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Results from the QA4ECV User Requirements Survey on Quality Assurance in Satellite Data Products

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Results from the QA4ECV Survey on Quality Assurance in Satellite Data Products

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EXECUTIVE SUMMARY

Policy makers are increasingly relying on Earth Observation (EO) data to make decisions on mitigating and adapting to climate change. These decisions need to be 'evidence-based', which requires confidence in EO-derived products. The Quality Assurance for ECV (QA4ECV) project will develop a robust system for the QA of satellite and in-situ algorithms and data records that can be applied to all ECVs. The project will also demonstrate how trustable assessments of satellite data quality and reliable means of interoperability can facilitate users in judging the fitness-for-purpose of the ECV Climate Data Records available. In order to develop and implement a truly functional and useful QA system, it must be based on and tailored to user requirements for various applications and appropriate for their range of competences. To gauge the current state of and need for quality assurance in satellite-derived data products, a ***user requirements survey*** (http://www.qa4ecv.eu/survey) was distributed targeting the satellite-data user community in the atmosphere, land and ocean research and applications domains. The survey focusses on four key areas of quality assurance including; availability of basic *quality flags* and *traceability*/provenance information, to more detailed and complex *uncertainty* assessment and evidence of independent product *validation*.

Results of this survey indicate that:

- Data users want satellite-derived products to contain all aspects of QA information, however this is often not readily available
- Product uncertainty and processing traceability information are the least accessible components of product QA
- Although basic quality flags are contained in many products, they are often insufficient for the users application
- Current QA in atmospheric products appears much more substantial and readily available than for land and ocean products

In parallel to the user survey, a survey of data producers/suppliers was conducted to gauge their views on how effectively QA information is provided for their data products. This survey involved phone interviews with six individuals responsible for developing and/or providing ECV data sets to the community. Three land and three atmosphere data suppliers within the EU and North America were contacted. The suppliers interviewed were not those supplying the products within the QA4ECV project, but they were representative of typical suppliers. In all cases, these data suppliers felt their products contained adequate QA information and the dissemination of this information to the data users was effective. The stark contrast in user and supplier opinions signals the requirement for an increased understanding of user needs and further investment from data suppliers to provide the QA evidence in a more comprehensible format. The development of an internationally endorsed QA system will facilitate the interaction between algorithm developers, data suppliers and data users in a consistent and robust manner.

Overall there are three key recommendations that result from this report that can be utilised to develop the QA4ECV framework specification:

- All QA information for satellite-derived products must be easily obtainable and published in a transparent manner.
- If uncertainty is known for a particular satellite product then this should be stated with details on how this is calculated. The QA4ECV project will develop an ECV uncertainty propagation tool.
- Full and comprehensible details of the processing chain for a satellite product should be available to users in a clear format.

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Approved on behalf of NPLML by David Gibbs,
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ACRONYMS

ATBD	Algorithm theoretical basis document
CCI	Climate Change Initiative
CEOS	Committee on Earth Observing satellites
CERES	Clouds and Earth's Radiant Energy System
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
ECV	Essential Climate Variable
EO	Earth Observation
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
fAPAR	Fraction of absorbed photosynthetically active radiation
GEO	Group on Earth Observation
HCHO	Formaldehyde
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organisation for Standardisation
LAI	Leaf area index
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectro-radiometer
NO2	Nitrogen dioxide
O_3	Ozone
OC	Ocean colour
POLDER	Polarization and Directionality of the Earth's Reflectance
PSD	Product specification document
QA	Quality Assurance
QA4EO	Quality Assurance for Earth Observation
QA4ECV	Quality Assurance for Essential Climate Variables
SAF	Satellite Application Facilities
SeaWIFS	Sea-viewing Wide Field-of-view Sensor
SI	International System of Units (from French: Le Système international d'unités)
SST	Sea surface temperature

CONTENTS

1 INTRODUCTION

As part of QA4ECV (Quality Assurance for Essential Climate Variables) Work Package 1, an online survey to determine *User* requirements for Quality Assurance (QA) in satellite-derived Essential Climate Variable (ECV) climate data records has been distributed globally to the broad scientific community (www.qa4ecv.eu/survey). The purpose of the survey was to capture the current state of and need for QA in satellite-derived land, ocean and atmosphere products from the perspective of the data user. The responses from this survey, along with continued interaction with the user community, will guide the development of the QA system and ensure it is robust, meaningful and ultimately beneficial to scientists, data analysts and policy-makers.

Two versions of the survey have been produced; one tailored for land/ocean and the other for atmospheric products. Though the questions in each survey are broadly similar as they relate to four key areas of quality assurance; *quality flags*, *traceability*, *uncertainty* and *validation*, separate surveys were required to account for nuances in technical terminology between the domains. The user surveys focussed on a set of specific ECVs that are being developed within the QA4ECV project; albedo, leaf area index (LAI), fraction of absorbed photosynthetically active radiation (fAPAR), nitrogen dioxide (NO_2), carbon monoxide (CO) and formaldehyde (HCHO), though the surveys were not exclusive of other ECVs.

A survey of data *Suppliers* was also conducted to gauge how effectively and successfully they believe that QA information is provided for their data products. This survey involved phone interviews with six individuals responsible for developing or providing data sets to the community. Three land and three atmosphere data suppliers within the EU and North America were contacted. Most of these suppliers are providing data products within the ESA CCI and EUMETSAT SAF programs, which provided the QA4ECV project with the opportunity to link in this early stage of the project to these relevant programs. The suppliers provide different satellite data (e.g. soil moisture, ocean colour, cloud parameters, ozone) than those covered by QA4ECV, but the process of data processing and dissemination are similar.

This report outlines the survey components and techniques used to maximise dissemination to relevant groups and summarises the main findings of both the *User* and *Supplier* surveys. Data from the responses of all questions can be found on the QA4ECV website.

2 USER SURVEY DISTRIBUTION AND RESPONSE RATES

The *User requirements* surveys were distributed globally to over 10 000 people across a wide range of disciplines that require the use of satellite-derived data. Dissemination of the survey was conducted via Linked-In remote sensing groups as well as email distribution lists, and individual personalised emails sent to former and present colleagues of collaborators in QA4ECV Work Package 1 (Appendix A).

The survey was also advertised at international conferences including the Land Product Validation and Evolution (LPVE) meeting (January 2014; http://congrexprojects.com/2014-events/13m49/introduction), the Global Vegetation Monitoring and Modelling (GV2M) conference (February 2014; https://colloque.inra.fr/gv2m) and the European Geosciences Union (EGU) conference (May 2014, http://www.egu2014.eu/). In addition, a *User Consultation* Workshop was held at the EGU conference. Over 40 conference delegates (both data users and

suppliers) attended the workshop to discuss the preliminary findings of the surveys and provide their opinions on the accessibility of QA information in satellite-derived climate data records.

At the time of publication of this report the land/ocean survey had been completed by 195 people (176 land/19 ocean) and the atmosphere survey by 69 people.

3 STRUCTURE OF THE USER REQUIREMENTS SURVEY

The User requirements survey is based on the principle of QA4EO (Quality Assurance for Earth Observation) (QA4EO, 2010 and http://QA4EO.org/) – "*all data and derived products shall have associated with them a fully traceable indicator of their quality*". QA4EO was established and endorsed by the Committee on Earth Observation Satellites (CEOS; http://ceos.org/) to support GEO (Group on Earth Observations; http://earthobservations.org/) in the delivery of comprehensive and timely "knowledge/information" to meet the needs of its nine Societal Benefit Areas.

The survey is divided into five sections:

1. User background and product specifications
2. Traceability
3. Quality flags
4. Uncertainty
5. Validation

The first section seeks to determine the nature of each data user in terms of the industry they work in (i.e. commercial, academic, government), their application area and target audience as well as more detail into the data sets they use and the product specifications they require. Sections 2-5 concern the four key aspects of QA.

Traceability refers to the provenance of the data and can be divided into three categories with increasing levels of detail, as summarised in Figure 1. The first level infers a basic understanding of the processes involved in the data derivation and summary of supporting documentation and data provenance (i.e. who, what, where, when, how?). The second level involves provision of information related to data processing, i.e. algorithms (and where possible access to code and look-up tables) used to develop the product as well as uncertainty assessments. Finally, if feasible, full SI traceability for the entire product processing chain should be provided.

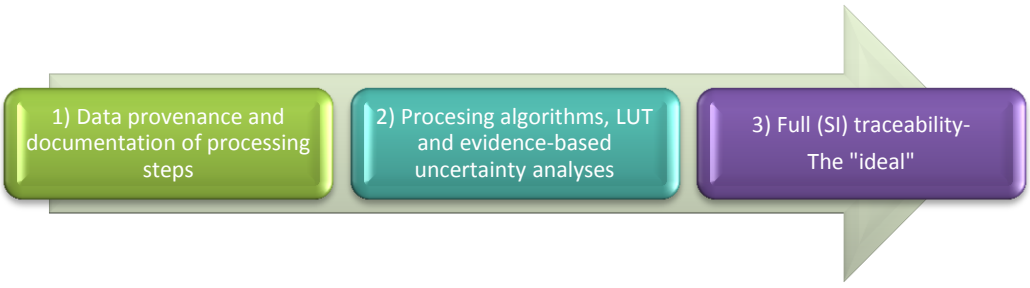

Figure 1- Levels of maturity of traceability information. Step (1) could be availability of the product specification document or basic traceability chain diagrams. Step (2) would involve knowledge of the algorithm codes used at each stage in the processing chain. Step (3) would involve the ability to trace the measurement at each stage of the processing chain back to SI units.

Quality flags are defined by as:
'A means of providing a user of data or derived products…with sufficient information to assess its suitability for a particular application…based on a quantitative assessment of its traceability to an agreed reference or measurement standard (ideally SI), but can be presented as numeric or a text descriptor, providing the quantitative linkage is defined' (QA4EO, 2013).

Uncertainty is defined by the Joint Committee for Guides in Metrology as:
The 'parameter, associated with the result of a measurement, that characterises the ***dispersion of the values*** *that could reasonably be attributed to the measurand'* (JCGM 100, 2008, p. 2).

Validation is defined as:
'The process of assessing, by ***independent means****, the quality of the data products derived from the system outputs'* (Justice, et al., 2000, p. 3383).

4 FINDINGS FROM THE USER REQUIREMENTS SURVEY

4.1. RESPONDENTS

The majority of respondents for both the atmosphere and land/ocean surveys are from universities or other academic research institutes (Figure 2). The target audience, particularly for academic institutions, is the scientific community involved in research advancement and decision support for national governments.

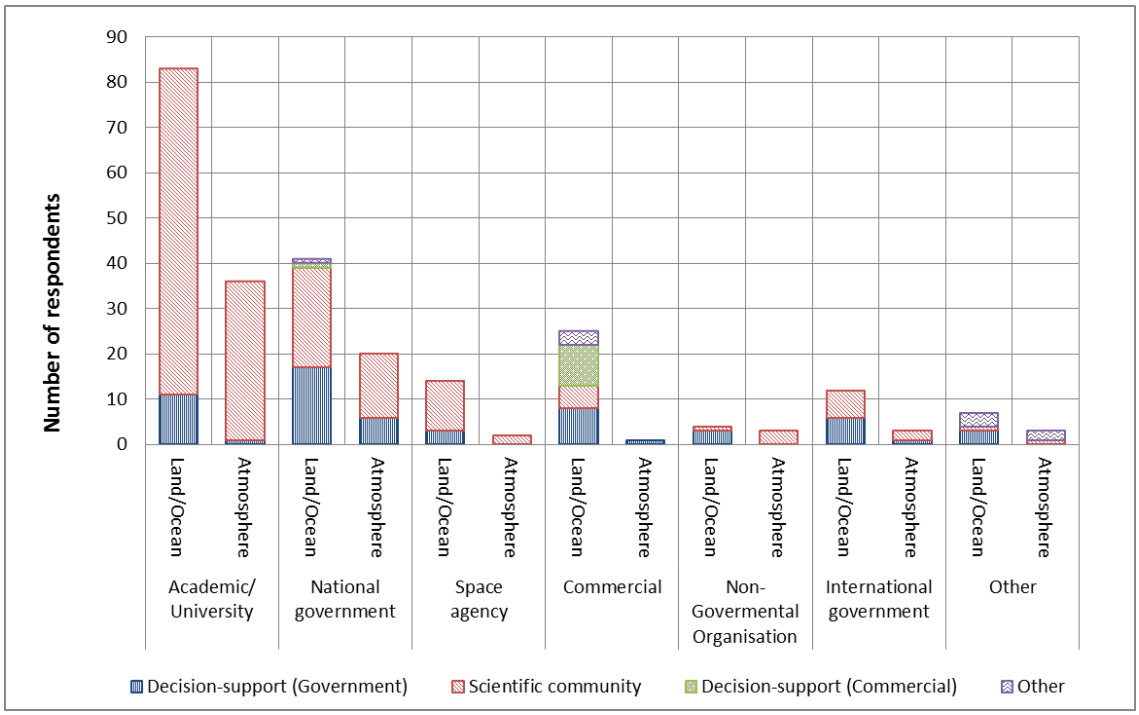

Figure 2- Distribution of respondents from sectors of industry and their respective target audiences (shown by different colours). Land and atmosphere survey respondents are reported separately.

A wide range of satellite-derived ECV parameters are utilised within the community (Figure 3). In addition to the land products of interest in QA4ECV (LAI, fAPAR and Albedo), land cover and soil moisture products are also extensively utilised. LAI had the strongest response with 37 respondents. Similarly for atmosphere products, ozone, aerosols, air temperature and cloud properties are of significant interest to the community in addition to the selected QA4ECV parameters, NO_2, CO and HCHO. NO_2 was the most popular parameter with 18 respondents, yet HCHO is less prevalent with only 3 respondents reporting its use. Several ocean related ECV products, including sea surface temperature (SST), sea level, ocean colour (OC), surface currents and sea state, were also reported.

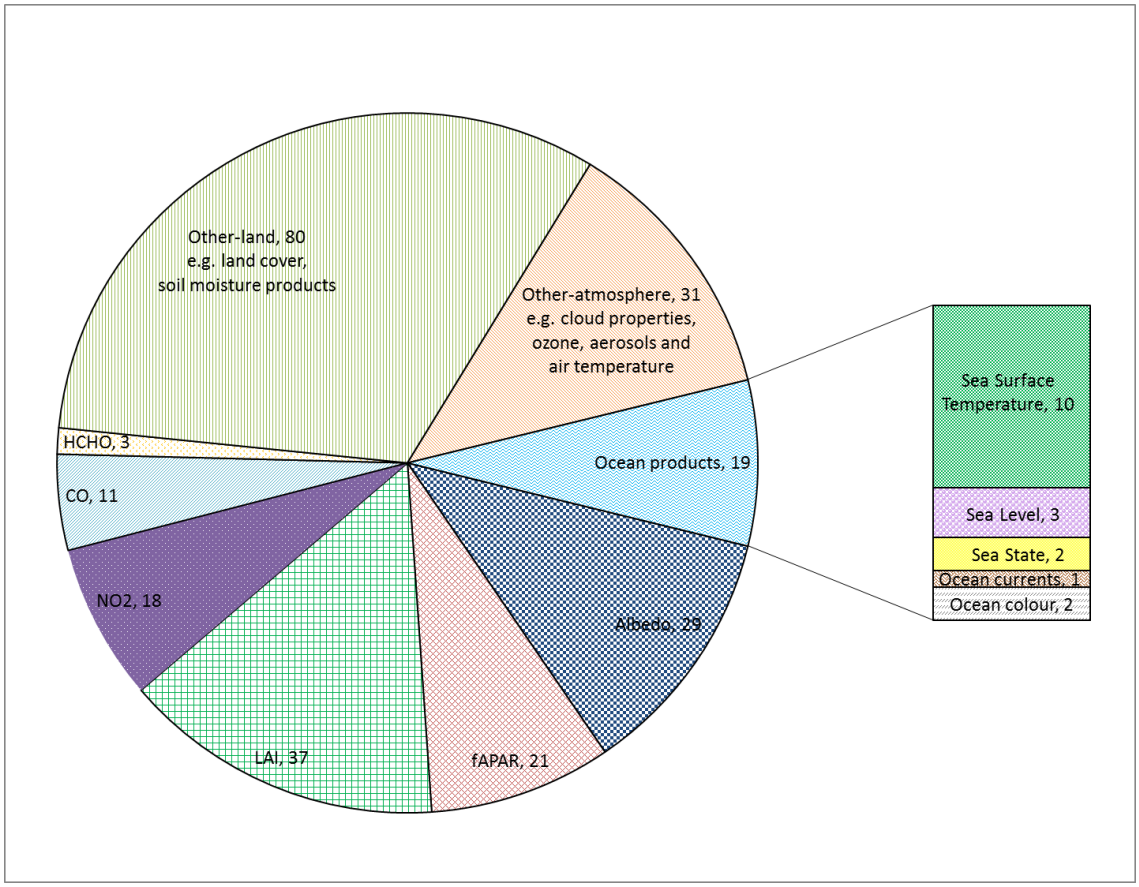

Figure 3- Proportion of respondents using QA4ECV ECVs for land, atmosphere, and ocean products. Number of respondents is given for each ECV.

Table 1 shows the three satellite data products for the six ECVs with the greatest number of responses (albedo, LAI, fAPAR, NO_2, CO and HCHO). For land parameters the most popular products appear to be MODIS products. While for atmosphere products it is more variable.

Table 1- Most widely utilised satellite data products for the QA4ECV parameters; albedo, LAI, fAPAR, NO_2, CO and HCHO

Parameter	Top three most widely utilised satellite data products (in descending order)
Albedo	1. Surface Albedo, derived from MODIS TERRA/AQUA 2. Geoland-2 Albedo, derived from VEGETATION-2 SPOT-5 3. Surface Albedo, derived from MSG SEVERI
fAPAR	1. FPAR, derived from MODIS TERRA/AQUA 2. FAPAR, derived from MERIS 3. CYCLOPES FPAR V3.1, derived from VEGETATION
LAI	1. LAI, derived from MODIS TERRA/AQUA 2. LAI, derived from MSG/SEVIRI 3. LAI, derived from MODIS
NO_2	1. Retrievals from Aura / OMI 2. Retrievals from ENVISAT / SCIAMACHY 3. Retrievals from MetOp / GOME-2
CO	1. Retrievals from Terra / MOPITT 2. Retrievals from MetOp / IASI 3. Retrievals from Aqua / AIRS
HCHO	All products used equally

Figure 4 shows the main application for the land, ocean and atmosphere products. The top four applications are radiation balance, climate modelling, ecosystem productivity modelling and phenology. Across all applications the most commonly required time-step is daily, with ~30% of respondents requiring this time-step. For the temporal range the majority of respondents (55% for land/ocean and 66% for atmosphere) required the entire record available, showing a need for obtaining as much data as possible. For radiation balance various time steps are required, although predominantly daily. For climate modelling the main time steps required are daily and monthly. Ecosystem applications mainly required a monthly time-step and phenology applications require daily, weekly and monthly time-steps.

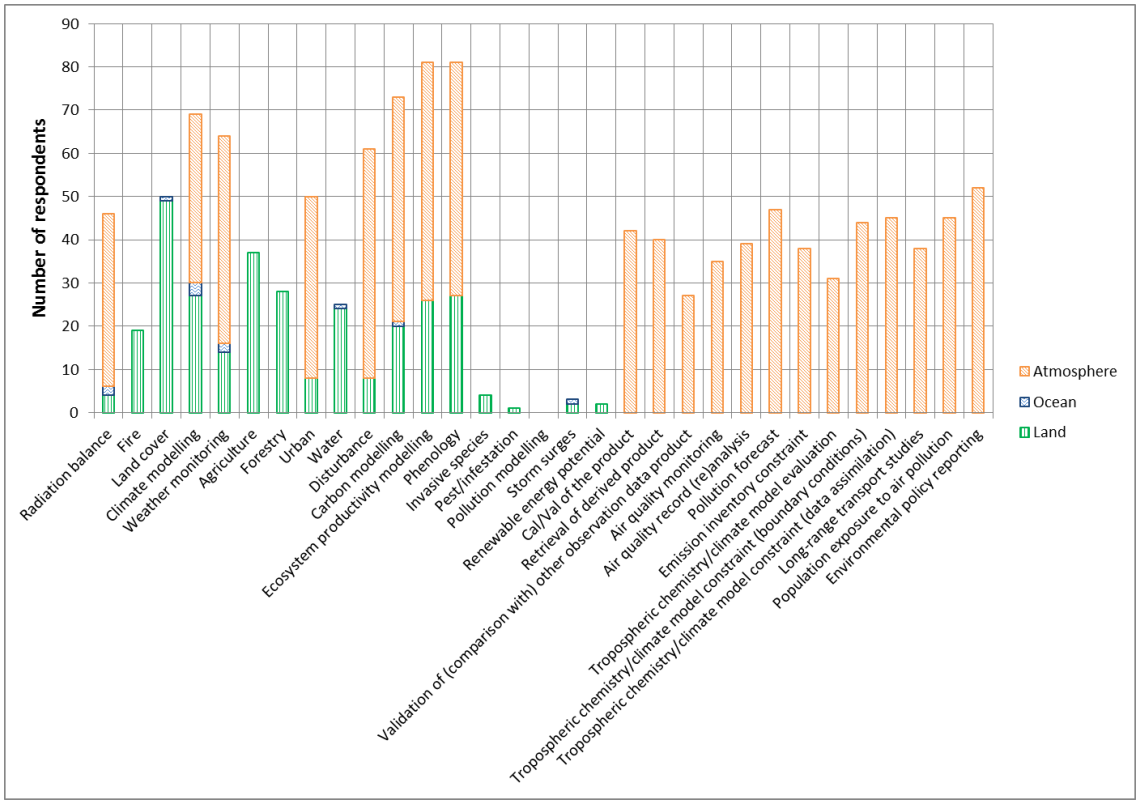

Figure 4- Main applications of land (top), atmosphere (middle) and ocean (bottom) products by number of respondents.

4.2. TRACEABILITY

The vast majority (>95%) of respondents stated that accessibility to data traceability/provenance information was *important* or *very important* across all applications. The information would be utilised if made available. However, product processing chain information is either unavailable or at least not easily accessible for most of the data products currently being utilised. Knowledge of the product processing chain would enable users to: propagate uncertainties; assess data quality; understand where the data has come from; design better ad hoc use for the data and; enable assessment of the fitness for purpose of individual data products. Several users also emphasised the need for transparency in the processing chain with a requirement on information of the exact steps carried out in order to be able to conduct an uncertainty analysis for their specific application.

4.3. QUALITY FLAGS

All atmosphere products contained some sort of QA flag information as opposed to only some of the commonly utilised land and ocean products (Figure 5). Fewer fAPAR and albedo products are provided with quality flag information. Overall, 95% of respondents make use of the quality flags provided, with the most common uses being thresholding and masking of data. Only 40% of land/ocean and 20% of the atmosphere survey respondents found quality flag information to be adequate for their applications.

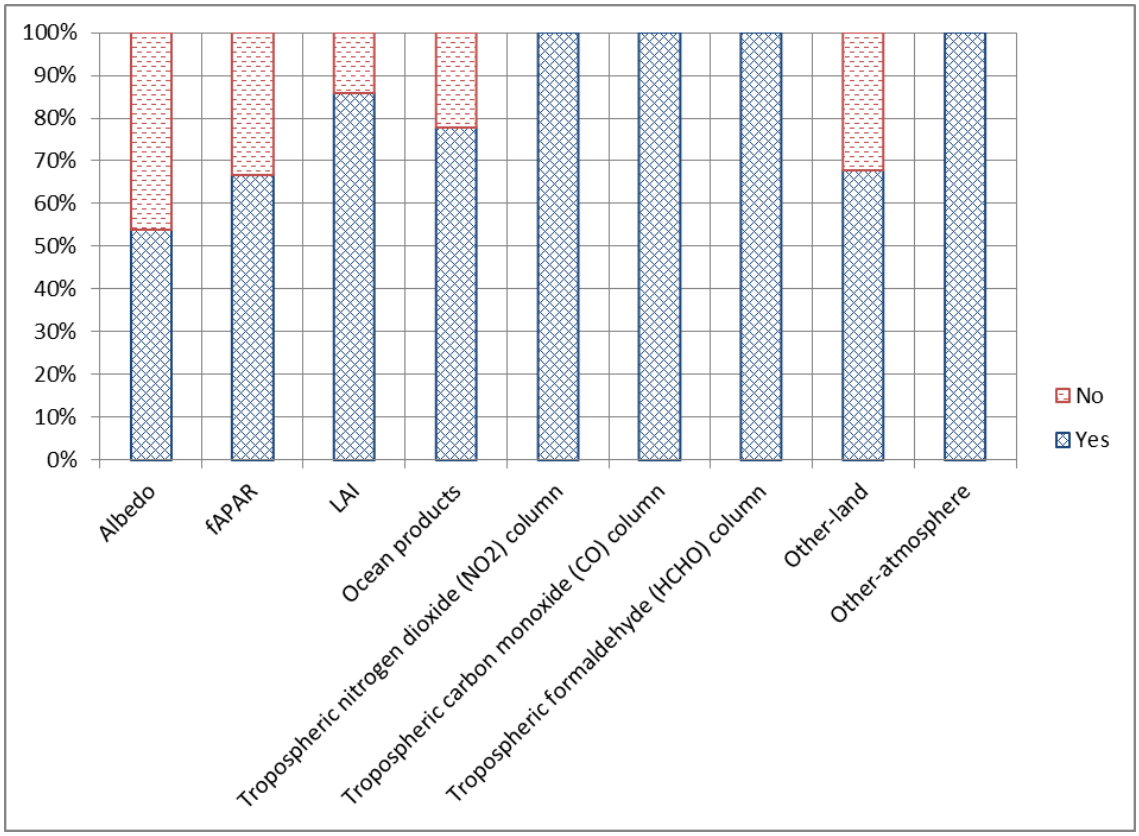

Figure 5- Percentage of products for each ECV that contain quality flags ("Other" products are listed in Figure 3)

Suggestions of useful QA flag information to be incorporated in products included; cloud properties (contamination and shadow), aerosol contamination, sensor issues, algorithm problems, use of a back-up algorithm, indication of gap-filling and smoothing routines (Figure 6).

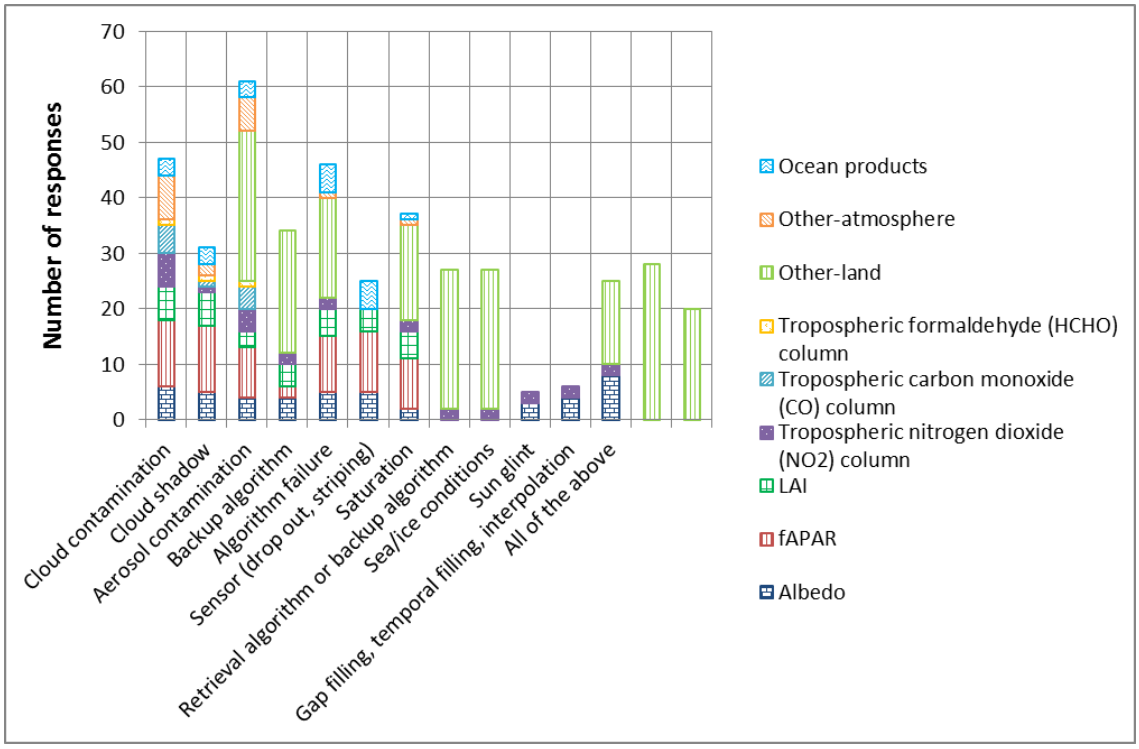

Figure 6- Suggested information that would be useful if it were provided as a quality flag.

4.4. UNCERTAINTY

Less than 40% of the land products utilised by the respondents have uncertainty information associated with them. While the majority (over 85%) of atmosphere products contain uncertainty information. There are insufficient results to analyse uncertainty information on a product by product basis. However, for several of the data products listed, some users claim that uncertainty information is provided, while others claim that it is not. For example, of those respondents that listed using surface albedo derived from MODIS TERRA/AQUA, 50% suggest uncertainty information is available, while 50% do not. This blatantly highlights the necessity and urgency for ensuring that quality assurance information is easily accessible and clearly presented. Of the products that do offer uncertainty information, all respective respondents took advantage of this when utilising that data in their applications. The majority of respondents would like uncertainty information to be provided in data products if not done so already. Per pixel uncertainty was the most commonly required information. Further to this, 70% of data users would value advice on how to evaluate uncertainty for a particular application.

4.5. VALIDATION

Similarly to other aspects of QA, more of the atmosphere products are reported by the users as being validated compared to the land/ocean products. Note that the Formaldehyde products are not validated, although this may be an artefact of the very small sample size (3 people). Around half of the land/ocean products currently utilised are validated and include VEGETATION, MERIS, SeaWIFS, MODIS, CERES TERRA/AQUA, POLDER and METEOSAT sensors. A large portion of respondents admit to not knowing if the products they use are validated or not (Figure 7).

Provision of validation information for land and formaldehyde products is substantially less than other ECVs. The majority of users report that the quality of validation documentation available overall is only “okay” or “good”. As a result, around 50% of users independently validate their products. In addition, most users (95%) would value best practise guidelines on product validation.

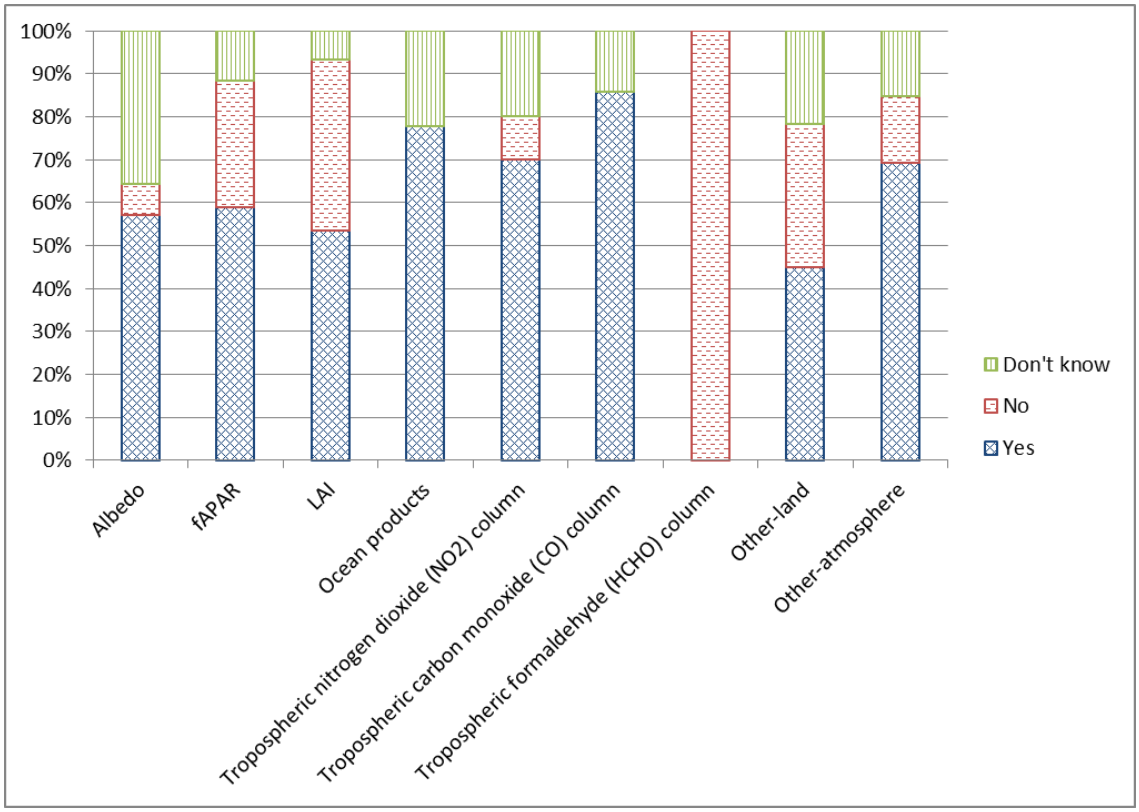

Figure 7- Is the product you use validated?

4.6. SUMMARY OF USER SURVEY

The results from the user survey clearly show that quality assurance information is generally not easily accessible for users. Respondents report that if this information was available, it would be useful to them. However, best practice guidance for implementation of the QA fields in their respective applications would be beneficial. Figure 8 shows the percentage of respondents who find information on each aspect of quality assurance studied easily accessible. Figure 8 shows the clear distinction between availability of quality assurance information in land and atmospheric products. The least accessible component is traceability in the case of both land and atmospheric products; even though about 90% of users say it is important or very important to know this. The most readily available information is quality flags, although these are often insufficient for the reported applications.

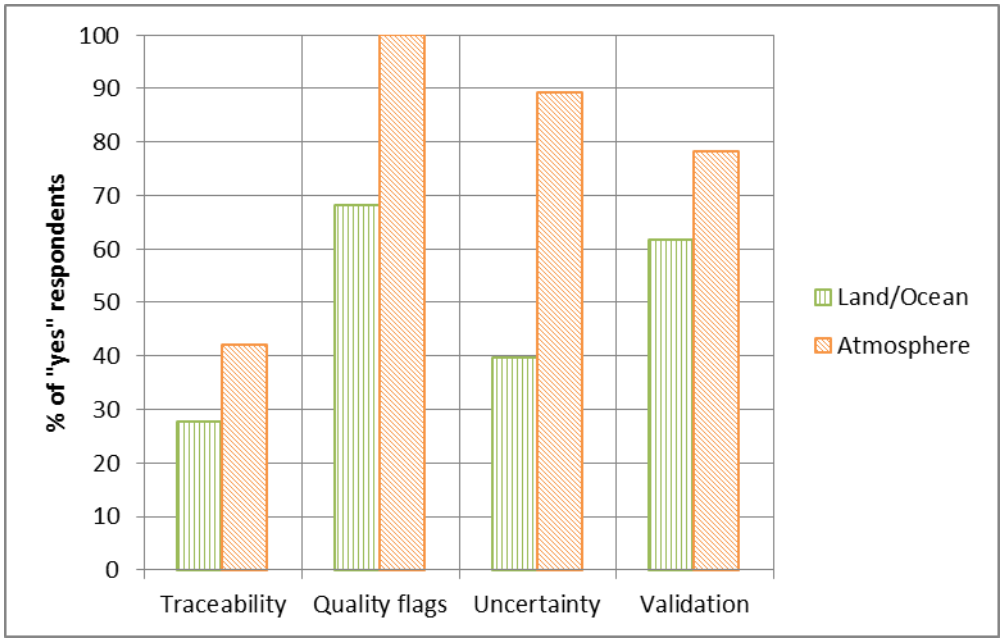

Figure 8- Percentage of respondents who answered "yes" when asked if a particular quality assurance component was easily accessible.

5 SURVEY OF DATA SUPPLIERS

The survey of data producer/suppliers was conducted to gauge their views on how effectively QA information is provided for their data products. This survey involved phone interviews with six individuals responsible for developing and/or providing data sets to the community. Three land/ocean (ocean colour, soil moisture and leaf area index) and three atmosphere (carbon dioxide and methane, ozone and clouds) data suppliers within the EU and North America were contacted. 5 out of 6 suppliers are involved in the production of ECVs for ESA's Climate Change Initiative (http://www.esa-cci.org) and EUMETSAT Satellite Application Facility (http://www.cmsaf.eu). One supplier produces long-term records of ozone columns on behalf of NASA. The supplier survey consisted of 4 sections:

1. Background and product delivery
2. User interaction questions
3. Data product quality
4. Validation questions

5.1. BACKGROUND AND PRODUCT DELIVERY

Data suppliers surveyed were from academia and from governmental organisations. The data provided is used predominately for scientific research purposes (80%), ~ 15% for policy evaluation and ~5% for commercial applications.

According to the suppliers, all the products produced are freely available via the internet and used for a wide range of applications. The top three most common applications were the carbon cycle, trend analysis and model evaluation.

5.2. USER INTERACTION

Suppliers were asked what information they supplied to users. Generally data products are provided with links to metadata, ancillary information, product specification documents (PSD), algorithm theoretical basis documents (ATBD), and publications on the algorithm and validation. The surveyed suppliers admit that traceable input files, read-in software and sensitivity analysis documentation and publications are currently not provided.

Suppliers recognise that direct communication with their data users is important. Most are in contact with users regularly ("daily" to a "few times per year"). This involves answering questions related to read in software, product format, flagging/selection procedures and the error budget.

5.3. DATA PRODUCT QUALITY

Suppliers were queried regarding the dissemination of information related to product processing chain traceability and provenance, uncertainty information, quality flags and validation. The data suppliers reported that most of their products are provided with retrieval error, product error and validation status information. The suppliers assume that all products have quality indicators appropriate for the users needs, but admit that these are not tied to international standards. There is doubt whether general quality indicators can be provided to allow a universal fitness-for-purpose test.

All suppliers reported that traceability information is supplied within the ATBD or the PSD, with one supplier having a strict requirement that ATBD, product consolidation, and data readiness reviews be carried out before the data is released to users. All products contain quality flags (except heavily filtered "already good" products). The quality flagging is strongly related to the nature of the data product. The products also all have error estimates reported per area (pixel, cell). In general, the data suppliers interviewed believed that all the necessary traceability and quality information is provided within the supplementary documentation and strongly urged the data user to read this documentation (including the ATBD and validation papers).

None of the surveyed data suppliers were particularly positive with regard to potential ISO (International organisation for standardisation) standardisation of satellite products. It was suggested that these standards would be too stringent and that there would be problems with the standards not being relevant to the product. However, it is important to note that the QA4ECV product is not aiming to apply or implement ISO standards to products. Suppliers were generally positive about benchmarking their satellite data against other scientific standards, such as from cross-calibrated global validation networks. Some of the suppliers used a number of standards for certain aspects of product generation including software engineering and data / metadata formats including ISO (International Organisation for Standardisation) and INSPIRE (Infrastructure for Spatial Information in the European Community).

5.4. VALIDATION

All products provided by the suppliers interviewed have been validated, with a minimum of one peer-reviewed paper concerning validation activities, with some products having up to five. Best practise guidelines for independent validation were welcomed by suppliers, but there was a general reluctance to have these imposed.

Supplier opinion concerning the quality /uncertainty of the reference data used to validate their products, varied from the notion of “grab what you can”, to the supplier being confident that they have stable, good quality reference information. Suppliers also commented that quality information for the reference data is often not available.

6 COMPARISON OF USER AND SUPPLIER OPINIONS

The results from the supplier survey generally contrast considerably with the opinions gathered from the user community. However it is important to note that only 6 suppliers were interviewed compared to over 200 data users, thus any comparison must be viewed within this understanding.

One of the most prominent discrepancies between the supplier and the user opinions of quality assurance in satellite products is the availability of traceability information. All suppliers interviewed stated that this was available compared to 28% of land users and 42% of atmospheric product users. Suppliers stated that this information was always available in ATBDs or PSDs. The suppliers stress the importance of users reading this available literature. Although one community member present at the QA4ECV user consultation meeting (EGU 2014) highlighted that these documents can be extremely long and tend not to be very interpretable. This statement was further emphasised by the fact that for the same product some users suggest processing chain information is available while others do not. A clear conclusion can be derived from this; *there is a clear requirement for processing chain information to be much more transparent and more easily accessible for the users.*

There is also considerable disagreement between users and suppliers over product validation with the suppliers suggesting products are always validated and users only suggesting that ~70% of products are validated. Again this could be due to unclear literature or that the validation information is not obtainable by users.

Conversely, users of atmospheric products agree that uncertainty information is provided with data products, which is in contrast to users of land data products. There is also fairly good agreement between users and suppliers on the current state of quality flags on products, with users suggesting these are fairly readily available. Albeit, some users suggest that the quality flagging is not sufficient for their application and could be improved with the provision of more useful information.

7 CONCLUSIONS

The results presented in this report are from the responses of the survey to date; the survey is still active and will remain so until the end of the QA4ECV project, thus opinions from users will continue to be gathered as the project develops and new contacts are made. At the project end a further report will be produced to show any developments in user opinions of quality assurance that have occurred during the course of the project.

The results presented in this report will provide guidance for the QA4ECV project moving forwards. The report has highlighted that users obviously require transparency in quality assurance information. Therefore, in the QA4ECV project the quality assurance information must be clear, understandable and readily obtainable, so the quality assurance provided in this project framework can be as useful and relevant as possible to users.

In summary, there are three key recommendations that result from this report which can be utilised for the QA4ECV framework specification:

1. All QA information for satellite-derived products must be easily obtainable and published in a transparent manner that is coherent to a variety of competencies of users.
2. If uncertainty is provided for a particular ECV then this should be stated with details on how this is calculated. The generation of uncertainty estimates will be advanced within the QA4ECV project through the development of an ECV uncertainty propagation tool.
3. Full and comprehensible details of the processing chain for a satellite should be available to users in a clear format. In QA4ECV “traceability chains” are being developed which diagrammatically show the stages in the processing chain for a particular product.

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APPENDIX A

List of recipients of the QA4ECV user survey

Mailing List	Description
International Groups	
CLIP-C	Climate Change Information Platform for Copernicus- provides access to climate information to a wide variety of users
LPVE meeting list	Land Product Validation and Evolution- workshop on calibration, validation and evolution of land products
GV2M	Global Vegetation Monitoring and Modelling- International Conference to discuss the new developments in the use of remote sensing observations and Earth system modelling
CEOS LPV general	Committee on Earth Observing Satellites Land Product Validation subgroup
CCM	
NCEO	UK National centre for Earth Observation- partnership of 26 institutions using data from Earth observation satellites to monitor global and regional changes in the environment.
WMO	World Meteorological Organisation
GEO	Group on Earth Observations
SPARC	Stratosphere-Troposphere Processes and their Role in Climate Office
GBIF	Global Biodiversity Information Facility
LinkedIn Groups	
ASPRS	American Society for Photogrammetry and Remote Sensing (ASPRS)- scientific association serving more than 7,000 professionals worldwide
ISPRS	International Society for Photogrammetry and Remote Sensing- International NGO devoted to the development of international cooperation for the advancement of knowledge, research, development and education in Photogrammetry, Remote Sensing and Spatial Information Sciences
RSPSoc	UK's leading Society for remote sensing and photogrammetry and their application to education, science, research, industry, commerce and the public service.
The Earth Observation Network	EONet is a group for academics, professionals and students who are active in remote sensing, EO satellite development/applications, or any other aspect of Earth observation
Countries – *Governments/Universities/Commercial*	
Australia	AEOCCG (Australian Earth Observation community coordination group)
South Africa	CSIR (Council for Scientific and Industrial Research) South African National Space Agency (SANSA)
USA	ORNL (Oak Ridge National Laboratory) and LP DAAC (Land Processes Distributed Active Archive Center) USFS (US Forest service) USGS (US Geological survey)National Center for Atmospheric Research (NCAR) National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) National Aeronautics and Space Administration (NASA) Johns Hopkins University in Baltimore, Department of Earth & Planetary Sciences New York University, Center for Atmosphere Ocean Science Cornell University University of Wisconsin-Madison, Atmospheric & Oceanic Sciences University of Connecticut Colorado State University in Fort Collins University of the South Pacific (USP) United States Environmental Protection Agency (US EPA) Northwest Research Associates (NWRA)
Canada	Environment Canada, Canadian Forest Service Université du Québec à Montréal (UQAM), Sciences de la Terre et de l'Atmosphère
Europe	INRA (The French National Institute for Agricultural Research), AMAP (Botanique et bioinformatique de

	l'Architecture des Plantes) Tropospheric Emission Service (www.temis.nl) - ESA-funded website for dissemination of various atmosphere products. Known/registered users of NO2 and HCHO data have been e-mailed. Joint Research Center (JRC) European Environment Agency (EEA) European Space Agency (ESA) MACC Validation Group European Centre for Medium-Range Weather Forecasts (ECMWF)
Japan	National Institute of Advanced Industrial Science & Technology (AIST) Hokkaido University Kyoto University
China	Chinese Academy of Science, Institute of Atmospheric Physics Tsinghua University Peking University, Department of Atmospheric and Oceanic Sciences Nanjing University of Information Science & Technology (NUIST) Nanjing University (NJU), Department of Atmospheric Sciences Sun Yat-sen University in Guangzhou Nanjing University Beijing Climate Center (BCC) Pondicherry University, Department of Ecology & Environmental Sciences Indian Institute of Tropical Meteorology (Pune) Indian Institute of Science Bangalore,
Russia	Centre for Atmospheric and Oceanic Sciences Siberian Center for Environmental Research and Training (Tomsk) Voeikov Main Geophysical Observatory (Saint Petersburg) Institute of Geography (Moscow) A.M. Obukhov Institute of Atmospheric Physics (Moscow)
UK	Cambridge Environmental Research Consultants (CERC) Rutherford Appleton Laboratory (RAL), NERC Earth Observation and British Atmospheric Data Centres (NEODC & BADC) Centre for Ecology & Hydrology (CEH) MetOffice University of Bristol Aston University University of Sheffield University of Reading, Department of Meteorology University of Cambridge
Switzerland	Swiss Federal Institute of Technology Zurich (ETH), Institute for Atmospheric and Climate Science (IAC)
Norway	Norwegian Institute for Air Research (NILU)
The Netherlands	BMT-ARGOSS Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek (TNO) Royal Netherlands Meteorological Institute (KNMI)
Italy	International Centre for Theoretical Physics (ICTP) Compagnia Generale per lo Spazio (CGS)
Greece	Aristotle University of Thessaloniki, Laboratory of Atmospheric Physics

Germany	Climate Service Center (CSC) German Aerospace Center (DLR) University of Cologne, Rhenish Institute for Environmental Research Helmholtz Centre for Ocean Research Kiel (GEOMAR) Freie Universität Berlin, Institut für Meteorologie Max Planck Institut für Meteorologie, Hamburg Karlsruhe Institute of Technology (KIT), Institute for Meteorology & Climate Research, Atmospheric Trace Gases & Remote Sensing
France	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS) Centre National de Recherches Météorologiques (CNRM) Centre de Prévision de Météo-France (ACRI-ST)
Finland	Finnish Meteorological Institute
Bulgaria	Bulgarian Academy of Sciences, Geophysical Institute
Belgium	Vlaamse Instelling voor Technologisch Onderzoek (VITO) Université Catholique de Louvain (UCL) Belgian Institute for Space Aeronomy (IASB-BIRA)