Gap Analysis for Integrated Atmospheric ECV CLImate Monitoring

WP1: Mapping Geographical Capabilities

D1.6: "Report on data capabilities by ECV and by system of systems layer for ECVs measurable from space"

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1	Fabio Madonna, Peter Thorne, Marco Rosoldi, Emanuele Tramutola	01/08/16	First revision round by Task 1.2 partners
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3	Fabio Madonna	07/09/16	Revision and integration to reconcile D1.6 and D1.7 based upon reviews
4	Fabio Madonna	13/09/16	Final version

Table of Contents

[1] Introduction

1.1 Scope and context

The goal of GAIA-CLIM WP1 is to "*identify the geographical capabilities and gaps in the existing surface-based and sub-orbital observing systems at the European and at the global scale for the characterization of EO measurement performance*". Within this context, Task 1.2 aims to provide a geographical review of the existing non-satellite observing capabilities at the global scale, identifying data capabilities for a subset of Essential Climate Variables and for the different layers of the global system of non-satellite observing systems articulated in the deliverable D1.3 (arising from Task 1.1). The ECVs (Bojinskii et al., 2014) considered in this study are those identified as target variables in the project Grant Agreement and described in the table 1.

Atmospheric	Oceanic	Terrestrial
Temperature	Sea Surface Temperature	Snow cover
Water vapour	Sea Surface Salinity	*Fraction Available Photosynthetic Absorption of Radiation*
Carbon dioxide		*Spectral albedo*
Methane		*Leaf Area Index*
Ozone		
Aerosols		
Carbon Monoxide		
Formaldehyde		
Nitrogen Dioxide		
VOCs		
Black and brown carbon		

Table 1. ECVs and additional variables for which capabilities will be classified in a system of systems approach and mapped in GAIA-CLIM. Bolded variables will, in addition, be further analysed in terms of measurement uncertainty mapping under WPs 2-5. The full list of GCOS ECVs is available at https://www.wmo.int/pages/prog/gcos/index.php?name=EssentialClimateVariables. Table is a direct copy from the Grant Agreement.

Specific goals of task 1.2 as given in the Grant Agreement are:

- To document and define system properties for each layer in a 'system of systems' approach to enable rigorous EO data characterization (in cooperation with task 1.1)
- To provide a geographical identification, at European and at the global scale, of 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.
- Preparation for the creation of a "Virtual Observatory" of ground based and satellite data by establishing common formats for metadata.

Deliverables D1.6 and D1.7 complementarily describe the approach followed to review the existing observing capabilities, summarise the results of the geographical gap assessment and of the classification for each target ECV by the system of systems model based on the Maturity Matrix Assessment (MMA), described in the deliverable D1.3, and then provide necessary discovery and measurement metadata.
In particular, D1.6 provides:

- An overview of the of existing non-satellite observing capabilities;
- A short description of the MMA and its application (fully documented in D1.3);
- The results of statistical analysis obtained from the maturity matrices collected during the 18 months of Task 1.2 activity, including a redundancy exercise to quantify the level of subjectivity of the MMA;
- Recommendations related to the maturity matrix data collection, the MMA usage, and the expected impact of the work carried out within Task 1.2.

The D1.7 then discusses:

- The technical solution and metadatabase collected in Task 1.2 as well as the proposed protocol for a common metadata format for GAIA-CLIM;
- The collected metadata and the related general statistics (i.e by ECV, by network, etc.);
- The statistics of the geographical representativeness in terms of density of measurements in the metadata database per 1000 km^2;
- The preliminary architecture of the Virtual Observatory (VO) for the visualization of the collected meta-dataset.

Within the current deliverable, metadata from existing networks have been retrieved, reviewed and used to create a discovery metadataset (WMO, 2015) consistent with ISO19115 (ISO, 20014). When metadata were either absent or only partly available, required information has been gathered from the available documentation or involving directly the network PIs and data managers. In addition, the discovery metadataset includes the scores of all the maturity matrices (D1.3) collected for each of the reviewed networks: scores are representative of the level of maturity of each network. This implies that network maturity level has to be intended as the maturity of the network's core stations and operations. A further granularity of assessment would be possible whereby the assessment was performed either site-by-site and / or instrument-by-instrument. Such an in-depth assessment was not practical within the time and resource constraints available.

1.2 How the assessment was performed

Task 1.2 entrained expertise from several partners involved in the GAIA-CLIM project to enable a comprehensive metadata-based mapping of capabilities and classification of the reviewed datasets maturity according to the criteria derived in Task 1.1 and discussed in deliverable D1.3. As noted above, the assessment was decided to be performed network-by-network rather than at a finer granularity given the available time and resource constraints. Metadata collection and maturity assessment were required to be consistent. This aspect was greatly facilitated by an in-person meeting hosted by KNMI in May 2016, which resolved a number of fundamental questions about how to perform the exercise and ensured a degree of homogeneity in approaches.

In the context of the broader GAIA-CLIM project, Task 1.2 significantly contributes to objective S2 that aims to "map in geographical space, and in terms of temporal congruence with EO measurements current and known future ground-based and sub-orbital capabilities into the system of systems framework for several of those atmospheric, oceanic and terrestrial GCOS ECVs that are measured from space".

[2] Overview of existing non-satellite observing capabilities with the potential to characterise satellite measurements

To accomplish the objectives outlined in Section 1, the work undertaken within Task 1.2 has included the following steps:

1. Study and comparison of several international metadata standards used in geo-information and atmospheric science. The ISO19115 standard was selected as the ideal solution for the discovery metadata type, also due to their large use within other synergistic projects and programmes (WIS, INSPIRE, GEOSS, ESA-CCI).
2. Provision of a customized web-interface for the metadata compiling, which is available to project participants (restricted access, description reported in the deliverable D1.7)
3. Undertaking a review of the existing ground-based networks measuring the core ECVs listed in Table 1.
4. Collecting information for the application of the maturity matrix approach;
5. Collection of discovery metadata at a station level.

Satellite measurements are not continuous in either space and/or time. The most common types are sun-synchronous polar orbiters or Geostationary satellites, although there are several additional orbit types. Satellite EO sensor characterisation capabilities are geographically identified according to the EO instrument characterisation requirements of the current and upcoming satellite missions, described by CEOS in The Earth Observation Handbook [http://www.eohandbook.com/]. Similarly, many of the non-satellite measurement systems are only periodic measurements for a range of reasons related to one or more of: the intrinsic nature of each measurement technique, to the different scientific missions, user requirements, and the associated commitments of stations and networks, and to available resources.

The Task 1.2 analysis will therefore in addition include an assessment of the degree of temporal sampling mismatch for those measurements which are discontinuous in nature whereby there can exist a range of sampling time offsets to different EO platforms depending upon their orbital configuration e.g 00 and 12Z sondes provide a better time match to a 10 am LST (Local Solar Time) orbit than a 5 pm overpass by a polar orbiter. The metadata tool (D1.7) and the analysis performed in task 1.2 aims at maximizing the value of existing observations for EO providers and users and robustly forms the basis for the mapping facility being developed under Task 1.3.

Domain	Network	Coverage	ECV	Maturity Matrix
Atmosphere	ACTRIS	regional	Aerosol, NOx, VOCs	
Atmosphere	AD-Net	regional	Aerosol	
Atmosphere	AERONET/ PHOTONS	global	Aerosol	
Atmosphere	AGSNET/ CSIRO	global	Aerosol	
Atmosphere	AGAGE	global	Aerosol	
Atmosphere	AMeDAS	regional	Temperature	
Ocean	ARGO	global	Temperature and saliitnity	
Atmosphere	ARM	regional	Various	
Atmosphere	BSRN	global	Aerosol (Radiation)	
Atmosphere	CAPMoN	regional	Aerosol , NOx, O3	
Atmosphere	CARSNET	regional	Aerosol , water vapor	
Atmosphere	CASTNET	regional	Aerosol , O3	
Atmosphere	CAWNET	regional	Aerosol	
Atmosphere	CREST	regional	Aerosol	
Atmosphere	EANET	regional	Aerosol , O3	
Atmosphere	EARLINET	regional	Aerosol	
Atmosphere	EMEP	regional	Aerosol	
Atmosphere	EPA	regional	Aerosol	
Atmosphere	ESRL	global	Aerosol, CO2, CO, CH4, VOCs	
Atmosphere	EUREF	regional	Water vapor	
Atmosphere	EuroSkyRad	regional	Aerosol	
Land	FLUXNET	global	Surface Albedo and fluxes, CO2, water vapour	
Atmosphere	GAW GALION	global	Aerosol	
Atmosphere	GAW PFR	global	Aerosol	
Atmosphere	GPS-Met	global	Water vapor	
Atmosphere	GRUAN	global	Temperature, Water vapor	
Atmosphere	GSN	global	Temperature	
Atmosphere	GUAN	global	Temperature, Water vapor	
Atmosphere	ICOS	regional	CO, CO2, CH4	

Table 2. List of the 49 networks reviewed in the frame of GAIA-CLIM task 1.2 for which complete discovery metadata have been collected. The first column reports the measurement domain, the second the network acronym, the third, the network coverage, the fourth includes the number of measured ECVs, and the last column reports the availability of one or more maturity matrix for the corresponding network (available if coloured in grey).

Domain	Network	Coverage	ECV	Maturity Matrix
Atmosphere	IDAF	regional	Aerosol, O3, NO2	
Atmosphere	IGS	global	Water vapor	
Atmosphere	IMPROVE	regional	Aerosol	
Atmosphere	LALINET-ALINE	regional	Aerosol	
Atmosphere	MESONET	regional	Temperature, Water vapor	
Atmosphere	MPLNET	global	Aerosol	
Atmosphere	MWRnet	global	Temperature, Water vapor	
Atmosphere	NDACC	global	Various	
Atmosphere	NPS	regional	Aerosol	
Atmosphere	RAOB	global	Temperature, Water vapor	
Atmosphere	RBSN	global	Temperature	
Atmosphere	Scripps CO2	regional	CO2	
Atmosphere	SHADOZ	global	O3	
Atmosphere	SKYNET	regional	Aerosol	
Atmosphere	SMEAR	regional	Temperature, Water vapor	
Atmosphere	SUOMINET	global	Water vapor	
Atmosphere	SURFRAD	regional	Aerosol (Radiation)	
Atmosphere	TCCON	global	CO, CO2, CH4	
Atmosphere	TOLNET	regional	O3	
Atmosphere	USCRN	regional	Temperature, Water vapor	
Atmosphere	WOUDC	global	O3	

Table 2. Continuation.

The current review of the existing observing non-satellite capabilities at the global scale has allowed us to identify 54 plausible networks and 2 aircraft permanent infrastructures for EO Characterisation in the context of GAIA-CLIM currently operating on different spatial domains and measuring different ECVs using one or more measurement techniques (Table 2). Complete discovery metadata have been collected thus far for all the stations belonging to 49 of the 54 networks. For the remaining networks, some degree of discovery metadata is available as well, although it was not possible to date to provide complete metadata because of a lack of information about their current status of operation. Their existence is confirmed by their continued participation in international programs, like the GAW program. At present the GAIA-CLIM metadataset does not include any discovery metadata for the aircraft observation programs (e.g E-AMDAR, IAGOS). Task 1.2 partners have found challenges to transfer and convert the existing aircraft metadata into the GAIA-CLIM ISO profile (see D1.7). This will be reconsidered and a solution will be found for the metadata visualization through the VO GUI, currently under implementation.

All the collected metadata are already available on the CNR GAIA-CLIM web interface (gaiaclimmd.imaa.cnr.it) or using a QGIS-based desktop application available on demand. This tool allows users to visualize using GIS technology both the existing satellite and non-satellite observing capabilities.

The collected discovery metadata includes information about:

- Topic category code (Climatology meteorology, atmosphere; Environment, Health, Ocean...)
- Begin date of the station historical data archive;
- Minimum value of the range covered by the measurements, mainly representing the station altitude level;
- Maximum value of the vertical range covered by the measurement;
- Discipline (Atmospheric Science, Meteorology ..);
- Measurement instrument;
- Product, i.e. ECV (temperature, water vapour, CO2, aerosol, ...);
- Platform type (fixed or mobile);
- Measurement feature type (profile, column, surface, tower, aircraft);
- Maturity matrix score (at a network level).

Below a snapshot is shown of the worldwide stations measuring at the surface at least one of the ECVs reported in Table 1, be that in-situ, integrated on the atmospheric column or providing range-resolved profiles. The assessment summarised in Figure 1 is attained through loading all the geo-locations available in the collated WP1 metadataset (see D1.7 for further details). These images are currently generated using the CNR-IMAA geo-portals (http://test.geosdi.org/gaiaclim and at gaiaclimmd.imaa.cnr.it), but a similar functionality will be made available in the GUI of the GAIA-CLIM VO being developed under Task 1.3 and to be incorporated under WP5 development.

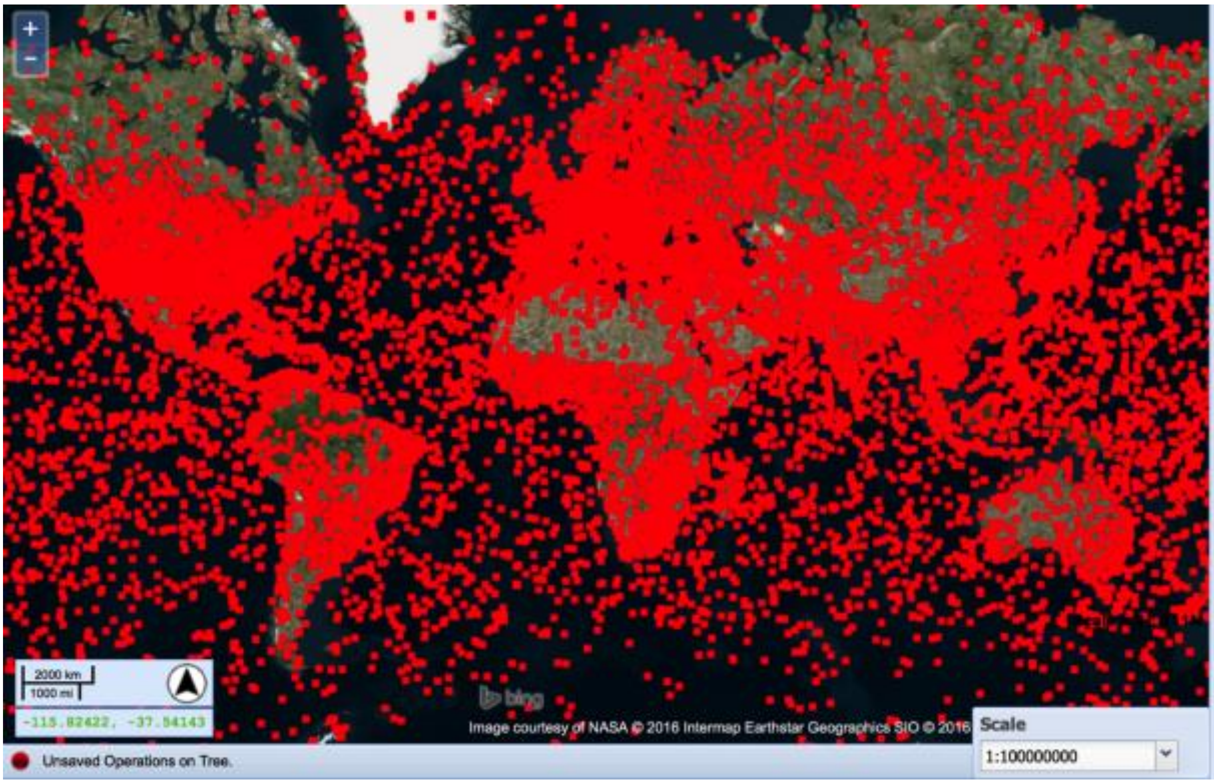


Figure 1: Worldwide stations measuring at the surface or over the ocean at least one of the ECVs reported in Table 1, in-situ, integrated on the atmospheric column or providing range-resolved profiles.

Figure 1 shows how, as expected, the most remote places of the Earth are the regions where the density of measurement stations is lower. It is important to remember that this document is mainly focussed on the reporting of higher-quality existing non-satellite observing capabilities at the global scale and to define network properties compared to the 'system of systems' approach proposed in D1.3. The Figure therefore omits certain observational capabilities at local, national and regional scales that we a priori consider highly implausible to be suitable for directly characterising satellite observations. Geographical gaps discussed on the basis of the geographical representativeness of each measurement station in the observing system derived by the outcome of this study are described in more detail within D1.7. The content of D1.7 will be used, upon further discussion, for the elaboration of specific geographical gaps which will be reported in subsequent versions of the Gaps Assessment and Impacts Document (GAID) (v4 and subsequent versions). It was not possible to incorporate such information into the v3 release which was concurrent with the present deliverables.

[3] Measurement Maturity Matrix Assessment (MMA)

The Measurement Maturity Matrix Assessment (MMA) is described in detail within the deliverable D1.3, which outlines both the proposed system-of-systems rationale and also a set of objective criteria against which the measurements from a given candidate site or network can be assessed. The interested reader is referred to this deliverable for further information than is given in the brief summary that follows.

The MMA proposes the following three tiers of measurement capabilities (Figure 2):

- **Reference measurements**. These measurements have a long-term commitment, deep understanding of the measurement system, traceability, metrologically robust uncertainty quantification, are well documented etc. Such measurements can be used with very high confidence that the true measurand lies within the reported measurement interval.
- **Baseline measurements**. These constitute a set of long-term sustained measurement capabilities that users can rely upon. Although measurements are well understood full traceability has not been attained.
- **Comprehensive measurements**. These consist of remaining capabilities which may or may not have a long-term commitment and are typically less managed observational assets.

Such a tiered capabilities concept could, theoretically, be extended to space-based capabilities but is proposed at this time to be applied to the non-satellite observational components. Adopting a specifically tiered network-of-networks approach to observing system design is foreseen in D1.3 to have multiple benefits around the appropriate use and analysis of available observations.

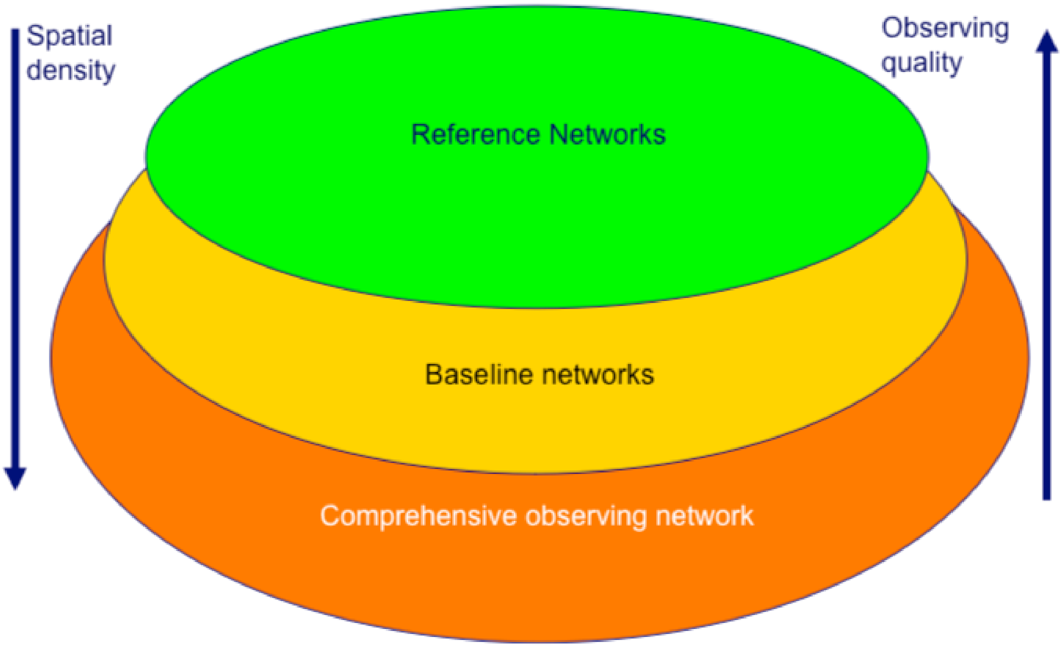


Figure 2: Posited system of systems approach to observing system maturity arising from Task 1.1.

[4] Classifying existing capabilities by system of systems layer for each target ECV

Articulating and agreeing a system of systems approach is a necessary, but not a sufficient, condition to enable its adoption and usage. The first step required is to agree objective criteria against which possible contributing programs or networks are operating. We have taken as a starting point the CDR maturity assessment criteria arising from the FP7 CORE-CLIMAX project (Su et al, 2013). There are aspects of measurements that are distinct from CDRs, which requires somewhat distinct guidance to be developed. The assessment is performed against quantifiable aspects of the measurement series under seven primary strands:

1. Metadata
2. Documentation
3. Uncertainty characterisation
4. Public access, feedback, and update
5. Usage
6. Sustainability
7. Software (optional)

Metadata	Documentation	Uncertainty characterization	Public access, feedback and update	Usage	Sustainability	Software (optional)
Standards	Formal Description of Measurement Methodology	Traceability	Access	Research	Siting environment	Coding standards
Collection level	Formal Validation Report	Comparability	User feedback mechanism	Public and commercial exploitation	Scientific and expert support	Software documentation
File level	Formal Measurement Series User Guidance	Uncertainty Quantification	Updates to record		Programmatic support	Portability and numerical reproducibility
		Routine Quality Management	Version control			Security
			Long term data preservation			
Legend						
1	2	3	4	5	6	Not applicable

Figure 3: Example of maturity matrix assessing the NDACC (Network for the Detection of Atmospheric Composition Change).

Each strand has two or more sub-strands. Within each sub-strand the maturity is assessed as being between level 1 and level 6 (sometimes 6 is not used) with the level reflecting the maturity against that sub-strand. The full details are available in D1.3 and are not repeated here for brevity. The assessors were provided with D1.3 and based their assessment on the guidance therein.

Typically, a reference quality measurement program would score 5s and 6s against relevant criteria, a baseline capability 3s and 4s and a comprehensive capability 1s and 2s. The final assessed maturity shall depend upon what is important to the user, but the exercise provides an objective framework to assess where different observations sit.

The guidelines also permit agreement of rules of the round. In the case of the exercise herein it was agreed to perform the assessment on a per network rather than a per site basis and that the final decision regarding tier assessment would place high weight on the uncertainty strand and not consider Usage or Software in the final assignment to categories.

An example of maturity matrix collected in the frame of task 1.2 is provide in Figure 3 for NDACC network as filled in by BIRA-IASB, which is the official contact of this network for GAIA-CLIM project.

The scores reported in Figure 3 show, for example, that NDACC can be considered, according the MMA, as a reference network in sub-categories like data traceability, but for the uncertainty quantification the network it currently assessed as being at a baseline level (score = 4). The full set of assessment results for all assessed networks is given in Appendix A using one cumulative table, while all the matrices in the same shape of the one shown in Figure 3 for NDACC are available on the GAIA-CLIM website, under WP1 section (http://www.gaia-clim.eu/project-structure/wp1).

[5] Maturity Matrix Assessment: Summary statistics

The maturity matrix collection has been carried out by the Task 1.2 partners based upon their individual areas of expertise and their involvement in several international measurement programme and networks for the monitoring of climate and environment. Significant effort has been made by the partners to fill in the matrix with scores representing, in the most reliable and consistent way possible, the level of maturity of each network (i.e. common level of maturity shared at minimum by the network's core stations). In those cases where filling in the matrix has been considered challenging by the partners for several reasons (e.g. low level of experience in the considered network, limited available documentation and datasets, etc. etc.), an assessment from / aided by the assessed network PI has been solicited with the aim to maximize the reliability of the information reported in the matrix. In such cases, the partners worked to fully support the network PIs to guarantee a consistent compiling of the maturity matrix.

In this section, the statistical analysis obtained from the maturity matrices collected during the 18 months of activity of Task 1.2 is reported. It has not been possible to classify a small number of additionally identified potential target networks using the MMA. In most cases this was because network PIs have not yet been forthcoming with the required information to complete the assessment. However, overall about 75% of the expected assessments have been successfully collected and statistically investigated and, though beyond the limits of the task time schedule, an additional effort to collect the missing information will be spent to incorporate them in the metadataset at a later stage and make them available through the VO by the end of the GAIA-CLIM project.

It is also worthwhile to reflect upon overall impressions from during the metadata collection exercise which may have implications for future applications:

- The importance and value of this assessment exercise was felt more strongly by those networks/infrastructures supported by large funding programs or having an international leading role (e.g. ARM, ACTRIS, NDACC, ….);
- Most of the participants were happy to contribute and acknowledge following the assessment the relevance of adopting a maturity matrix assessment for the performance of their networks;
- Maximum care has been adopted by all the maturity matrix compilers to provide information as reliably as possible. To this end, in a few cases, a plenary discussion with all the network representatives has been carried out and was felt to be useful;

Three (Russian, Chinese and Canadian) networks were not responsive at all (e.g. CAWNET, CARSNET, CISLiNet), though they are officially involved in international programs like GAW.

In the following sub-section 5.1-5.6, the statistical analysis of the maturity matrices is summarised for each of the categories and for the corresponding sub-categories. In section 5.7, a summary of the outcome of the analysis is presented.

As discussed in section 4, a network can be classified as "Reference" in one of the sub-categories if it has a score 5-6, "Baseline" with a score 3-4, and "Comprehensive" with a score 1-2. The reader should bear in mind that the choice of candidate networks to consider with the MMA likely skews towards the results presented herein towards higher scores on average than those that would be attained by the non-satellite observing system as a whole by construction. To improve the quality of the presented assessment and, in general, to support the MMA usage, in Section 6 a redundancy exercise is presented with the aim to quantify the level of subjectivity of the approach. Further recommendations to apply the MMA in the most possible robust way are provided in Section 7.

5.1 Metadata

Figure 4 reports the frequency of occurrence for the "Metadata" category of the MMA which is made up of three sub-categories (Standards, Collection level, File level). Metadata is key to understanding the measurements and enabling their subsequent analysis / reprocessing. The plots show that:

- Relevant international standards for metadata are assessed as having been adopted by most of the networks we have considered;
- Collection level metadata for the majority of networks can still be improved from a baseline to a reference level;
- Classification of file level metadata appears to be robust throughout the networks and includes for most of them complete location, file level and measurement specific metadata.

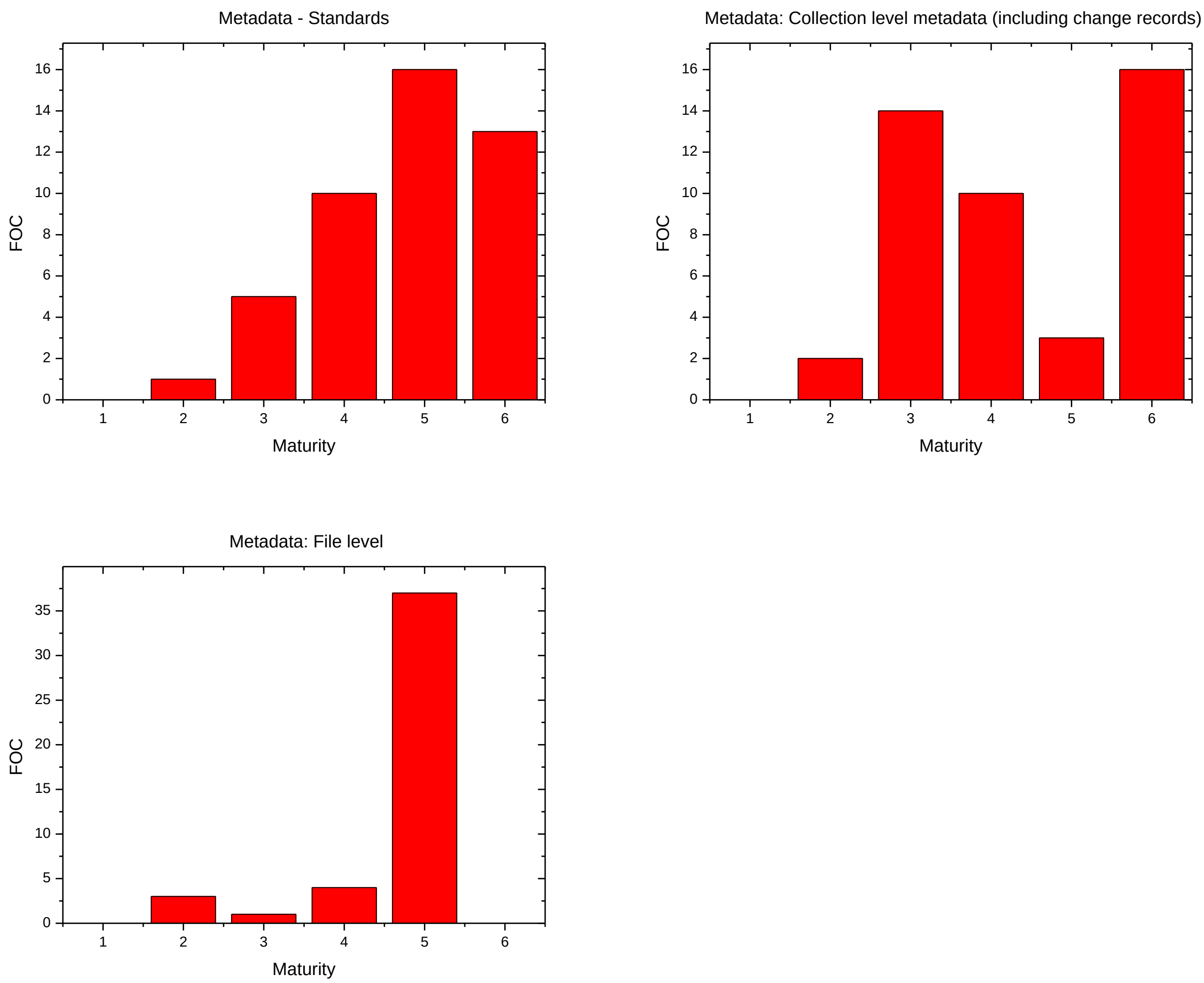


Figure 4: Frequency of occurrence of the maturity matrix scores for the three sub-categories (Standards, Collection level, File level) of the main category "Metadata".

5.2 Documentation

Figure 5 reports the frequency of occurrence for the "Documentation" category of the MMA, which is made up of three sub-categories (Formal description of measurement methodology, Formal validation report, Formal measurement series User Guidance). The plots show that:

- A high level of maturity is assessed for the provided formal description of measurement methodology with the provision of journal papers on measurement system updates published for most of the assessed networks;
- The level of maturity for the provided formal validation reports is characterized by a score higher than 4 for the majority of the networks, which indicates the availability of published reports or journal papers on product validation or on intercomparison to other instruments;
- For the provision of formal guidance to perform measurements, documentation of manufacturer independent characterization and validation is provided by the majority of the networks. However, more of the networks attain baseline or comprehensive than reference scores overall in this sub-category, highlighting it as an area where improvements could, in general, be made.

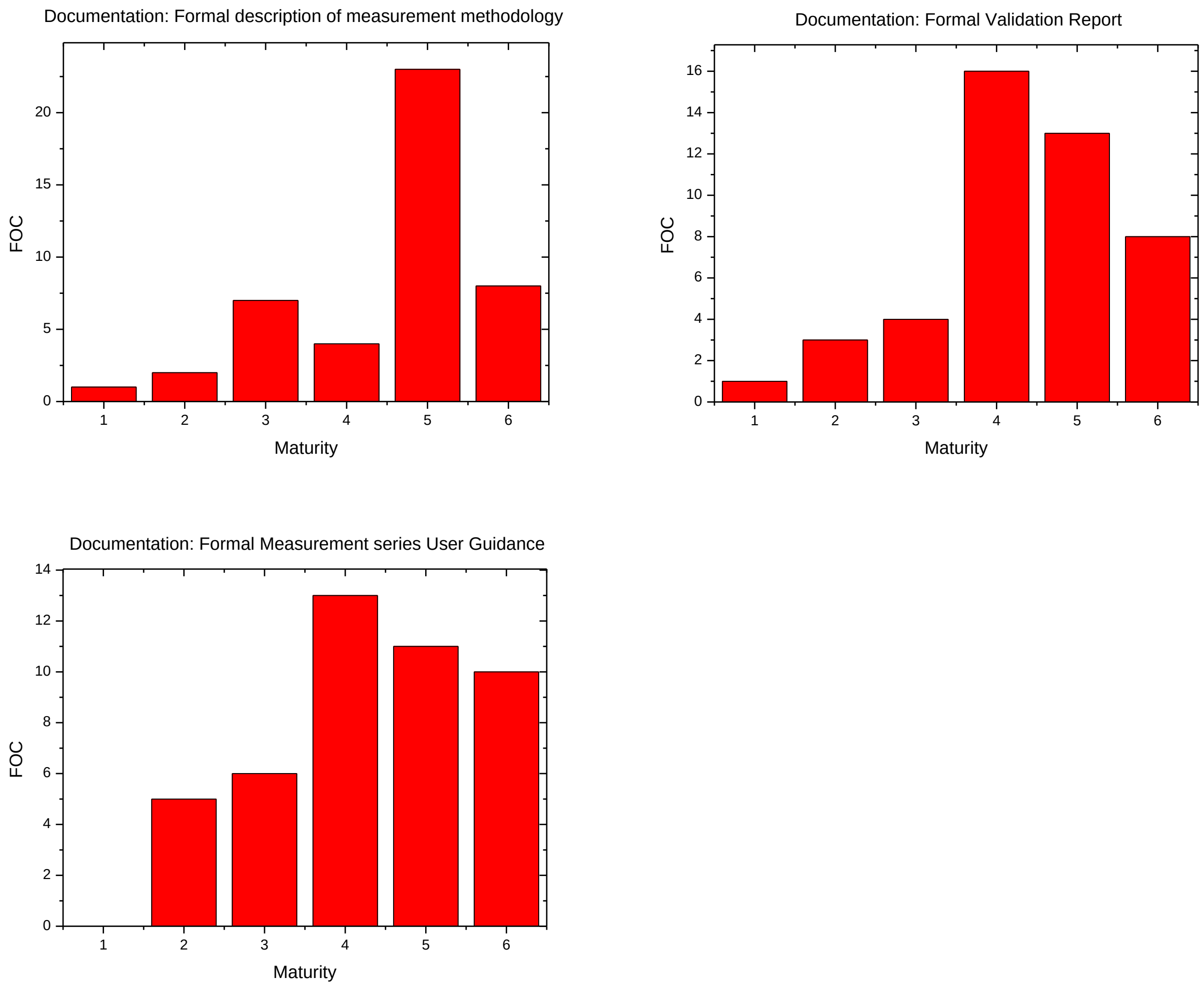


Figure 5: Frequency of occurrence of the maturity matrix scores for the three sub-categories (Formal description of measurement methodology, Formal validation report, Formal measurement series User Guidance) of the main category "Documentation".

5.3 Uncertainty

Figure 6 reports the frequency of occurrence for the "Uncertainty" category of the MMA, which is made up of four sub-categories (Traceability, Quantification, Comparability, and Routine quality monitoring). The plots show that:

- Measurement traceability is assessed as constituting a reference level only for about 50 % of the networks;
- Quantification of uncertainty is of extremely mixed maturity level among the different networks, and only a few of them can be ranked with a score corresponding to the level of a reference network;
- Inter-comparison and cross validation are well established mechanisms of uncertainty quantification and validation in less than a half of the reviewed networks, highlighting an area in which many networks could improve in future;
- Routine quality monitoring is performed at a high level by most of the networks with a clear majority assessed as meeting standards expected of reference networks.

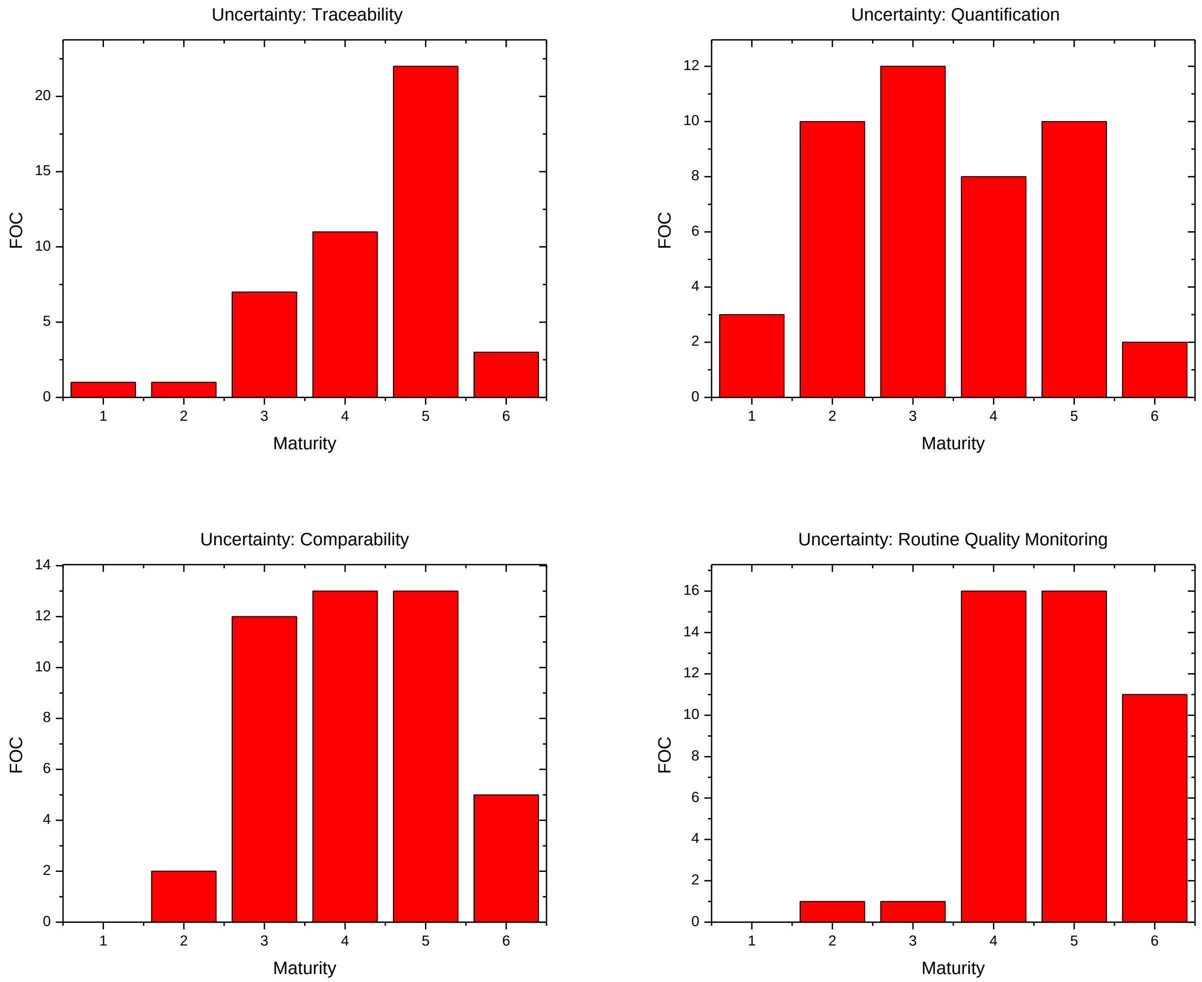
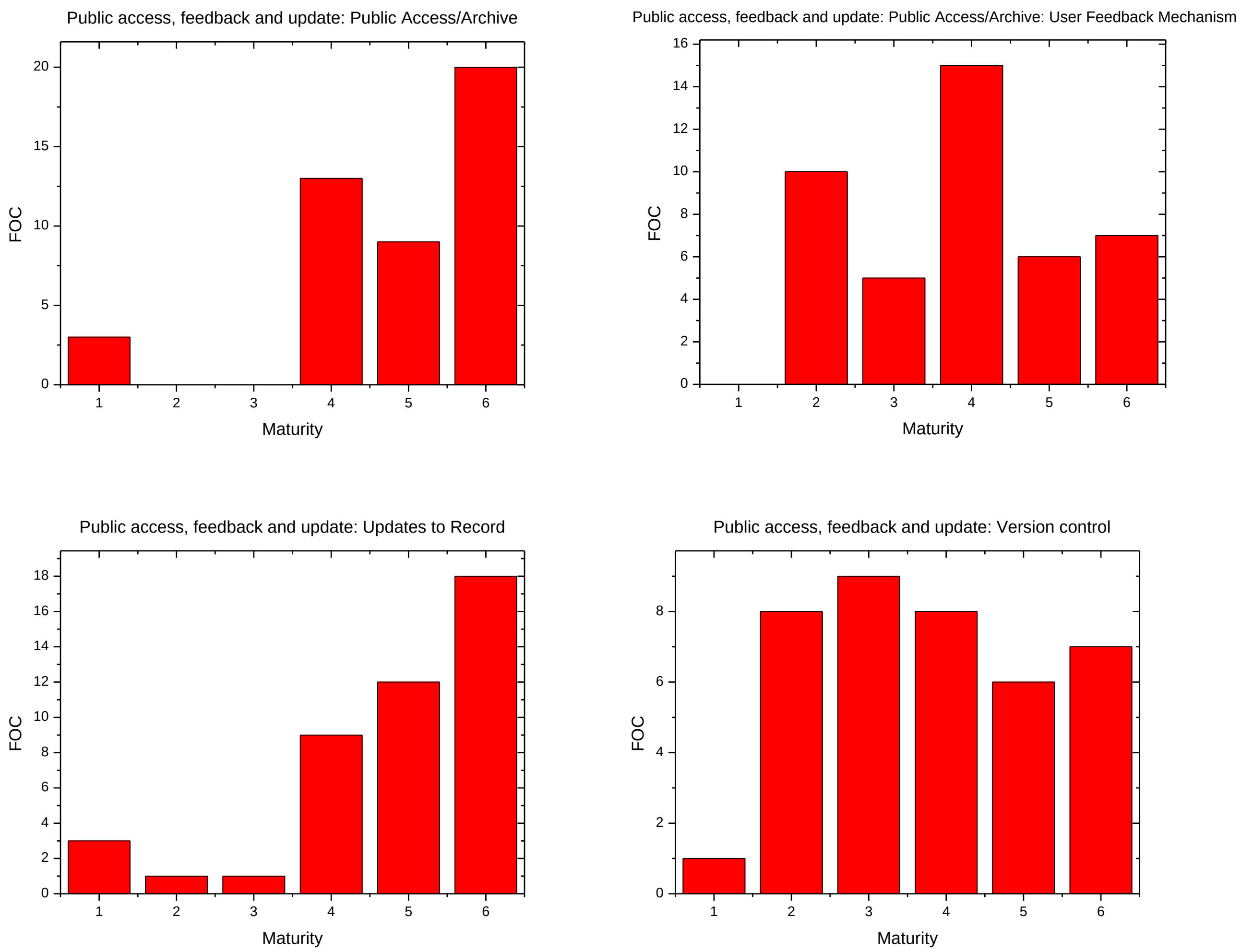


Figure 6: Frequency of occurrence of the maturity matrix scores for the four sub-categories (Traceability, Quantification, Comparability, and Routine quality monitoring) of the main category "Uncertainty".

5.4 Public access, feedback and update

Figure 7 reports the frequency of occurrence for the "Public access, feedback, and update" category of the MMA, which is made up of four sub-categories (Public Access/Archive, User Feedback Mechanism, Research, and Exploitation, Long-term data preservation). It must be acknowledged that, in general, it was not always easy to find detailed information about data usage. However, the plots show that:

- Access to networks' public databases is high and, as such most of the networks are assessed as being at a reference level;
- Systematic collection of user feedbacks is based on a robust mechanism only for a few networks and most of them are at a baseline level;
- Updates to data records are mature for most of the networks along with long term data preservation;
- Control of data version and preservation of the different versions varies hugely across the networks, with most of them assessed as at a baseline level.



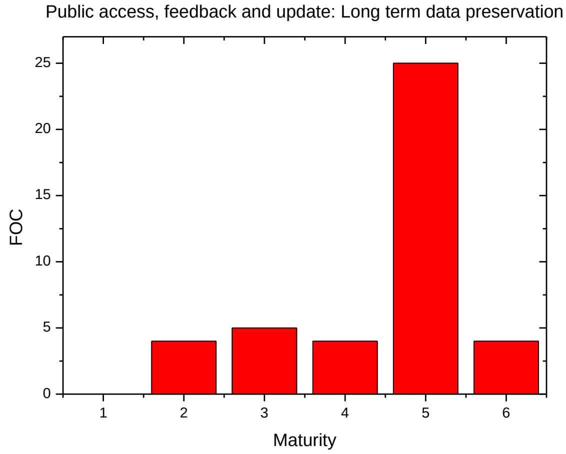
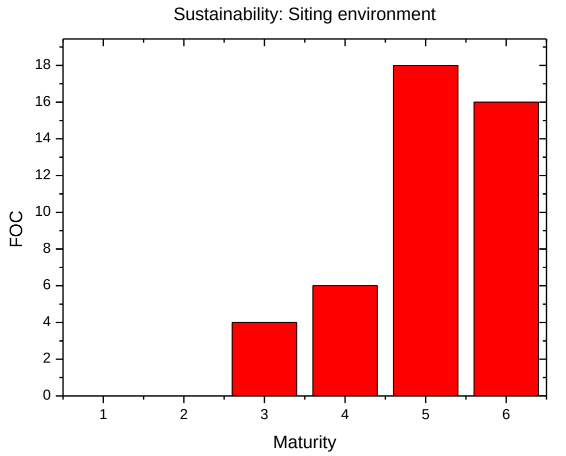


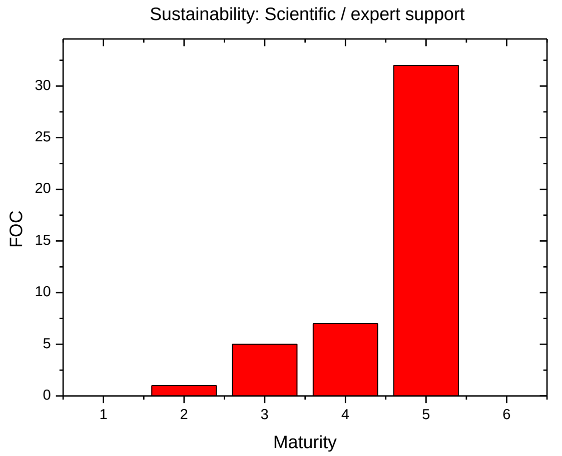
Figure 7: Frequency of occurrence of the maturity matrix scores for the five sub-categories (Public Access/Archive, User Feedback Mechanism, Research, and Exploitation, Long-term data preservation) of the main category "Public access, feedback, and update".

5.5 Sustainability

Figure 8 reports the frequency of occurrence for the "Sustainability" category of the MMA, which is made up of four sub-categories (Public Access/Archive, User Feedback Mechanism, Research, and Exploitation, Long-term data preservation). The plots show that:

- For most of the networks, long-term ownership and rights are guaranteed;
- Most of the networks offer a robust scientific support framework provided by at least two experts, which includes active instrumentation research and development being undertaken;
- A programmatic funding support to the network activities is ensured and not dependent upon a single investigator or funding line, with only a few networks with expectation of follow on funding (only in one case project pending).





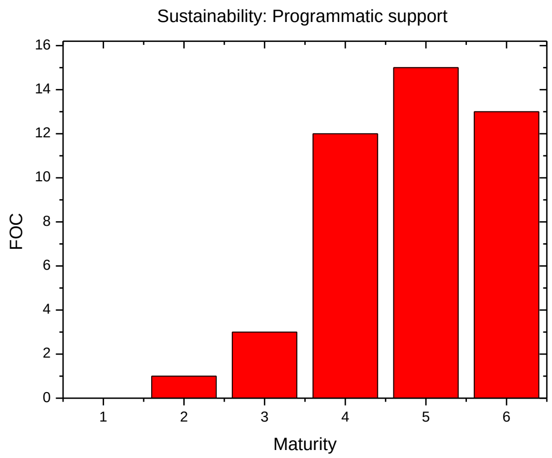


Figure 8: Frequency of occurrence of the maturity matrix scores for the three sub-categories (Siting environment, Scientific/expert support, Programmatic support) of the main category "Sustainability".

5.6 Other categories not considered

After the collection of the maturity matrices, two main categories have been not considered mature enough for the MMA at the current stage: Software and Usage; and so these are not reported in the final results or being used to decide which data to propose be carried forward to the Virtual Observatory. The principal reason was that most of the maturity matrix compilers were either unsure of the definitions in these two categories or not able to provide the requested information. "Software" category was not always able to represent the number of different conditions for the whole set of networks. However, we can mention that "Usage" category has revealed that, for most of the networks, societal and economic benefits and influence on decision-makers (including policy) of the provided data is still limited. The GAIA-CLIM activities, if successful, will increase usage for the specific case of satellite characterization.

5.7 Summary

Here, a summary of the outcome of the statistical analysis provided in Section 5 is reported. The maturity matrix assessment applied to the networks reviewed under Task 1.2 shows that the reviewed networks have an overall medium-high level of maturity (scores > 4) in the following categories of the maturity matrix:

- Metadata, though improvements must still be targeted at the creation and curation of collection level information; this is related to the collection of enhanced or complete discovery metadata which is missing or does not meets appropriate (at the time of assessment) international standards;
- Sustainability, which is for most of the networks not dependent upon a single investigator or funding line, while finance to support continued operations can be envisaged given national and international funding;
- Documentation, where improvements are required towards the adoption of formal measurement user guidance; a significant effort must be spent on the regular update by data provider with instrument/method of measurement updates and/or new validation results; the availability in peer-reviewed literature of measurement description and examples of data usage are also another

added value missing in the majority of the networks; a more in-depth analysis of the statistics on an ECV basis, reveal that this latter issue is particularly important for those networks measuring trace gases;

The reviewed networks have an overall medium level of maturity (scores 3 - 4) in the following categories of the maturity matrix:

- Uncertainty, where it is clear that focus is required on aspects around robust uncertainty quantification and comparability in a large number of the assessed networks if they are to be considered reference quality measurements; the analysis on an ECV basis, reveals that a more mature approach is adopted in the frame of networks measuring aerosols, water vapour and ozone;
- Public access, feedback and update, where a quite heterogeneous scenario is offered by the reviewed networks, though it is clear a large effort must be spent to assess shortcomings in user feedback mechanisms and version control in this assessed strand.

The outcome of the present analysis will be also discussed in the context of GAIA-CLIM WP6 with the aim to strengthen the elaboration of the existing gaps reported in the GAID (e.g gap G1.06 for the metadata, several WP2 gaps and gap G4.11 for uncertainty) or to provide new gaps for the GAID future versions. New gaps will likely be provided on the need to adopt more efficient solutions for public usage of networks' measurements and to regularly provide formal measurement user guidance along with the publication in peer-reviewed literature of measurement descriptions.

[6] Redundancy exercise

The main issue in the use of the MMA is related to the inevitable and irreducible level of subjectivity of the approach. Even though quantifiable metrics are used there will be inevitable subjectivity in interpretation from assessor to assessor. This has been evaluated through a redundancy exercise based on the compilation of the matrix for the same network by at least three persons. The exercise has been limited to five networks (EARLINET, GRUAN, TCCON, AERONET, NDACC) which are also the most well represented by the GAIA-CLIM partners.

The outcome of the exercise shows an average uncertainty in the attribution of the maturity matrix scores among the selected compilers of ±1 for a given sub-category. This can be considered as the minimum possible quantification of the level of objectivity of the MMA. In some cases, the uncertainty is much larger, and this appears to most frequently arise from an incorrect or inhomogeneous interpretation of scores and categories of the matrix based upon the guidance given. This may, in turn, point to potential for improvements in that guidance documentation in future versions.

Below summarises the outcome of the redundancy exercise for TCCON: maturity matrices have been filled by four different assessors, each deeply familiar with the network (Figure 9). The case of TCCON confirms an average uncertainty in the attribution of the score of ±1 but also that for some sub-categories assessor-to-assessor uncertainty may be much larger. This fostered a discussion within the TCCON community, the outcome of which has been to provide a MMA which finally represents the official maturity matrix for TCCON and represents a reasonable compromise among the four compiled matrices (Figure 10).

Discussion has also allowed Task 1.2 participants and participating network PIs to fully exploit the MMA to elaborate suggestions on which improvements are required to bring the networks towards the maximum score (i.e. to be a "reference network" in all the sub-categories). Although it is too early to assess, it may be that some networks shall undertake actions which improve their maturity based upon the assessment process.

During the work of the Task 1.2 there was a general consensus about the need to describe with the maturity matrix the whole status of a network, at a "station" level or even an instrument level, and not only at a "network" level. To fulfil this request towards the increase of the objectivity of the MMA, it was agreed that the maturity matrix originators will improve the description of the MMA adding another option that will allow each person filling in the matrix to define the level of heterogeneity of a network with respect to the overall network performances.

The future objective should be to apply the MMA for each station (and instrument where the network consists of multiple measurement techniques) of each network. This commitment for GAIA-CLIM (and more generally) is potentially quite challenging as it requires in-depth knowledge of site and instrumentation particulars. Therefore, specific resources from other projects of international programs must be identified to come up with such a detailed study.

TCCON Maturity Matrix redundancy exercise (marked fields show differences > 1)

Metadata	Documentation	Uncertainty characterization	Public access, feedback and update	Usage	Sustainability	Software (optional)
Standards 6, 4, 5, 4	Formal Description of Measurement Methodology 5, 6, 6, 3	Traceability 6, 5, 5, 5	Access 5, 5, 5, 4	Research 5, 6, 6, 5	Siting environment 4, 2, 3, 4	Coding standards 1, 5, 4, 3
Collection level 6, 4, 6, 3	Formal Validation Report 6, 5, 4, 1	Comparability 5, 5, 4, 4	User feedback mechanism 4, 4, 4, 6	Public and commercial exploitation 6, 6, 5, 5	Scientific and expert support 5, 5, 5, 3	Software documentation 4, 4, 4, 2
File level 5, 5, 5, 5	Formal Measurement Series User Guidance 6, 5, 5, 6	Uncertainty Quantification 5,4,5,5	Updates to record 4, 4, 5, 5		Programmatic support 1, 1, 2, 4	Portability and numerical reproducibility 5, 5, 3, 3
		Routine Quality Management 5, 4, 5, 3	Version control 6, 5, 6, 5			Security 1, /, 2, 1
			Long term data preservation 5, 6, 6, 4			

Figure 9: Scores of the four maturity matrices provided for TCCON.

Suggested rating based on results from redundancy analysis and further investigation (see comments above)

Metadata	Documentation	Uncertainty characterization	Public access, feedback and update	Usage	Sustainability	Software (optional)
Standards 5	Formal Description of Measurement Methodology 5	Traceability 5	Access 5	Research 6	Siting environment 2	Coding standards 4
Collection level 5	Formal Validation Report 5	Comparability 4	User feedback mechanism 4	Public and commercial exploitation 6	Scientific and expert support 5	Software documentation 4
File level 5	Formal Measurement Series User Guidance 5	Uncertainty Quantification 5	Updates to record 5		Programmatic support 1	Portability and numerical reproducibility 5
		Routine Quality Management 5	Version control 6			Security 1
			Long term data preservation 4			

Figure 10: "Official" maturity matrix provided by TCCON applying the described MMA

[7] Recommendations related to the MMA data collection and use.

Recommendations, in view of the adoption of the maturity matrix approach as a tool to self- or external assessment of the maturity level of network or a measurement program, are provided in this section. Challenges to the adoption of the MMA have been already described in D1.3.

1. People filling in a maturity matrix have provided their scores in several different ways that have been adopted by the partners. If the MMA will be adopted as a tool for the self- or external assessment of a network, a new template that is able to meet the expectation of most of the compilers should be provided. An optional proposal for the implementation of an interactive online maturity matrix tool showing each category by clicking on the scores was considered, but its implementation is beyond the scope and the resources of GAIA-CLIM. It would be a helpful tool in future if broader adoption were foreseen as e.g. potentially by GCOS (GCOS IP 2016, public review draft accessed, July 2016)
2. As mentioned above, two categories of the MMA, "Software" and "Usage", have been not considered robust enough at the current stage and were excluded from this current assessment. They should not be adopted in the MMA after GAIA-CLIM without further discussing and improving their usefulness and assessability.
3. For each reviewed network, the scores related to each of the sub-categories must be retained and made available. The score from the main categories only is not appropriate and does not show the real value of this approach.
4. To provide a value representative for each main category of the maturity matrix, the user must consider the minimum value from the related sub-categories. This means that for the example reported in Figure 3 related to the NDACC network, the main category “Uncertainty”, made up of four sub categories with scores:

Traceability	5
Comparability	4
Quantification	4
Routine Quality Management	4

   must be scored with a value of 4 which is the minimum of the score for the four sub-categories.
5. However, given also the consideration reported in Section 6, we recommend great care in handling these scores and to retain them for all the sub-categories to allow each of the maturity matrix compilers to identify which are the stronger and less strong aspects of the evaluated networks. As such, the MMA represents a good tool to think about the status of each network and to identify missing aspects that would allow a network to become more mature to become a reference network for the community. In this sense, the MMA is a good tool for discussion and assessment (internal or external) of the existing observing capabilities. This goes beyond the uncertainties, discussed above, affecting the scores put in each sub-category of the matrix.

Each maturity matrix refers the "lowest common denominator" of the performance of networks' core stations; therefore, for the measurements relevant to the Virtual Observatory (VO), each data provider (network PIs or data managers) will be requested to filter out those measurements that cannot be considered representative of the network quality assurance program, i.e not collected following the recommended best practice.

[8] Maps of the assessed existing capabilities on an ECV-by-ECV basis and by system of systems layer for ECVs measurable from space

The collected discovery metadataset has been used to undertake initial geographical mapping of the existing non-satellite capabilities. In this section, the attention is focussed on two ECVs: aerosol and water vapour. Maps of the existing station at the global scale measuring these two ECVs, at the surface, on a tower, over the vertical profile, or integrated over the whole atmospheric column are provided.

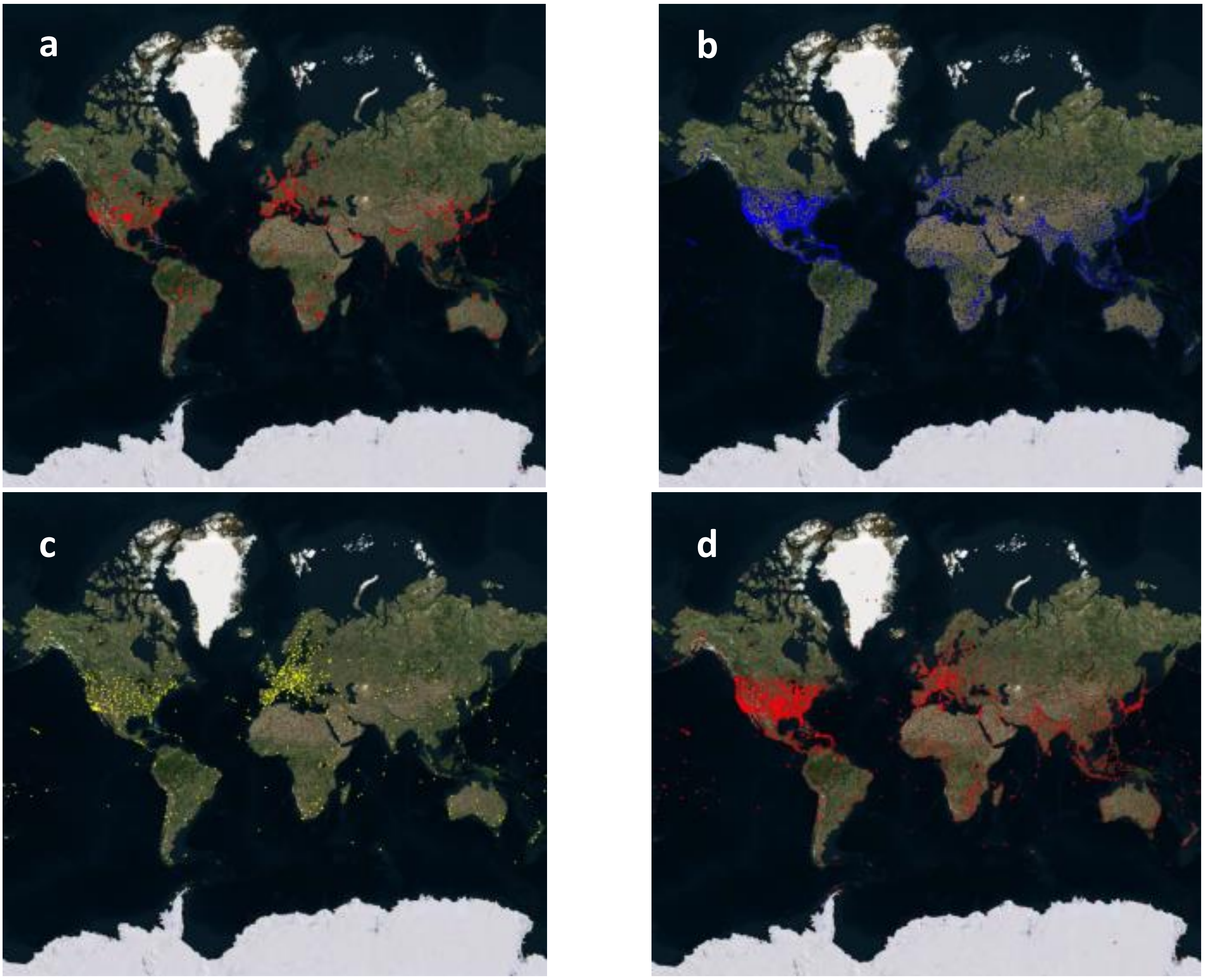


Figure 11: upper left panel (a), water vapour networks classified as "Comprehensive" according to the MMA for the category "Uncertainty"; upper right panel (b), networks classified as "Baseline"; lower left panel (c), networks classified as "Reference"; lower right panel (d), all the networks measuring water vapour at the global scale.

Maps of the existing observing capabilities have been generated for all the ECVs reported in Table 1 and for all the categories of the MMA: all of them are available at http://www.gaia-clim.eu/page/maps-d16. In addition, these maps have been differentiated for all the different measurement types (profile, column, surface, tower). Task 1.3 will complement the Task 1.2 activities through the creation of interactive web-based tools for the visualization of the existing non-satellite capabilities.

In Figure 11, water vapour networks classified as Comprehensive, Baseline and Reference according to the MMA for the category "Uncertainty" are compared, and the "global" picture of all the networks measuring water vapour is also reported. In this picture, networks measuring the vertical profile, the full column content or at the surface have not been differentiated from one another. This figure highlights that most of the networks are classified as "Baseline" in their capability to report the measurement uncertainty. Most of the water vapour measurements are collected in the Northern hemisphere and there is a clear lack of reference measurements in the Southern hemisphere. Figure 12, that reports the same comparison for the "Documentation" category of the MMA, provides results consistent with Figure 11.

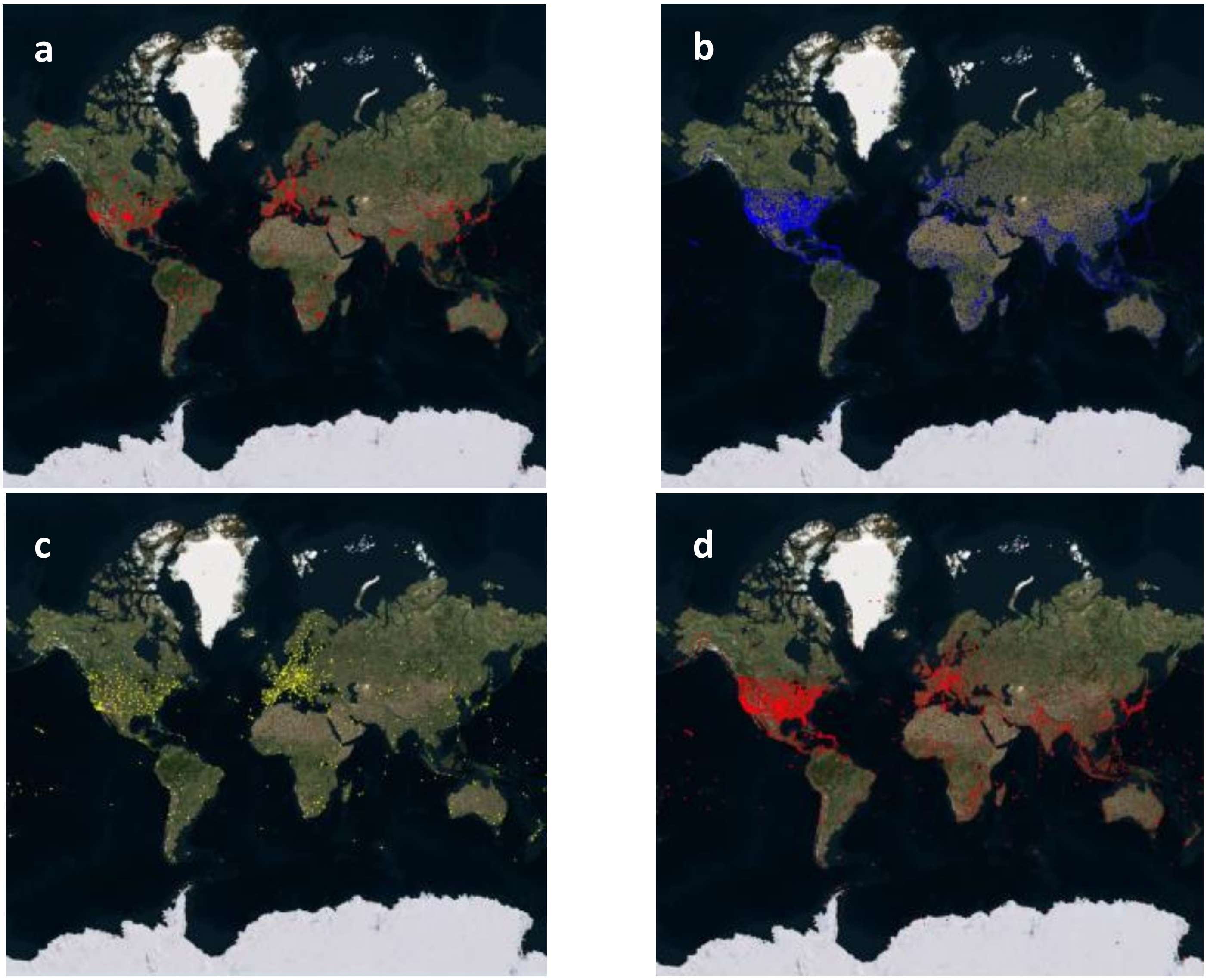


Figure 12: Same as Fig. 9 but for the category "Documentation" of the MMA

Figures 13 and 14 repeat the analysis given in Figures 11 and 12 but for the “Aerosol” ECV. Both Figures 13 and 14 show that most of the aerosol measurements available at the global scale are concentrated in US and central Europe and the majority of them belong to “Comprehensive” networks with respect to the “Uncertainty” category of the MMA.

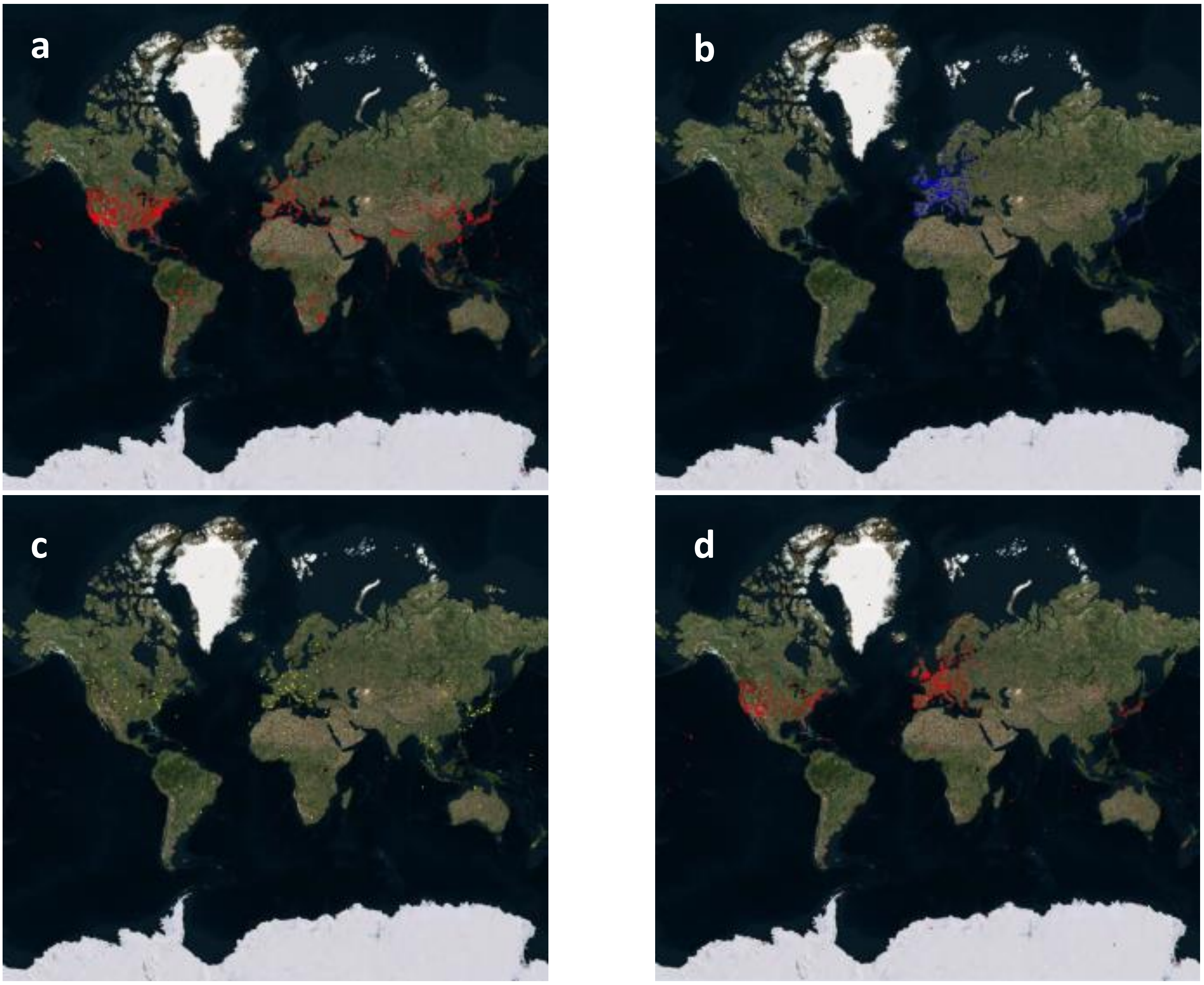


Figure 13: Same as Fig. 9 but for the ECV Aerosol

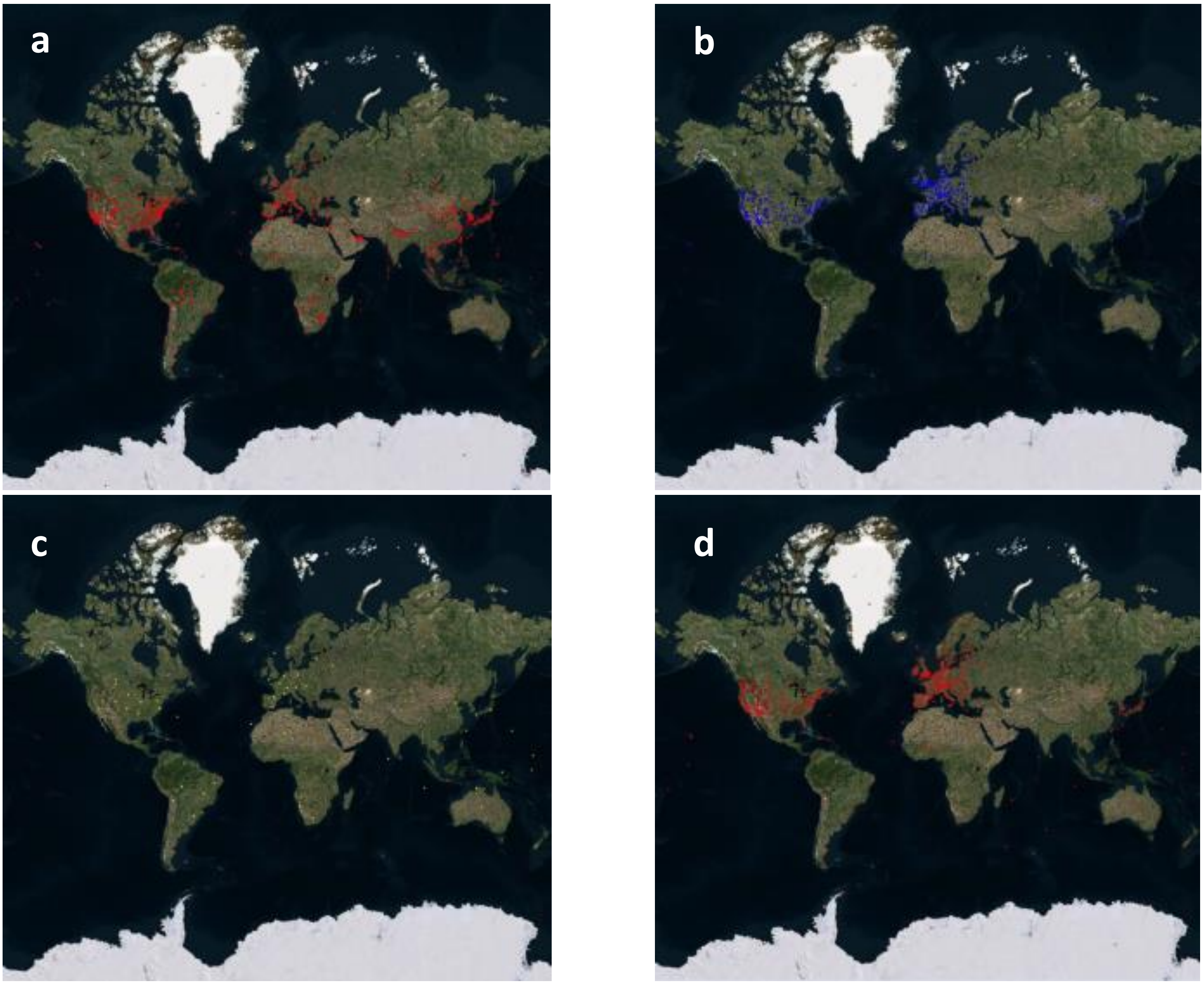


Figure 14: Same as Fig. 10 but for the ECV Aerosol

Along with the geographical mapping of the existing observing capabilities, the mapping tools described above permit an analysis to include the degree of temporal sampling mismatch with a large number of EO platforms. This has the aim to maximize the value of existing observations and forms the basis for the visualization tools developed under Task 1.3.

To this end, the tools developed under Task 1.3 shall allow users to submit queries to the metadataset and to plot at the same time all the available stations measuring one or more ECVs (for a different maturity level) along with the ground track of a selected satellite platform. An example is reported in Figure 15, where all the GUAN stations are plotted along with the ground track of MetOp-A. The list of the available satellites includes 115 platforms and largely goes beyond those of interest for GAIA-CLIM.

In Figure 16, a detail of the map in Figure 15 is provided in correspondence of the GUAN station of Athalassa (Cyprus, Latitude: 35°.14083, Longitude: 33°.39639, Altitude: 162.00 m a.s.l.). This further option of CNR-IMAA webportal allows to match, within a given time window selected by the user, the satellite ground-track with the ground-based stations available in a specific geographical domain. The stations can be selected according the measured ECV, the used measurement technique, and the level of maturity as assessed against the MMA strands.

Figure 15: Maps of the GUAN (GCOS Upper-Air Network) stations and of the MetOp-A ground track.

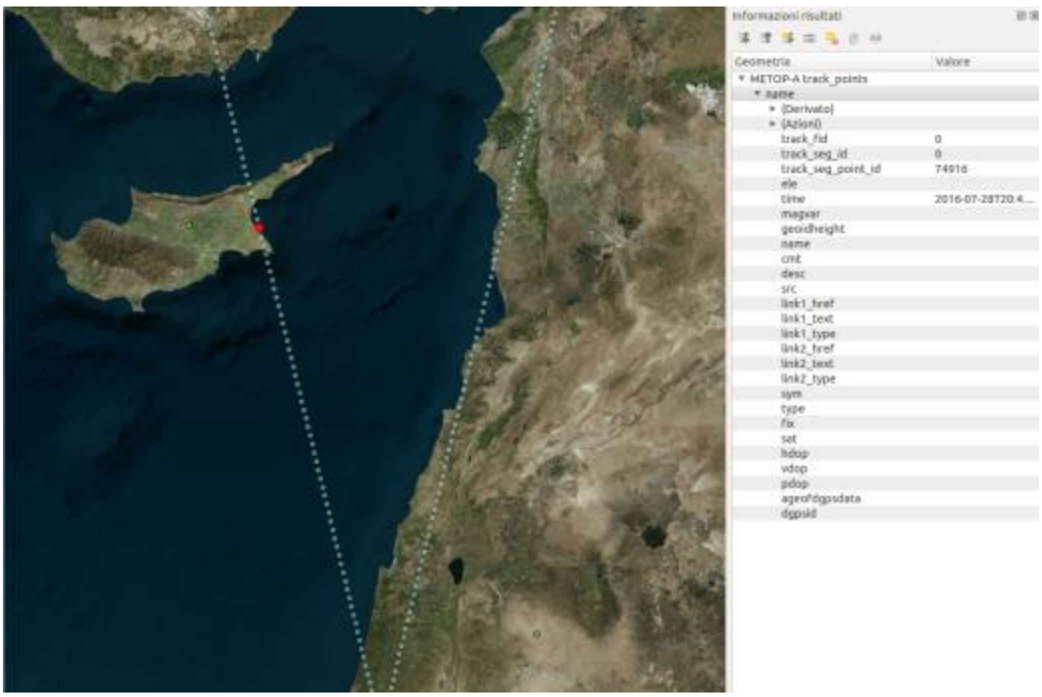


Figure 16: Maps of the GUAN station of Athalassa in Cyprus along with the specific segment of the MetOp-A ground track closer to the station itself.

The described mapping capabilities have been designed using QGIS application (http://www.qgis.org). Specifically, for the satellite orbits, the resources used are

- Sets of TLE (two-line element) files available from www.celestrak.com;
- The open source Java library predict4java available on the portal GitHub (https://github.com/badgersoftdotcom/predict4java);
- The open source Java library GPXParser (http://gpxparser.alternativevision.ro/pages/index.html).

The TLE files contains the orbital parameters which requires a conversion to GPS coordinates using the SGP4 embedded in the Java predict4java. The library GPXParser, imported in QGIS, enable additional Q-GIs functionalities to track the satellite orbit.

[9] WP1.2 expected impact

The outcome of Task 1.1 and Task 1.2, in conjunction with Task 1.3 running until month 24 of GAIA-CLIM project may be expected to provide the impact described below:

1. Improve and enlarge the scope of the international initiatives on metadata collection carried out by WMO, GEOSS, EU research infrastructures, and the forthcoming C3S;
2. Stimulate international and regional capacity development in the data and metadata exchange and support the existing framework (at EU level e.g. INSPIRE) for the management of environmental metadata;
3. Provide an open source platform for metadata collection and their interactive visualization that can continuously be improved over the years and established as a long term service in support of the needs of future projects and research programs;
4. Stimulate a critical approach to the existing components of the global observing system by providing a tool (i.e. MMA) to assess the performance of ground-based networks advising on the strong and weak points of each network, also in support of the design of future satellite missions for climate monitoring and of European funding programs.

The timeline for an initial assessment and quantification of these impacts can be quantified only after at least two years beyond 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. Nevertheless, for point 2 and 4 reported above, first tangible results could be made available after the closure of Task 1.3 (Month 24).

More details about the strategies to adopt towards the establishment of the metadata collection as a permanent service in support of the Copernicus programme and GAIA-CLIM are reported in the accompanying deliverable D1.7.

Acknowledgements

We gratefully acknowledge all the PIs and data manager of the measurements networks who facilitated out work to deal with the maturity matrix assessment of each of these components of the global observing system. In non-alphabetical order: A. Shimizu (NIES), M. Fujiwara (JMA), M. Palecki (NOAA), S. Lolli (NASA-JCET), T. Leblanc (NASA-JPL), M. Campanelli (ISAC-CNR), A. Thompson (NOAA), V. Estelles (CSIC), R. Dirksen (DWD), A. Comeron (Univ. Politecnica de Catalunya), M. Fujiwara (Hokkaido University), D. Sisterson (DOE-ARM, US), T. Eck (NASA-GSFC). We also acknowledge the requirements of the BING maps add-in, its use of is done in agreement to the terms and conditions and privacy statement.

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Acronyms

ACTRIS	Aerosols, Clouds, and Trace gases Research Infrastructure Network
ADNET	Asian Dust Network
AGSNET	CSIRO Aerosol Ground Station Network
AEROCAN	AERONET Canadian network
AERONET	Aerosol Robotic Network
AMeDAS	Automated Meteorological Data Acquisition System
ARGO	The Global Array of Profiling Floats
ARM	Atmospheric Radiation Program
BIRA-IASB	Belgium Institute for Space Aeronomy
BSRN	Baseline Surface Radiation Network
CCI	Climate Change Initiative
CEOS	Committee on Earth Observation Satellites
CORE-CLIMAX	COordinating earth observation data validation for RE-analysis for CLIMAte ServiceS
CNR	Consiglio Nazionale delle Ricerche
C3S	Copernicus Climate Change Service
ECVs	Essential Climate Variables
EMEP	European Monitoring and Evaluation Programme
EO	Earth Observation
EPA	Environmental Protection Agency
ESA	European Space Agency
ESRL	Earth System Research Laboratory
EUREF	European Reference Organisation for Quality Assured Breast Screening and Diagnostic Services
EUROSKYRAD	European SkyRad radiometer network
GPSMET	GPS/Meteorology
GAID	Gaps Assessment and Impacts Document
GAW	Global Atmospheric Watch
GCOS	Global Climate Observing System
GEOSS	Global Earth Observation System of Systems
GNSS	Global Navigation Satellite System
GRUAN	GCOS Reference Upper Air Network
GUAN	GCOS Upper Air Network
ICOS	Integrated Carbon Observation System
IGS	International GNSS Service
IMPROVE	Interagency Monitoring of Protected Visual Environments
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organization for Standardization
MESONET	MESOscale NETwork
MetOp	Metrological Operational satellite
MPLNET	Micro-Pulse Lidar Network
MWRnet	Microwave Radioemter Network
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NOAA	National Oceanic and Atmospheric Administration (USA)
SCRIPPS	Scripps Institution of Oceanography
SHADOZ	Southern Hemisphere ADditional OZonesondes
SMEAR	Stations for Measuring Atmosphere-Radiation Relations.
SUOMINET	Suomi Network

SURFRAD	Surface Radiation Network
SKYNET	Sky Radiometer Network
TCCON	Total Carbon Column Observing Network
TOLNET	Tropospheric Ozone Lidar Network
USCRN	U.S. Climate Reference Network
VOC	Volatile Organic Compounds
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Organization
WOUDC	World Ozone and Ultraviolet Radiation Data Centre
XML	eXtensible Markup Language

APPENDIX A: Table of maturity matrices

NETWORK	METADATA			DOCUMENTATION			UNCERTAINTY CHARACTERISATION				PUBLIC ACCESS, FEEDBACK, AND UPDATE					USAGE		SUSTAINABILITY			SOFTWARE READINESS						ECV	Measurement type
	Standards	Collection level metadata (including change records)	File level	Formal description of measurement methodology	Formal validation report	Formal measurement series user guidance	Traceability	Comparability	Uncertainty quantification	Routine quality monitoring	Public access/archive	User feedback mechanism	Updates to record	Version control	Long-term data preservation	Research	Public and commercial exploitation	Siting environment	Scientific expert support	Programmatic support	Coding standards	Software documentation	Portability and numerical reproducibility	Security	Compiler	Institution		
ACTRIS surface	5	5	5	3	4	4	4	4	5	4	4	4	4	3	5	5	4	5	5	6	3	2	1	1	L. Mona	CNR-IMAA	AEROSOL,	surface
ACTRIS profiles	5	5	5	5	4	4	5	4	5	4	6	4	5	3	5	3	4	5	5	6	5	2	1	1	L. Mona	CNR-IMAA	AEROSOL	profile
ADNET	6	6	5	5	6	5	5	4	5	5	6	6	5	6	6	5	4	5	5	6	6	6	6	5	A. Shimizu	NIES	AEROSOL	profile
AEROCAN																									A. Arola	FMI	AEROSOL,	column
AERONET_PHOTONS	4	3	5	6	4	5	5	5	3	6	5	5	6	5	5	5	5	6	5	5					A. Arola	FMI	AEROSOL,	column
AGSNET_CSIRO	4	3	5	6	4	5	5	5	3	6	5	5	6	5	5	5	5	6	5	5					F. Madonna	CNR	AEROSOL,	column
AMeDAS	5	6	5	6	6	5	6	5	5	5	4	5	6	6	5	6	6	4	5	6	6	5	4	5	M. Fujiwara	JMA	TEMPERATURE	surface
ARGO	6	6	5	6	4	4	4	3	2	6	6	4	6			5	3		5	6	6				F. Madonna	CNR	TEMPERATURE	profile
BSRN	6	6	5	5	5	5	6	6	6	6	6		6			5	3	6	5	6		6			F. Madonna	CNR	AEROSOL,O3	column
EARLINET	6	6	5	5	6	5	5	4	5	5	6	6	5	6	6	5	4	5	5	6	6	6	6	5	L. Mona	CNR	AEROSOL	profile
EMEP	4	6	5	4	6	6	5	4	5	5	4	2	4	4	5	6	5	6	5	6	3	5	5	2	L. Mona	CNR	AEROSOL	surface
EPA																									F. Madonna	CNR	AEROSOL	surface
EUREF	5	6	5	5	5	6	5	6	5	6	6	6	6	5	5	6	6	6	5	6	1	1	1	1	K. Rannat	TUT	WATER VAPOR	column
EUROSKYRAD	3	4	3	3	4	5	5	4	3	5	5	2	3	3	3	4	2	5	5	4		6	6	4	F. Madonna	CNR	AEROSOL,	column
GAWPFR	4	2	5	5	5	4	4	5	2	5	4	2	4		5	5	2	4	5	5					Antii Arola	FMI	AEROSOL	column
GPSMET	6	6	4	6	4	4	4	3	3	5	6	3	6	3	3	5	3	6	4	5	6	6	6	5	F. Madonna	CNR	WATER VAPOR	column
GRUAN	5	6	5	5	6	6	4	6	4	6	4	6	6	6	5	4	4	4	5		3				P. Thorne	NUIM	TEMPERATURE	profile
GSN	6	6	5	3	3	3	3	3	3	5	6	3	6	2	2	4	3	3	4	5	6	5			F. Madonna	CNR	TEMPERATURE	surface
GUAN	6	6	5	5	3	3	3	3	3	5	6	3	6	2	2	4	3	5	4	5	6	5	3	4	F. Madonna	CNR	TEMPERATURE	profile
ICOS (including InGOS)																									J. Marshall	MPG	CO, CO2, CH4	In situ & tower
IGS	5	6	5	5	5	6	5	6	5	6	6	6	6	5	5	6	6	6	5	6	1	1	1	1	K. Rannat	TUT	WATER VAPOR	column
IMPROVE	3	4	5	5	2	3	5	3	4	6	6	3	5		5	2	4	6	4	5				5	F. Madonna	CNR	AEROSOL	surface
MESONET	3	4	4	1	1	2	1	2	1	2	1	2				2	3	6	2	4					F. Madonna	CNR	TEMPERATURE	surface
MPLnet	5	4	5	6	5	5	4	3	6	5	6	5	2	6	6	6	3	6	5	5	2	3	3	5	S. Lolli	NASA/GSFC	AEROSOL	profile
MWRnet	4	4	5	4	5	5	4	3	4	4	4	4	4	3	4	5	5	6	5	6	4	4	4	2	D. Cimini	CNR	TEMPERATURE	profile, column
NDACC	4	3	5	3	5	6	5	4	4	4	5	6	5	5	4	6	6	4	3	4	3	4	3	1	M. De Maziere	BIRA	CO,CH4,NO2, O3, WATER VAPOR	profile, column
NOAA ESRL WV profiles	5	3	5	5	6	6	3	4	2	4	5	4	5	4	5	5		5	5	4					J. Marshall	MPG	WATER VAPOR	profile
NOAA ESRL O3 profiles	5	3	5	3	4	3	3	3	1	4	4	4	5	3	5	5		5	5	4					J. Marshall	MPG	O3	profile
NOAA ESRL O3 dobson	5	3	2	5	6	6	3	4	2	4	5	4	5	4	5	5		5	5	4					J. Marshall	MPG	O3	column
NOAA ESRL O3 in-situ	2	2	2	2	3	2	5	3	1	4	4	4	4	2	5	5		5	5	4					J. Marshall	MPG	O3	surface
NOAA ESRL O3 aircraft	5	3	5	5	4	4	5	5	2	4	4	4	5	4	5	5		5	5	4					J. Marshall	MPG	O3	aircraft
RAOB																									F. Madonna	CNR	TEMPERATURE	profile
RBSN	6	6	5	2	2	2	2	2	2	4	6	2	6	2	2	2	3	3	4	5	6	5			F. Madonna	CNR	TEMPERATURE	surface
SCRIPPS CO2 program	4	3	2	3	5	2	5	5	4	5	4	6	4	3	5	5		5	5	3					J. Marshall	MPG	CO2	surface
SHADOZ	4	5	4	5	5	6	3	5	4	6	6	5	5	4	5	6	6	4	3	5	6	5	5	2	K. Kreher	BKS	O3	profile
SKYNET	3	4	3	3	4	5	5	4	3	5	5	2	3	3	3	4	2	5	5	4		6	6	4	F. Madonna	CNR	AEROSOL,NO2, O3,TEMPERATURE, WATER	column, profile, surface
SMEAR	4	4	5	3	4	4	4	4	3	5	6	4	6	4	5	4	5	5	4	5					A. Manninen	UHEL	AEROSOL,CO2, CO,CH4,NO2,O3,	surface, tower
SUOMINET	6	6	4	5	4	4	4	3	3	5	6	3	6	3	3	5	3	6	4	5	6	6	6	5	F. Madonna	CNR	WATER VAPOR	column
SURFRAD	3	4	5	4	5	6	5	4	3	5	6	2	6	2	5	4	3	6	5	6	5	4			F. Madonna	CNR	AEROSOL	column
TCCON	6	6	5	5	4	5	6	4	5	3	5	4	5	6	4	5		3	5	2	3	2	5	1	M. Buschmann	Ubremen	CO2,CH4	column
TOLNET	3	2	3	4	4	3	4	3	4	3	4	5	4	4	4	5	5	5	3	3	5	2	2	1	T. Leblanc	JPL NASA	O3	profile
USCRN	6	6	5	6	6	6	5	6	5	6	6	2	6	6	6	4	4	6	5	6	5	5	2	5	M. Palecki	NOAA	TEMPERATURE	surface
WOUDC																									K. Kreher	BKs	O3	column, profile