comprehensive characterization of the important physical parameters, and limit the accuracy of our predictive models and the satellite cal/val. Existing ground-based assets have not all been integrated into a coordinated observing network. Inadequacies include some large continental regions that are not monitored by any measurement stations or other assets. It is essential to understand the impacts of and, if scientifically necessary, reduce these gaps in the measurement data coverage, or at a minimum, to prevent these gaps from expanding if they would have deleterious impacts. Considering the importance of continuous, long-term observations for ECVs for many applications, an assessment of gaps on a scientifically sound basis is a necessary step for future improvements of the global observing system.

Activities within GAIA-CLIM related to this gap

GAIA-CLIM will start addressing this gap, proposing an assessment of the geographical gaps in the current surface-based and sub-orbital observing capabilities for a few variables like water vapour and aerosol on the basis of two different techniques (functional regression technique, Markov-chain Monte Carlo). GAIA-CLIM will also use insights arising from modelling studies through Task 1.5.

GAIA-CLIM Tasks 1.4 and 1.5 will provide an innovative approach to remedy to this gap. GAIA-CLIM results will be delivered before the end of the project (deliverable D1.9, M36).

Gap remedy(s)

Remedy

<u>Specific remedy proposed</u>

Many non-satellite observing systems are inadequate to address the needs of satellite data characterisation, particularly so for climate monitoring purposes. Some systems are in a state of decline, with limited resources for investment available, and some past investments have under-delivered. This highlights the need for network design methods and analyses that guarantee investments are appropriate for addressing the science questions being posed. A comprehensive scientific approach to assessing the gaps in the current observing capabilities of the system of observing systems does not exist. Such an approach would support the identification of research questions that could be answered with current or posited observational capabilities. Typically, such decision-making has been performed without a scientific basis or using an ad hoc approach, but has never been applied in an extensive and systematic way. Often the assessment is carried out on the basis of the experience gained by the international experts in the context of past research projects.

Recent research to assess gaps in the global observing system is based the use of natural variability on appropriate time scales to understand the power of a system to address a testable hypothesis (Weatherhead et al., 2016 ICM-8 Boulder available at http://www.dwd.de/EN/research/international_programme/gruan/download/icm-8/pres_406_weatherhead.pdf?__blob=publicationFile&v=1).

GAIA-CLIM Task 1.4 will undertake an assessment of the geographical gaps in the current surface-based and sub-orbital observing capabilities for temperature, water vapour and aerosols on the basis of two different techniques (functional regression technique, Markov-chain Monte Carlo). GAIA-CLIM Task 1.5 is using NWP and atmospheric chemistry models to assess the impacts of gaps for a number of additional target ECVs.

Measurable outcome of success

Success will come from the identification of gaps in the global observing system in a consistent manner that is actionable by observational program stakeholders. Use of different techniques will assure confidence.

Achievable outcomes

Technological / organizational viability: medium, some challenges are still related to the insufficient number of reference measurements available to precisely address the proposed gap (e.g. gap G1.10) and the poor characterization of measurements from baseline networks.

Indicative cost estimate: low (<1 million)

Relevance

GAIA-CLIM will approach this gap using modelling and advanced statistical approaches whose application may be generalized and extended to other ECVs with the potential to become a robust assessment framework available to the community. The proposed approach will also support the remedy to gap G1.12.

Timebound

GAIA-CLIM will deliver results to address this gap by end of the project (Feb. 2018). Nevertheless, several studies are likely required in order to comprehensively assess existing gaps and this can only be accomplished through fostering closer cooperation between the measurement community, geo-statisticians and modellers to design different solutions to assess the gaps and then to inter-compare the elaborated approaches to provide robust and reliable solutions. GAIA-CLIM has setup such a cooperation (that includes US partners like NOAA-CIRES, B. Weatherhead) that needs to be extended and consolidated in the future to support global stakeholders.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**

Lack of an interdisciplinary approach with a consequent under-exploitation of the available data and resources.	High	Lower quality products delivered to downstream applications
Inadequate or sub-optimal observational infrastructure investments for addressing current and future science questions	High	Loss of resources for ensuring an efficient atmospheric monitoring if an identification of gaps in a scientifically robust way is missing.

4.7 G1.08 Evaluation of the effect of missing data or missing temporal coverage of fully traceable data provided by ground-based networks

Gap detailed description

Missing data are a common problem for geophysical data sets. For instrumental data sets obtained currently, the uneven spatio-temporal coverage arises for myriad reasons, depending on the type of instrumentation. For example, remote sensing is influenced by atmospheric conditions and can be hampered by clouds, aerosols, heavy precipitation, or extreme weather conditions. Alternatively, instrumentation may be limited to night-time or to periods when relevant staff are on-site or by similar factors.

Missing data are, in particular, a source of problems in climate research, e.g., in the analysis and modelling of spatio-temporal variability. This is particularly so when the missing data is not entirely random such that there may arise a geophysical difference between the measured period and the potential fully sampled period. Analyzing the full extent of the climate time series, with the missing points filled in, allows for greater accuracy and better significance testing in the spectral analysis. The full record can also improve our knowledge of the evolution of the oscillatory modes in the gaps, and provide new information on changes in climate. Spatio-temporal filling techniques have been developed (Kondrashov et al., 2006) but there are only a few efforts at quantification of the effect of temporal sampling in the determination of atmospheric variability. This prevents full traceability of both the model/assimilation quantity and also the observational dataset.

Activities within GAIA-CLIM related to this gap

GAIA-CLIM will initiate limited work relevant to address this gap within Task 1.4, but more research is needed to fully address this topic.

Gap remedy(s)

Remedy

<u>Specific remedy proposed</u>

The use of geo-statistical approaches for time series with missing data allows the evaluation of the effect of missing data or missing temporal coverage to assess this effect. Research should characterize model-observation differences with focus on enhancing representation of “observation operators”.

<u>Measurable outcome of success</u>

Tests using complete records and simulated incomplete records obtained from the complete ones can show the validity of the approach. This should also build confidence in the applicability of the approach for climate studies.

<u>Achievable outcomes</u>

Technological / organizational viability: medium, challenges are related to the scarce literature available on this topic.

Indicative cost estimate: low (<1 million)

Relevance

Robust geo-statistical approaches are needed in order to analyze timeseries affected by the problem of missing data; their misuse or their poor exploitation will lead to sub-optimal usage and incorrect decision making.

Timebound

GAIA-CLIM will provide work relevant to address this gap by the end of the project (Feb. 2018). A complete remedy depends on future studies and projects working on it.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Less efficient exploitation of the available data with impact on the design of global observing system and climate monitoring.	High	Under-exploitation of datasets in presence of missing -data or temporal gaps.
Reduced potential of using observational data for addressing current and future science questions	Medium	Under-exploitation of datasets collected using technologies considered obsolete or superseded

4.8 G1.09 Limited availability of quantitative CO profiles

Gap detailed description

Assess gaps in the observation system for CO vertical profiles and their impact on the evaluation of models and the derivation of top-down CO emissions. Source inversion techniques will help to evaluate how ground-based measurements can provide useful constraints in the derivation of top-down estimates for CO sources and sinks on the global scale. The impact of improved vertical resolution on the inversion of emissions, i.e. on posterior flux uncertainties and on the ability of the system to differentiate between different emission sources, will be determined.

Activities within GAIA-CLIM related to this gap

Methyl chloroform-derived constraints on OH fields from the recent literature will be used, and based on their uncertainties we shall perform sensitivity source inversions using either MOPITT or IASI CO retrievals. Vertical CO profile measurements by ground-based FTIR instruments are used as additional constraints in the source optimizations, since vertical concentration gradients reflect the effects of chemical sinks. Vertical FTIR data are scarce, but better characterized than vertical information from satellites. The main outcomes will be (1) an updated top-down determination of CO emissions and photochemical productions, (2) an assessment of the sensitivity of the top-down emissions to errors in [OH] as well as other model parameters, and (3) a determination of the added value represented by vertical CO profiles at FTIR stations. These analyses will start in November 2016 and shall be the subject of a deliverable due in M34.

Gap remedy(s)

Remedy

Specific remedy proposed

Within GAIA-CLIM, the existing scarce quantitative vertical profiles of CO will be used to quantify their added value and to determine the potential benefits of additional data collection. If the existing data are found insufficient, the likely remedy would consist in the retrieval of FTIR vertical profiles from an additional 5-10 well distributed stations over a period of several years, with at least 1-2 stations per 30 degree latitude band between the North and the South Pole.

Measurable outcome of success

Success would be if it is shown that the use of vertical CO profiles at FTIR stations and in situ observations from surface networks (e.g. GMD, GAW) provides a measurable added value to the top-down emission estimates of CO derived by inversion of satellite observations. This approach will then be adopted and specific recommendations will be provided to the EO community regarding its scientific, and technological benefits.

Achievable outcomes

Technological / organizational viability: Medium. From the technological point of view the undertaking is entirely feasible. The scientific results will have to be presented and discussed through open dissemination and two-way interactions with the EO community, in order to ensure the involvement of potentially interested actors outside the GAIA-CLIM community.

Indicative cost estimate: Difficult to estimate, but most likely higher than 1 million.

Relevance

This approach should help to ensure better use of observations for the derivation of CO budget on the global scale. It should also indicate future directions for a possible extension of the observational network for CO.

Timebound

The sensitivity analyses will be performed and completed within the framework of the GAIA-CLIM project. A peer-review publication, summarizing the approach and the results, is also planned before the end of the project. The remedy to the gap will require at least several years before sufficient data are obtained.

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Low added value from the use of available vertical CO profile measurements.	Medium	Benefits from using vertical profile information not fully proven.
Too high sensitivity of top-down CO emissions to errors in [OH] or other model parameters	Medium	Message that there are large gaps in our understanding of the atmospheric composition

4.9 G1.13 Uncoordinated lidar and microwave radiometer water vapor measurements

Gap detailed description

Water vapour and carbon dioxide (CO_2) are the principle greenhouse gases (GHGs). CO_2 is the main driver of climate change. Water vapour changes largely happen as a response to the change. Sustained observations of water vapour in the troposphere and UT/LS in the next decades will benefit from the integration of existing networks and observatories and the implementation of a coordinated effort at the global scale. Several stations are routinely performing water vapour measurements with microwave radiometers and with Raman lidars (column and profiles) often at the same site exploiting synergies, but they are often not coordinated thus losing their powerful observing capability at a large scale. However, the construction of such an integrated system will strongly depend on the creation of long-term sustainability of the research based observational initiatives. Long-term commitment of national and international funding agencies to maintain research and development efforts and funding for atmospheric observations is of fundamental importance. In this sense, the joint effort spent by ACTRIS and NDACC to have a common strategy in future, still under implementation, is worthwhile and could strongly improve this gap over the next 5-10 years.

Activities within GAIA-CLIM related to this gap

No activities are expected within GAIA-CLIM related to this gap.

Gap remedy(s)

Remedy

Specific remedy proposed

A federated approach is the most comprehensive remedy in order to minimize the number of redundant initiatives and to maximize the impact of the observational assets. The ESFRI funding might in the near future support this type of federated approach over long term (10 years at least). ACTRIS is a candidate to become an ESFRI research infrastructure starting from 2016. GAIA-CLIM will ideally contribute to this initiative by setting the metrology for both these techniques and thus facilitating their routine use at every site.

Measurable outcome of success

The common strategy recently agreed between ACTRIS and NDACC is already providing good results, but the most optimal supporting measure would be the implementation of a global federated network for the measure of water vapour for lidars and microwave radiometers.

Achievable outcomes

Technological / organizational viability: High, commercial lidars and microwave radiometer facilitate the resolution of this gap.

Indicative cost estimate: High (>5 million)/ medium (>1million), the total cost of this operation is not easy to quantify at the current stage and pending on project funding.

Relevance

Given the lack of funding tools to support such kind of infrastructure at the global scale, the establishment of a federated network is at present the only viable approach.

Timebound

The timeline for the proposed remedy is uncertain at the current stage, but some results maybe reported in 5 year from now when the ESFRI-ACTRIS strategy will be consolidated.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Missing strategy for water vapour monitoring at the global scale	Medium	Lacking of harmonization in water vapour measurements at the global scale for user application.

4.10 G1.14 Currently limited aircraft measurements in Eastern Europe

Gap detailed description

Missing aircraft information for many locations in Eastern Europe cause issues. Very few aircraft currently provide water vapour measurements over Europe, and even fewer O_3. Both of these parameters require additional sensors to be added to the aircraft. There is EUMETNET funding available for a slow increase in the number of aircraft that carry humidity sensors, but nothing is currently planned for O_3.

Activities within GAIA-CLIM related to this gap

We have conducted a study to understand how the gaps might be filled by the inclusion of new airlines. This study has been provided to the E-AMDAR program manager to allow for further development of the program. Including new airlines is a complicated approach and can be expensive, it is therefore unlikely that the gaps will be readily filled in the short term. No other work within GAIA-CLIM is suggested to fill the AMDAR coverage gaps.

Gap remedy(s)

1. Inclusion of new airlines
2. Expansion of Mode-S MRAR usage. This is dependent on air traffic management organisations, air space density and national meteorological services.

Remedy #1

Specific remedy proposed

New airlines identified in the study, or others operating in the correct regions being included in E-AMDAR

Measurable outcome of success

New airlines, providing regular profiles to airports not currently served by E-AMDAR airlines.

Achievable outcomes

Technological / organizational viability: High

Indicative cost estimate: low (<1 million) [depends on airlines, aircraft and software development and installation costs]

Relevance

More airlines operating to more airports would close the coverage gap.

Timebound

Of the order 5 years.

Remedy #2

Specific remedy proposed

More air traffic management secondary surveillance radar interrogating Mode-S MRAR (BDS 4,4). The collection and processing of this data.

Measurable outcome of success

MRAR data from more areas.

Achievable outcomes

Technological / organizational viability: Low

Indicative cost estimate: low (<1 million)

Relevance

This will provide AMDAR quality temperature and wind data. It is only possible in relatively low density air space due to bandwidth limitation of Mode-S

Timebound

Of the order 10 years.

Gap risks to non-resolution

Identified future risk / impact	**Probability of occurrence if gap not remedied**	**Downstream impacts on ability to deliver high quality services to science / industry / society**
Unreliable climate scenarios due to typical use of approximation for the missing data in space and time using interpolation/smoothing	High	Decreased level of confidence of future climate projects at both global and regional scale and impact on mitigation strategies.

4.11 G1.15 Northern Hemisphere bias in NDACC and PANDORA network sites distribution

Gap detailed description

NDACC and PANDORA total column O_3 observation sites are concentrated in Europe and the US. There is definitely a strong bias towards Northern Hemisphere mid-latitudes and a lack of measurements in Asia, the tropics and Southern latitudes. (Note also that NDACC stations often include a variety of instruments measuring total column ozone such as UV/visible spectroscopy, MAX-DOAS, Brewer, Dobson, LIDAR, ozonesonde, FTIR).

The lack of coverage in space and time limits the potential of the networks for e.g. latitudinal dependencies and global trend studies, climate change detection, satellite validation and long-term assessment of ECVs such as O_3. This gap is partially addressed within GAIA-CLIM.

Activities within GAIA-CLIM related to this gap

This will be addressed but only in terms of the development of strategies and suggestions for network extensions, not in terms of implementation.

Gap remedy(s)

One potential remedy is foreseen and explained in more detail below.

Remedy

Specific remedy proposed

Develop strategies for network extension, and long-term preservation of data and measurement capabilities based on an in-depth study of the capabilities of the existing sites as well as a literature study on what distribution patterns would be most desirable (e.g. Kreher et al., 2015).

Measurable outcome of success

A measure for success would be that the suggested strategies and recommendations are picked up by any of the networks and will provide them with useful support for their specific network development strategies.

Achievable outcomes

Technological / organizational viability: medium

Indicative cost estimate: low (<1 million)

Relevance

An important requirement for an observational network to provide a global picture of e.g. O_3 trends is that the measurement sites are strategically placed and sample a sufficiently diverse range of regimes. Most of the current measurement sites, however, are located close to populated areas and with around 90% of the global population living in the Northern Hemisphere, measurement sites clearly favour the Northern Hemisphere. As a result, such a distribution of sites is unlikely to be representative of the global climate and hence the need exists to provide a range of methods to determine the optimal location of sites and to advice on network extension taking into account the different nature of each of the networks of relevance.

Timebound

It will take the approximately 1 year to develop and apply the suggested strategic remedy.

Gap risks to non-resolution

Identified future risk / impact	Probability of occurrence if gap not remedied	Downstream impacts on ability to deliver high quality services to science / industry / society
Most networks will stay strongly NH biased	medium-high	Limited ability to represent global trends correctly
Decision making re network expansion strategies is not based on a sound scientific basis	medium-high	Efforts concentrated in the wrong location and not necessarily where needed most, hence unnecessary escalation of costs

5. Summary

This Deliverable has provided an update to the list of 15 gaps, provided in the second version of the GAID document. It covers progress of activities carried out in the last 16 months with the aim to provide a geographical identification, at European and at the global scale, of the current surface-based, balloon-based and airborne observing capabilities on an ECV-by ECV basis for parameters which can be obtained using space-based observations from past, present and planned satellite missions. This update reflects substantial progress also in the preparation for the creation of a "Virtual Observatory" of ground based and satellite data by establishing common formats for metadata.

The list of gaps covers both the current deficiencies of the global non-satellite observing system, but also the improvements solicited in the atmospheric modelling community. A further in-depth investigation of the provided gaps in the frame of the project will mainly deal with those gaps affecting the global observing system.

The results delivered in the D1.3 and in the upcoming deliverables D1.5, D1.6 and D1.7 will provide the scientific community with new datasets and tools to assess, totally or partly, several of the listed gaps herein. The outcome of this further investigation will be also the main content of the deliverables D1.9 and D1.10 but will also provide substantial input to the version of GAID v4 with improvements in the description of the "gaps remedy" and in the estimation of the gaps "timebound". Potentially, a number of new geographical gaps identified by the review carried out in the frame of task 1.2 and assessed on a scientific basis in the frame of task 1.4 and task 1.5 are reasonably expected to be part of the next version of the GAID as well.

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Glossary

ACTRIS	Aerosols, Clouds, and Trace gases Research Infrastructure Network
CEOS	Committee on Earth Observation Satellites
C3S	Copernicus Climate change Service
E-AMDAR	Eumetnet Aircraft Meteorological Data Relay
ECV	Essential Climate Variable
ESA-CCI	European Space Agency Climate Change Initiative
ESFRI	European Strategy Forum on Research Infrastructures
EUMETNET	Grouping of 31 European National Meteorological Services
FTIR	Fourier Transform InfraRed Spectroscopy
GAW	Global Atmosphere Watch
GEOSS	Group on Earth Observations
IASI	The Infrared Atmospheric Sounding Interferometer
INTAROS	Integrated Arctic Observing system
LS	Lower Stratosphere
MRAR	Meteorological Routine Air Report
MOPITT	Measurement of Pollution in the Troposphere
NDACC	Network for the Detection of Atmospheric Composition Change
NOAA-CIRES	National Oceanic and Atmospheric Administration (NOAA), Cooperative Institute for Research in Environmental Sciences
NWP	Numerical Weather Prediction
PANDORA	Pandora spectrometer system for measure trace gas column amounts
TOA	Top of Atmosphere
UT	Upper Troposphere
WIGOS	WMO Integrated Global Observing System