GAIA-CLIM Report

Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring:

Final review of and update to the GAID from the perspective of WP6

A Horizon 2020 project; Grant agreement: 640276

Date: 12/01/2018

Beneficiary: NUIM

Nature: R

Dissemination level:

Work Package	WP 6
Deliverable	D6.12 Final review of and update to the GAID from the perspective of WP6
Title	
Nature	R
Dissemination	PU
Beneficiary	NUIM
Date	12/01/18
Status	Final
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This document has been produced in the context of the GAIA-CLIM project. The research leading to these results has received funding from the European Union's Horizon 2020 Programme under grant agreement n° 640276.

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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 6. It provides a formal delivery of WP6 input to the process after former informal inputs to prior versions. 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 WP6

Table 1.1. Overview of the gaps identified under work package 6 under GAID V4 and retained in the current deliverable and their identified remedies. Note that G6.07 has been retired as discussed in the next section.

Gap reference	Gap title	Remedies
G6.01	Dispersed governance of high-quality measurement assets leading to gaps and redundancies in capabilities and methodological distinctions	• (R1) Undertake short-term cross-network governance improvements • (R2) Longer-term rationalisation of observational network governance
G6.02	Analysis and optimisation of geographical spread of observational assets to increase their utility for satellite Cal/Val, research, and services	• (R1) Reviews of capabilities leading to action plans for rationalisation of current non-satellite observational capabilities
G6.03	Lack of sustained dedicated periodic observations to coincide with satellite overpasses to minimise co-location effects	• (R1) Optimization of scheduling to enhance capability for satellite Cal/Val activities • (R2) Operationalise use of double-differencing techniques in co-location matchups to minimise the effects of scheduling mismatch
G6.06	Provision of reference-quality measurements where technically feasible on a continuous basis, to maximise opportunities for the validation of satellite and derived products	• (R1) Operationalize measurements to be 24/7 on an instrument by instrument and site by site basis • (R2) Ensuring sustained funding of the non-satellite observing system.
G6.12	Under-capacity of workforce to exploit satellite data and satellite characterisation	• (R1) Undergraduate, masters, and doctoral training in Copernicus-relevant programs • (R2) Instigate professional training, including formal qualification of competency in provision of Copernicus services

2. Detailed update on traces for the gaps arising from WP6

The changes made in the existing gaps identified as relevant for the WP6 activities are based on the following motivations:

- The need for an updated description of gaps and remedies linked to the timing and the progress of the activities carried out within GAIA-CLIM and other EU or international projects;
- The progress within GAIA-CLIM which has contributed to the refinement of the gap analysis since the last version, v4, of the GAID;
- Improved knowledge of the motivation behind the gaps and an enhanced capability to clarify the description of gaps and remedies;
- Identified overlap between remedies to WP6 gaps and remedies to related gaps identified by other WPs.

In particular, noting the almost complete overlap between G5.01 and G6.07 and the need for the GAID to be considered as a whole, it was decided to retire G6.07. Reviews of G5.01 were undertaken to ensure all prescient aspects of G6.07 were retained.

Specific important content edits, beyond grammatical tidying, which have been applied in all cases per gap that remains are as follows:

G6.01 Dispersed governance of high-quality measurement assets leading to gaps and redundancies in capabilities and methodological distinctions

Minor text edits, including to title of remedy 1, to better describe the remedy to the GAID users. Gap dependency changed from G6.07 to G5.01 per the prior discussion.

G6.02 Analysis and optimisation of geographical spread of observational assets to increase their utility for satellite Cal/Val, research, and services

Both the gap and remedy titles were changed so that they were more self-describing to GAID users. The gap description text was substantively redrafted to better reflect the real-world reasons why sometimes co-location is either not feasible or undesirable. The role of the non-satellite segment as a potential insurance policy against catastrophic satellite segment failure arising from, e.g., an extreme space-weather event was more explicitly noted. Reference to work on observational entropy added to the remedy description.

G6.03 Lack of sustained dedicated periodic observations to coincide with satellite overpasses to minimise co-location effects

The gap title, abstract, and description were all altered to make clear the distinction between G6.03 and G6.06. Gap 6.03 refers to instruments which can never be operated 24/7 but where scheduling can be altered (e.g. the measurement is not dependent upon a solar view), whereas gap 6.06 refers to instrumentation that in theory can be run 24/7 but is not currently operated in that manner. A new remedy was added which looks at ways that compliment work on co-location effects quantification by considering means by which the effect may be able to be removed via the use of double differencing techniques. This work was not undertaken in GAIA-CLIM but the approach advocated on at least two “roadshow” events.

G6.06 Provision of reference-quality measurements where technically feasible on a continuous basis, to maximise opportunities for the validation of satellite and derived products

The gap title was modified to better draw the distinction with G6.03, as noted previously. The importance of timely data access was noted in edits to the gap description and remedy and through linking to G5.11 which describes this generic gap. The role of funding, as well as technical impediments, was better highlighted in revisions. Ensuring sustained funding has been added as a distinct remedy.

G6.12 Under - capacity of workforce to exploit satellite data and satellite characterisation

Edits to remedy two to make clearer that the proposed work pertains to both professional development and certification. Some minor clarifications to the first remedy to better articulate the potential role for the academic sector. General tidying of gap text for clarity and specificity.

3. Conclusions

Following several prior informal inputs to the GAID process, here we have formalized the WP6 inputs to the GAID for the first time in a deliverable as agreed at the review meeting in Bergen in May 2017. This review has afforded the opportunity to reflect critically both on the WP6 gaps and how they interact with gaps arising from other WPs. This has led to the removal of one gap (G6.07) and the addition new remedies to G6.03 and G6.06. In addition, several gaps and remedies have been substantively altered.

4. Annex I Updated GAIA-CLIM Catalogue of gaps for WP6

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

G6.01 Dispersed governance of high-quality measurement assets leading to gaps and redundancies in capabilities and methodological distinctions

Gap abstract:

Current governance of high-quality measurement programs is highly fractured. Numerous networks exist at national, regional, and global levels that have been set up and funded under a variety of governance models. This fractured management of observational capabilities can lead to, amongst others: redundancies, spatiotemporal gaps, varied data policies and formats, varied data processing choices, and fractured provision of data. The gap thus contributes to various other more specific gaps identified in the gaps-assessment process undertaken within GAIA-CLIM.

Part I Gap description

Primary gap type:

Governance (missing documentation, cooperation, etc.)

Secondary gap type:

- Spatiotemporal coverage
- Vertical domain and/or vertical resolution
- Knowledge of uncertainty budget and calibration

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 (space agencies, EU institutions, WMO programmes/frameworks etc.)

Non-satellite instrument techniques involved:

Independent of instrument technique

Related gaps:

- G6.02 Analysis and optimisation of geographical spread of observation assets to increase their utility for satellite Cal/Val and research.
- G6.03 Lack of sustained dedicated observations to coincide with satellite overpass to minimise co-location effects
- 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

The G6.01 gap is an effect multiplier on many of the gaps identified in the GAID. As such, its resolution would facilitate resolution of numerous other gaps. Solely a handful of important dependencies are noted here.
The gap identified in G6.02 arises as a result of G6.01. One of the key benefits of resolution of G6.01 would be the potential to rationalise dispersed observational assets.
The resolution to G6.03 will be simpler if a more unified governance of non-satellite measurement networks is achieved and the data is provided from these networks in a more unified manner.
The data policy landscape is a direct result of the fractured governance of observational assets identified in the current gap. Resolving the current gap would aid steps to address the issues detailed in G5.01.

Detailed description:

Non-satellite data sources identified as "reference" and "baseline" quality within GAIA-CLIM have greatly dispersed governance structures. There are numerous national, regional, and global networks, which aim to measure GAIA-CLIM target ECVs to a high standard. This dispersed governance leads to decisions, which, although sensible on an individual network basis, are sub-optimal on a more holistic basis.
This fractured governance both results from but also augments a diversity in historical and present-day funding support, authority, and observational program priorities. Inevitable deleterious results accrue from a fractured governance and support mechanism, which include:

- Geographical dispersal of capabilities
- Unintended and undesirable competition between otherwise synergistic activities
- Different networks take different approaches to data acquisition (measurement practices), data processing and serving, which reduces both accessibility to and comparability of the resulting data.

As such, many of the remaining gaps identified within the GAIA-CLIM GAID are symptoms of the effects of G6.01 remaining unaddressed (see prior section). Although the gap has been identified and articulated here solely for GAIA-CLIM target ECVs, it is symptomatic of broader issues that pervade the governance of all but perhaps for a small handful of non-satellite observational assets and programs. The norm is for multiple parties to be interested in measuring given ECVs and other variables. These parties inevitably undertake a diverse range of approaches, which reduces their comparability and interoperability.

Validation aspects addressed:

- Radiance (Level-1 product)
- Time series and trends
- Representativity (spatial, temporal)
- Calibration (relative, absolute)

Gap status after GAIA-CLIM:

After GAIA-CLIM this gap remains unaddressed

Part II Benefits to resolution and risks to non-resolution

Identified benefit	User category/application area benefitted	Probability of benefit being realised	Impacts
More unified voice for non-satellite data management	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	High	Improved ability to engage in strategy planning. Improved responsiveness in a unified fashion to identified user and stakeholder needs.
Rationalisation of observational assets	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	Medium	Closer to optimal co-location of high-quality instrumentation leading to better characterisation of atmospheric properties.
Consistency of data provision	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	Medium	More consistent provision of data (reduction in variety of portals and / or formats) leading to better ability to utilise the data.
More efficient use of resources	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High Medium	Greater value to funders
Identified risk	**User category/application area benefitted**	**Probability of risk being realised**	**Impacts**
		Medium	

Reduction in funding opportunities for high-quality measurements owing to fractured and competing demands.	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)		Reduced value of observations.
Continued fractured governance leading to sub-optimal management and development of high-quality measurement networks.	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	High	Reduced utility of observational data assets through fractured decision-making.

Part III Gap remedies

Gap remedies:

Remedy 1: Undertake short-term cross-network governance improvements

Primary gap remedy type:

Governance

Specify remedy proposal:

Strengthen existing efforts to ensure meaningful collaboration between potentially synergistic or complementary networks. This could be achieved via several means. Improved cross-governance group representation could be implemented between networks that have similar aims / remits which may start to enforce a degree of collaboration and cross-fertilisation of best practices. A more formal approach, which may be relevant in certain cases, is a more formal network memoranda of understanding. On a more practical and working level, synergies can be realised through involvement in joint research and infrastructure activities such as EU Research Infrastructures, Horizon 2020, and Copernicus grants and service contracts or similar activities outside of Europe. Networks should be actively encouraged to participate in such funding opportunities. Funders should explicitly advertise such opportunities and consider targeted research funding opportunities that aim to build synergies between observational networks.

Relevance:

The remedy would lead to improved cross collaboration and understanding between networks of potential synergies and serve to improve the visibility of activities between synergistic groups.

Measurable outcome of success:

Demonstrable increase in collaboration between networks through joint projects, publications describing joint research outcomes, and participation in network meetings.

Expected viability for the outcome of success:

High

Scale of work:

Programmatic multi-year, multi-institution activity

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 funding agencies
- Copernicus funding
- WMO
- ESA, EUMETSAT or other space agency

Remedy 2: Longer-term rationalisation of observational network governance

Primary gap remedy type:

Governance

Specify remedy proposal:

Take steps to assess and as necessary rationalise the number of networks involved in taking high-quality measurements by merging, where possible, leading to more unified governance and planning for these measurement programs, both regionally and globally. To undertake this robustly requires an analysis of the current observational capabilities and governance structure, which should take account of funding, geopolitical remit, and other relevant factors. This may include in-depth survey interviews and other means to fully understand the role, support-model, and uses of each network. Then a rationalisation plan would need to be produced, circulated, and gain broad buy-in amongst the affected networks and associated global oversight bodies. Mergers should only proceed on a no-regrets basis and should not be enforced, if funding support or other essential support would be weakened as a result of the decision. Merged entities must be scientifically more robust, complete, and sustainable as a result of any merger.

Relevance:

The remedy would make it easier for funding and research communities to interact with the high-quality measurement networks.

Measurable outcome of success:

Reduction in complexity of the "ecosystem" of observing networks through time while retaining and enhancing observational capabilities.

Expected viability for the outcome of success:

Medium

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

More than 10 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

No

Potential actors:

- EU H2020 funding

- Copernicus funding
- National funding agencies
- National Meteorological Services
- WMO
- ESA, EUMETSAT or other space agency

G6.02 Analysis and optimisation of geographical spread of observational assets to increase their utility for satellite Cal/Val, research, and services

Gap abstract:

As a result of fractured governance along with historical funding decisions, the geographical spread of observation systems, which may, in principle, be synergistic, are not presently sufficiently optimised in order to realise the potential benefits for numerous research applications, including, but not limited to, satellite cal/val. For example, a twice-daily radiosonde program may currently be undertaken 100km from a facility with lidars and an FTIR. This dispersion of observational capabilities may substantially reduce their overall value to the user community for multiple uses.

Part I Gap description

Primary gap type:

Spatiotemporal coverage

Secondary gap type:

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 (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
- G6.01 Dispersed governance of high-quality measurement assets leading to gaps and redundancies in capabilities and methodological distinctions

Part of the closure of G1.10 may include a rationalisation of the dispersed observational capabilities in data-sparse regions to maximise both their value and their long-term sustainability.
G6.02 arises as a direct result of G6.01, which is the fractured governance of measurement systems. Addressing G6.01 will strongly facilitate closing G6.02.

Detailed description:

A direct result of the fractured governance of observational networks is that instruments that could derive synergistic analysis benefits are very frequently not geographically co-located. That is to say that an instrument may belong to network or operator X and be located 100km distance from a suite of potentially complimentary instruments belonging to network or operator Y. Because the measurements are geographically dispersed, this serves to reduce their value for numerous applications, including, but not limited to, satellite characterisation. This arises either because they measure complementary ECVs that enable fuller understanding, or measure distinct aspects of the same ECV such that, when combined, a fuller understanding of the measurand accrues. This is especially important for certain satellite instruments such as hyperspectral sounders, which, across the sensed channels, are sensitive to a broad range of ECVs such that to adequately characterise them requires quasi-coincident measures of a broad number of ECVs with an overpass.

In a worst-case scenario of a catastrophic space weather event, there remains a risk that multiple satellites are simultaneously unavailable. To bridge such an event from a climate perspective requires the persistence of a set of in-situ sounding capabilities that can measure what is sensed by the satellite instrumentation across the gap. For the more complex instruments, there is value to this being achieved by a set of super-sites that measure multiple ECVs simultaneously and to high quality.

However, in some cases, there may be good reasons to not co-locate measurements: (1) if long time series already exist, it would be counterproductive to climate monitoring to disrupt the time series by re-locating the instrument to another site; (2) the atmospheric variability may be different from one target species to another, justifying their observation at different sites, and (3) the benefits of a site for satellite validation are not necessarily the same as for other research purposes. For example, a mountain site may be very appropriate for stratospheric observations, but is much less appropriate for satellite validation.

Therefore, a careful scientific analysis should be carried out before implementing a new observation site, and before deciding to re-locate an instrument, taking into account the existing data, the existing sites in the neighbourhood, and the main scientific objectives of the (new) observations. Funding authorities and network coordinators should take these scientific analyses into account before taking decisions about the implementation of new observations or moving existing capabilities.

Operational space missions or space instruments impacted:

Independent of specific space mission or space instruments

Validation aspects addressed:

- Radiance (Level 1 product)
- Representativity (spatial, temporal)
- Calibration (relative, absolute)
- Auxiliary parameters (clouds, lightpath, surface albedo, emissivity)

Part II Benefits to resolution and risks to non-resolution

Identified benefit	User category/Application area benefitted	Probability of benefit being realised	Impacts
Improved characterisation of state of atmospheric column characteristics at co-located sites	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High	Better ability to characterise processes and undertake vicarious calibration of satellites and other instrumentation
Development of novel products combining information from multiple instruments	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	Medium	Improved understanding of relevant processes, new products, and services
Cooperation between investigators, networks, and funders	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	Medium	Better planning and deployment of future observational capabilities
Cost reduction	all application areas	High	Larger benefit/cost ratios
Identified risk	**User category/Application area benefitted**	**Probability of risk being realised**	**Impacts**
Continued lack of strategic placement of research infrastructure, leading to diminished scientific value across the range of application areas.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.) International (collaboration) frameworks (space agency, EU	High	Reduced quality of data services provided by dispersed instruments. Potential research insights arising from co-located observational strategy not realised.

	institutions, WMO programmes/frameworks etc.)		
Threat to instrument long-term continuity arising from not realising full value of assets.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High Medium	Reduction in overall non-satellite measurement constellation capabilities.
Reduced ability to bridge across catastrophic satellite failure.	Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	Medium Low	Many satellite instruments take measurements that are sensitive to multiple parameters. To bridge the effect of catastrophic failure requires surface assets capable of sufficiently mimicking the measurement series.
Observational needs cannot be satisfied because of too high cost	All application areas	Medium	Non-optimised deployment of research infrastructures leads to instruments not working effectively, which reduces available data for many applications

Part III Gap remedies

Gap remedies:

Remedy 1: Reviews of capabilities leading to action plans for rationalisation of current non-satellite observational capabilities

Primary gap remedy type:

Deployment

Secondary gap remedy type:

Governance

Proposed remedy description:

Undertake reviews of high-quality observational assets to assess potential value of different reconfigurations of capabilities to address multiple potential applications. These assessments may be carried out nationally, regionally, or internationally. The assessments must be guided to the extent available by quantitative research and well-formulated stakeholder needs. The reviews would lead to steps towards consolidation of facilities where a clear

overall benefit to multiple data stakeholders is identified in doing so. The analysis may be facilitated by activities such as OSSEs, short period field campaigns or other activities, which permit a quantitative assessment of the benefits of collocating capabilities. It may also make use of a number of existing instrument-rich sites such as the US department of energy's Atmospheric Radiation Measurement (ARM) Southern Great Plains site, Ny Alesund, Lindenberg, Lauder, and others. It may build on work assessing the observational entropy of different measurement configurations (Madonna et al., 2014)

Relevance:

The remedy would lead to rationalisation of observing capabilities to selected super-sites where justified.

Measurable outcome of success:

Evidence of more strategic decision-making and long-term planning in research infrastructure investments and progressive creation of more co-located facilities.

Expected viability for the outcome of success:

Medium

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

High cost (> 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- Copernicus funding
- National funding agencies
- National Meteorological Services
- WMO
- ESA, EUMETSAT or other space agency

References

Madonna, F., Rosoldi, M., Güldner, J., Haefele, A., Kivi, R., Cadeddu, M. P., Sisterson, D., and Pappalardo, G.: Quantifying the value of redundant measurements at GCOS Reference Upper-Air Network sites, Atmos. Meas. Tech., 7, 3813-3823, https://doi.org/10.5194/amt-7-3813-2014, 2014.

G6.03 Lack of sustained dedicated periodic observations to coincide with satellite overpasses to minimise co-location effects

Gap abstract:

There are many non-satellite measurement systems that, in principle, could be used for the purposes of satellite characterisation on a sustained basis. Such measurements are metrologically well characterised and understood. They often measure variables, which are measured or measurable from space. However, many of the measurement systems are discontinuous (discrete) in time and their measurement scheduling is typically made with no regard to satellite-overpass times. This considerably diminishes their value for satellite Cal/Val activities. Better scheduling would increase their intrinsic value for satellite programs.

Part I Gap description

Primary gap type:

- Governance

Secondary gap type:

- Spatiotemporal coverage
- 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 and bodies (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
- Ozonesonde
- Lidar
- FPH/CFH

Related gaps:

- G6.01 - Dispersed governance of high-quality measurement assets leading to gaps and redundancies in capabilities and methodological distinctions
- G6.06 - Provision of reference-quality measurements on a sustained and continuous basis to maximise opportunities for the validation of satellite and derived products

G6.01 - To be addressed with G6.03

Argument: The resolution to the current gap will be simpler if a more unified governance of non-satellite measurement networks is achieved and the data is provided from these networks in a more unified manner.

G6.06 To be addressed with G6.03

Argument: Operationalising instruments that can be operated 24/7 removes the current gap for the instruments affected.

Detailed description:

For some non-satellite instruments, there are geophysical limitations as to when measurements can be undertaken, e.g. an FTIR requires direct line of sight to the sun or a MAX-DOAS can only measure at sunrise/sunset.

Other instruments can and do operate 24/7 and therefore could always capture a co-location, if the satellite passes overhead. For example, both GNSS-PW and microwave radiometers, in principle, operate on a 24/7 basis. G6.06 discusses issues around their continuous operation where this is not yet assured.

But for many non-satellite measurement techniques, it is for financial or logistical reasons that measurements are solely episodic. For example, operational radiosonde launches tend to be twice-daily or at best four times daily at fixed local times. Similarly, for many instrument configurations, lidar operations may be made only when staff are available. These types of considerations effect very many non-satellite measurements, which could, in principle, be better targeted to support EO-sensor characterization by taking measurements much closer to satellite-overpass time. This would reduce the co-location mismatch and thus the attendant mismatch uncertainties. Because funding for these observations typically is not concerned with satellite characterisation, the current sampling strategy ends up being sub-optimal for satellite characterisation. Better aligning sampling strategies with times of satellite overpass, which are predictable a substantial time in advance, would increase their utility to satellite Cal/Val activities.

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)
- Time series and trends

- Representativity (spatial, temporal)
- Calibration (relative, absolute)
- Auxiliary parameters (clouds, lightpath, surface albedo, emissivity)

Gap status after GAIA-CLIM:

After GAIA-CLIM this gap remains unaddressed

Part II Benefits to resolution and risks to non-resolution

Identified benefit	**User category/Application area benefitted**	**Probability of benefit being realised**	**Impacts**
Better intra-satellite and inter-satellite data characterization using the ground (non-satellite) segment through increased pool of co-locations to common non-satellite tie-points	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	Better characterized satellite data will yield improved utilization in derived products, including reanalyses products and resulting services.
More robust funding support for ground-based observations continuity, recognising that ground-based products may have unique value in, e.g., providing vertically resolved profiles to characterise satellites.	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.) International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	Medium	Increased diversity and quality of tools and data available to support service providers to develop bespoke products.
Identified risk	**User category/Application area benefitted**	**Probability of risk being realised**	**Impacts**
Insufficient number of high-quality co-locations in the future that meet co-location match-up criteria to	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS,	High	Reduced confidence in satellite measurements and products and services derived therefrom.

meaningfully constrain (at least some) satellite missions.	operational data assimilation development, etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)		
Inability to use non-satellite segment to effectively bridge across any unplanned gap in spaceborne EO capabilities	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)	Low	Reduced colocations reduces the opportunity to use the non-satellite series to bridge the effects of any gap and yield a homogeneous series. This reduces the value of the satellite record for monitoring long-term environmental changes.
Reduction in perceived utility and value of measurements leading to reduction in funding	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	Low	Diversifying the usage base of the high-quality measurements increases their intrinsic value and helps support widespread adoption.

Part III Gap remedies

Gap remedies:

Remedy 1: Optimization of scheduling to enhance capability for satellite Cal/Val activities

Primary gap remedy type:

Deployment

Secondary gap remedy type:

Governance

Proposed remedy description:

Sustained funding and governance mechanisms need to be instigated and assured that optimise the observational scheduling of relevant high-quality non-satellite periodic (non-continuous) measurements and their provision in NRT for satellite characterisation, if the full potential value of these measures is to be realised. To be effective, space

agencies and non-satellite high-quality observing networks need to work together to design, instigate, and fund a sustained program of targeted measurements that optimise collection and dissemination of non-satellite data in support of the space-based observational segment. The scientific benefits will be maximised if a strategy can be devised, which optimizes the ability of the non-satellite data segment to characterize satellite instrument performance across time, across platforms and across instrument types. This, in turn, points to individual non-satellite observational segments being tasked with helping to characterise across multiple missions from multiple agencies from multiple countries to maximise the scientific value of the cal/val exercise rather than this support being extended and decided on a per mission basis. The strategy should include recourse to other measurements. For example, EUMETSAT have recently introduced a forecasting tool, which can, with high probability, forecast colocations of radio-occultation measurements with a ground-based instrument and any given polar orbiter mission. Finding such occurrences potentially enhances the value of co-locations substantially by making them multi-point comparisons.

Care must be taken for any changes in scheduling not to impact deleteriously upon existing functions and purposes of the non-satellite segment. This implies that, in at least some cases, the remedy will need to involve funding support commensurate with taking new or additional measurements at sites. The most obvious solution would be to instigate an international measurements support program, which would administer and disperse funding support for sustained satellite cal/val with reference-quality data from operators who optimise spending decisions and have as active stakeholders space agencies, non-satellite data providers, and end-users.

Relevance:

Better scheduling would increase the number of co-locations available for measurement systems that are discontinuous in time and increase the intrinsic value of the non-satellite observations for satellite Cal/Val.

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
- National funding agencies
- WMO
- ESA, EUMETSAT or other space agency
- Academia, individual research institutes
- SMEs/industry
- National measurement institutes

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Remedy 2: Operationalise use of double-differencing techniques in co-location matchups to minimise the effects of scheduling mismatch

Primary gap remedy type:

Deployment

Secondary gap remedy type:

Research

Proposed remedy description:

In some circumstances, competing demands make it impossible to better align scheduling of non-satellite measurements to satellite measurements. In other cases, the measurement itself is constrained by the measurement technique. Thus, efforts are required to quantify and reduce the impacts of scheduling mismatches if these cannot be avoided. Within GAIA-CLIM, much effort has been made on quantifying mismatch effects, but there are also potentially tools and techniques to effectively remove the effects, at least to first order. One potential way to do so, which has shown promise for ECVs amenable to data assimilation in NWP models, is double differencing (Tradowsky et al., 2017). This involves the calculation and comparison of the pair of differences to a model estimate between observations that are relatively proximal in space and time under the assumption that the model biases are either negligible or constant. In theory, the technique could be applied to a broad range of ECVs and problems although work would be required to develop such approaches using chemistry models or similar models. Work is additionally required to operationally produce such estimates and tag the co-locations with these estimates, if they are to prove useful in reducing the impact of unavoidable mismatch effects arising from conflicting scheduling requirements.

Relevance:

Reduces the potential impact if a scheduling mismatch is unavoidable by removing a first order dynamical estimate of the effects of the differences in the sensed air mass.

Expected viability for the outcome of success:

High

Scale of work:

Single institution
Consortium

Time bound to remedy:

Less than 5 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- National meteorological services
- Academia, individual research institutes
- National measurement institutes
- SMEs/industry

References

Tradowsky J S, C P Burrows, S B Healy and J Eyre, 2017: A new method to correct radiosonde temperature biases using radio occultation data. J. Appl. Meteor. Climatol., 56, 1643-1661, https://doi.org/10.1175/JAMC-D-16-0136.1

G6.06 - Provision of reference-quality measurements where technically feasible on a continuous basis, to maximise opportunities for the validation of satellite and derived products

Gap abstract:

Many non-satellite reference measurements have the potential to be operated on a continuous basis, or can at least be made available to operate at any time, even if in practice they cannot take uninterrupted observations, e.g. because the measurement technique requires certain geophysical conditions. Providing continuous observations to the extent possible would maximise opportunities for the validation of satellite-based measurements, as well as higher level data products derived from them. For various reasons - including scientific, technical, operational, organisational, and financial reasons - this potential has not been fully realised to date as many reference observations are obtained only intermittently or are discontinuous because of the lack of funding. This gap sets out the general and overarching case for 'operationalising' and sustaining key reference measurements.

Part I Gap description

Primary gap type:

Spatiotemporal coverage

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 (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:

- Lidar
- Microwave Radiometer
- GNSS-PW
- FTIR
- Brewer/Dobson
- UV/VIS zenith DOAS
- UV/VIS MAXDOAS
- PANDORA
- Other non-GAIA-CLIM targeted instrument techniques: sunphotometer

Related gaps:

- G6.03 Lack of sustained dedicated periodic observations to coincide with satellite overpasses to minimise co-location effects

To be addressed with G6.06.

Argument: Operationalising and maintaining instruments that can possibly be operated 24/7 increases the number of dedicated observations to coincide with satellite overpass.

- G5.11 Non-operational provision of fiducial reference-measurement data and some (L2) satellite products may prevent use in Copernicus operational product monitoring

To be addressed with G6.06.

Argument: Provision of reference-quality streams to users in near-real-time increases their utility to numerous applications, including satellite cal/val

Detailed description:

The ECVs addressed in the GAIA-CLIM project (temperature, water vapour, aerosols and atmospheric composition) are measurable by a diverse range of instruments. For some non-satellite instruments, there are geophysical limitations as to when measurements can be undertaken, e.g., FTIR requires direct line of sight to the sun under clear-sky conditions. However, other instruments (e.g., GNSS-PW and microwave radiometers) can, in principle, operate on a continuous basis.

The primary benefits of sustained and continuous operations are two-fold: Firstly, the opportunities to achieve spatiotemporal match-ups with satellite measurements - if this is the primary approach to validation - are maximised; and secondly the validation of higher level data products (spanning the full range from retrieved products, through gridded products, to global reanalysis-based products) is enhanced through the use of continuous, or almost continuous, datasets.

The measurement techniques potentially available to serve as reference measurements for the relevant ECVs include: ground-based microwave radiometry and infrared spectrometry; differential optical absorption spectroscopy (DOAS and Pandora), lidar (including Rayleigh, Raman, rotational Raman and differential absorption lidar), Brewer/Dobson spectrometers, and sunphotometers. There are a number of reasons why, in practice, many measurements are not made on a continuous basis:

- Technical - instruments may require frequent maintenance, adjustment, calibration, or retuning requiring manual intervention, which may not be available on a continuous basis; data acquisition and analysis may still require too many manual interventions;

- Scientific – particular site-specific conditions may prevent measurements being made. For example, cloud conditions may preclude certain measurements (e.g., FTIR – for composition measurements, or for passive measurements of temperature and humidity, also rotational Raman lidar for temperature).
- Operations / logistics – the site may not be manned continuously and instruments cannot, as yet, operate in an automated way; also, the data analysis may not be sufficiently automated.
- Financial - funding authorities often neglect the importance of the non-satellite observing system, whereas it is indispensable for ca/val of the space segment of the observing system and as a transfer standard between successive satellites.

Funding, clearly, plays a key role in determining the capacity for a given instrument to make (continuous) measurements and to rapidly deliver the data. Targeted funding support to meet multiple stakeholder needs including, but not limited to satellite cal/val, could ensure that a station/instrument is capable of more continuous operations and more rapid delivery of the data through higher levels of manning. Funding could also support technical development work to improve the degree of automation of the instrumentation across entire national or international networks and of subsequent data analysis, thereby lowering the cost for continued operations and rapid data delivery.

The purpose of this gap is to recognise this general deficiency in many observing networks, and to encourage support to rectify these deficiencies. A funding mechanism (or mechanisms) needs to be instigated that recognises the costs to be covered by those communities which shall benefit from such sustained operational capabilities (including but not only satellite applications). Such targeted support would ensure sustainability, recognising the substantial diversity of competing demands on resources of in-situ measurement 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
- Calibration (relative, absolute)
- Auxiliary parameters (clouds, lightpath, surface albedo, emissivity)

Gap Status after GAIA-CLIM:

After GAIA-CLIM this gap will remain

Part II Benefits to resolution and risks to non-resolution

Identified benefit	User category/Application area benefitted	Probability of benefit	Impacts

		being realised	
Better intra-satellite and inter-satellite data characterization using the ground segment through increased pool of co-locations to common non-satellite tie-points.	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	Better characterized satellite data will yield improved utilization in derived products, including reanalyses products and resulting services.
More robust funding support for ground-based observations continuity, recognizing that ground-based products may have unique value in, e.g., providing vertically resolved profiles, serving cal/val purposes and being a transfer standard between successive satellites.	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.) Climate research (research groups working on development, validation and improvement of ECV Climate Data Records)	Medium	Diversity of tools and data available to support service providers to develop bespoke products.
More rapid availability of the data to detect possible problems with the satellite and derived products	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	medium	Faster turn-around between observations and data availability; more rapid dissemination of reliable satellite and derived products.
Identified risk	**User category/Application area benefitted**	**Probability of risk being realised**	**Impacts**
Insufficient number of high-quality co-locations in the future that meet co-location match-up criteria to meaningfully constrain (at least some) satellite missions.	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	Reduced confidence in satellite measurements and products and services derived therefrom.
Inability to use non-satellite segment to effectively bridge	Operational services and service development (meteorological	Medium Low	Reduced co-locations reduces the opportunity to use the non-satellite series to

across any unplanned gap in spaceborne EO capabilities.	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)		bridge the effects of any gap and yield a homogeneous series. This reduces the value of the satellite record for monitoring long-term environmental changes.
Reduction in perceived utility and value of measurements leading to reduction in funding.	International (collaboration) frameworks (space agency, EU institutions, WMO programmes/frameworks etc.)	Medium Low	Diversifying the usage base of the high-quality measurements increases their intrinsic value and helps support widespread adoption.

Part III Gap remedies

Gap Remedies:

Remedy 1: Operationalize measurements to be 24/7 on an instrument-by-instrument and site-by-site basis.

Primary gap remedy type:

Technical

Secondary gap remedy type:

Laboratory

Specify remedy proposal:

The precise remedy will be specific to individual cases. But, in general, it requires an assessment on a per-instrument and per-site basis of the current impediments to continuous operation of the asset and to rapid data delivery. Once the reason(s) underlying are known, then work can be undertaken to address them. Generally, these reasons may fall into several categories:

- Technical innovations or modifications to the instrumentation to enable continuous operations;
- Modifications to instrument housing;
- Modifications to data analysis system
- Funding increases to maintain the instrumentation and operations (data acquisition and analysis) and to enable more continuous operation and more rapid data analysis and dissemination.

Automation of observations and data analysis are key to achieving an optimised non-satellite observing system. Another path to more rapid data delivery is centralisation of the data processing in a network, with the condition that the central facility has the required expertise, maintains contacts with the network partners to evolve as the state-of-the-art evolves, and has sustained funding support. Amongst others, resolution of these issues shall require the participation of instrument scientists, site operators, networks, and funding agencies.

Relevance:

Remedy will be specific to individual cases. But, in general, it requires an assessment on a per-instrument and per-site basis of the current impediments to continuous operation of the asset.

Measurable outcome of success:

Increased number of high-quality non-satellite data available, providing a sufficient number of co-locations with satellite measurements on a sustained and more continuous basis, and providing the possibility to bridge successive satellite missions.

Expected viability for the outcome of success:

High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 10 years

Indicative cost estimate (exploitation):

Yes

Potential actors:

- National funding agencies
- National Meteorological Services
- WMO
- ESA, EUMETSAT or other space agency
- Academia, individual research institutes
- SMEs/industry
- National measurement institutes

Remedy 2: Ensuring sustained funding of the non-satellite observing system

Primary gap remedy type:

Governance

Specify remedy proposal:

Providing the resources to enable operationalizing the non-satellite observing system is key to the viability of the above remedy 1. Currently several funding agencies do not sufficiently recognize the importance of sustaining the non-satellite long-term observing system. The stakeholder communities that benefit from the provision of non-satellite reference data should also take the responsibility to provide continued funding support that enables the operators of the system to maintain it to ensure compliance with state-of-the-art quality specifications, and to increase the benefit/cost ratio by proper automation and operationalisation. This could be achieved, e.g., by including the provision of support to the non-satellite observing system in the mandate of relevant funding agencies. Without the perspective of sustained support, the system operators cannot engage in system maintenance and optimization.

Relevance:

Remedy 2 underpins remedy 1.

Measurable outcome of success:

Increased long-term availability of continuous (where technically feasible) high-quality non-satellite data series, providing appropriate sampling of the atmosphere, a sufficient number of co-locations with satellite measurements and providing the possibility to bridge successive satellite missions.

Expected viability for the outcome of success:

High

Scale of work:

Programmatic multi-year, multi-institution activity

Time bound to remedy:

Less than 10 years

Indicative cost estimate (exploitation):

Yes

Potential actors:

- National funding agencies
- National Meteorological Services
- WMO
- ESA, EUMETSAT or other space agency
- SMEs/industry
- National measurement institutes
- Copernicus funding
- EU H2020 funding

G6.12 Under - capacity of workforce to exploit satellite data and satellite characterisation

Gap abstract:

While it is necessary to address technical and organisational gaps that reduce the availability, effectiveness, and quality of satellite characterisation data, such improvements need be exploited by a sufficient workforce capacity to develop and deliver products and services to the marketplace. There is a shortage of skilled personnel to enable activities from the development and deployment of high-quality non-satellite instrumentation, through its processing to its exploitation, in order to successfully provide high-quality data products merging satellite and non-satellite data. If Copernicus services are to realise their full potential, additional training through formal and informal routes is required to train the next generation of data providers, analysts, and users that can fully exploit the substantive investment in space-based and non-space based observational assets and tools and, hence, deliver the envisaged step-change in capabilities and services to the marketplace.

Part I Gap description

Primary gap type:

Governance (missing documentation, cooperation etc.)

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.)
- 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:

Underpins many other gaps but not any critical relationship per se.

Detailed description:

European and global space agencies are investing substantially in improved satellite based remote-sensing capabilities. At the same time, numerous national and trans-national networks are performing high-quality non-

satellite measurements. To realise a return on investment on these observational assets requires a skilled workforce capable of understanding and exploiting these data to their full potential. Experience within the GAIA-CLIM project, which aims to develop a set of tools and approaches to highlight potential applications of non-satellite data to better characterise satellite observations, has highlighted the relatively limited pool of available expertise at the present time. This expertise deficit pertains to varying degrees to all aspects of the end-to-end chain from instrument experts through practitioners capable of delivering products to end-users. Without addressing the educational / training deficit highlighted, it will be impossible to fully realise the value of the substantive investments to date in the space and non-space observational segments. A range of training needs are envisaged from formal educational routes that train the next generation of instrument specialists, data analysts and product developers through to more informal training of those professionals delivering user services and advice. For example, training should be a mandatory service provided by the Environmental European Research Infrastructures.

Validation aspects addressed:

Generic education gap underpins all aspects but is not directly related to any single other gap.

Gap status after GAIA-CLIM:

After GAIA-CLIM this gap remains unaddressed

Part II Benefits to resolution and risks to non-resolution

Identified benefit	User category/Application area benefitted	Probability of benefit being realised	Impacts
Innovative research	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High	New products, analyses, improved observations, and approaches, innovations to research infrastructures
Increase in practitioners capable of delivering user services	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High	Better provision of service and advice to users
Identified risk	**User category/Application area benefitted**	**Probability of risk being realised**	**Impacts**
Lack of capacity to uptake and use	Operational services and service development (meteorological services,	Medium	Lack of competition in marketplace, incorrect provision

Copernicus data services	environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)		of advice and / or services to end users, non-utilisation of observational data to support decision making
Long-term observational operation compromised	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	High Medium	Observational capabilities not sustained leading to critical gaps in service / information provision.
Long-term management of observational capabilities and programs compromised	Operational services and service development (meteorological services, environmental services, Copernicus services C3S & CAMS, operational data assimilation development, etc.)	Medium Low	Next generation of science and service leaders not available leading to reductions in service quality and / or provision.

Part III Gap remedies

Gap remedies:

Remedy 1: Undergraduate, masters, and doctoral training in Copernicus-relevant programs

Primary gap remedy type:

Education/Training

Proposed remedy description:

The exploitation of Copernicus data and services requires the training of a competent workforce of data providers, analysts, managers, and service provision experts. This requires a substantial increase in the number of relevant degree programs at undergraduate, masters and PhD levels. Via the Copernicus academy system, ERASMUS+, national programs, or other avenues, innovative teaching courses should be developed and shared to help develop competency in use of Copernicus data to derive products and services, including the use of satellite and non-satellite data and their appropriate synthesis / fusion / merging.

Perhaps most acute is training at the doctoral level, which provides the next generation of expert scientists capable of maintaining and improving the observational program and driving innovative analysis approaches. In many countries within Europe, there is very limited, if any, access to doctoral funding program support specifically targeted at Copernicus-relevant activities. Increasingly within H2020 / FP, and national projects, work seems shifted to postdoctoral and senior staff at the expense of doctoral training. There, hence, exists a looming capability capacity issue as the existing EO expert workforce is likely not being adequately replaced in time. The Copernicus

program, along with other relevant stakeholders (a.o. ESA, EUMETSAT, national bodies), through the Copernicus Academy or other means, should facilitate a dedicated doctoral training program to questions relevant to Copernicus and dispersed via member states. This would enhance the ability of academic institutions within Europe to engage with Copernicus activities, while simultaneously training potential future researchers to support the sustained operation of Copernicus services. Such doctoral candidates and their supervisors would naturally act as champions of Copernicus within their institutions, potentially aiding uptake within the academic sector, and acting as a force multiplier.

Doctoral studentships are relatively inexpensive and offer an opportunity to explore issues in depth. Many of the gaps and remedies identified by both GAIA-CLIM are amenable to doctoral thesis type work. A targeted doctoral program addressing questions of mutual interest to host institutions and Copernicus would facilitate the provision of a sustainable programmatic capability while simultaneously better engaging academia within the programmatic structure of Copernicus.

Relevance:

The exploitation of Copernicus data and services requires the training of a competent workforce of data providers, analysts, managers, and service provision experts.

Measurable outcome of success:

Increase in range of qualified individuals supporting the Copernicus program provision.

Expected viability for the outcome of success:

High

Scale of work:

- Individually
- Single institution

Time bound to remedy:

Less than 10 years

Indicative cost estimate (investment):

Low cost (< 1 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- Copernicus funding
- National funding agencies

Remedy 2: Instigate professional training, including formal qualification of competency in provision of Copernicus services

Primary Gap remedy type:

Education/Training

Specify remedy proposal:

The effective provision of services from Copernicus data requires users to have confidence about the quality of the service provider. This would be greatly aided by a program of training and certification of competency targeted at professionals working in the field who deliver user services and advice. This would assure that a basic level of service provision in the use and analysis of satellite and non-satellite data was attained by the party offering the service. This may result from a combination of proof of prior service engagement with users and / or formal training course(s) attendance. Service providers should show competency in accessing relevant observational data and products, their appropriate fusion, and the provision of advice to the user. A Copernicus service provision certificate could be provided by one or more accredited institutions offering training in required competencies with appropriate assessment. Training should be provided in a range of languages and need not be limited to European domain.

Relevance:

Ensure that users can be confident of competency of service provider to deliver relevant information services.

Measurable outcome of success:

Increased uptake of Copernicus services by end-users.

Expected viability for the outcome of success:

High

Scale of work:

- Individually
- Single institution

Time bound to remedy:

Less than 3 years

Indicative cost estimate (investment):

Medium cost (< 5 million)

Indicative cost estimate (exploitation):

Yes

Potential actors:

- Copernicus funding
- National funding agencies
- National Meteorological Services
- ESA, EUMETSAT or other space agency
- Academia, individual research institutes
- SMEs/industry
- National measurement institutes