Copernicus Cal/Val Solution

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Changes Log

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Table 1: Acronyms used in this report

Acronym	Definition
ACTRIS	The Aerosol, Clouds and Trace Gases Research Infrastructure
ANA	National Water Agency of Brazil
Cal/Val	Calibration and Validation
CCVS	Copernicus Cal/Val Solution
CDOM	Coloured Dissolved Organic Matter
CPRM	Geological Survey of Brazil
DOAS	Differential Optical Absorption Spectroscopy
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DTM	Digital Terrain Model
eLTER	European Long-Term Ecosystem Research Infrastructure
FRM	Fiducial Reference Measurement
FTIR	Fourier Transform Infra-Red spectrometer
GAW	Global Atmosphere Watch programme
GCOS	Global Climate Observing System
GEWEX-GDAP	Global Energy and Water Cycle Experiment - Data and Analysis Panel
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICOS	Integrated Carbon Observation System
LAI	Leaf Area Index
Lidar	LIght Detection And Ranging
MAX-DOAS	Multi-axis DOAS instrument
NDACC	Network for the Detection of Atmospheric Composition Change
NEON	National Ecological Observatory Network
NOAA	National Oceanic and Atmospheric Administration
PGN	Pandonia Global Network
POD	Precise Orbit Determination
QA4EO	Quality Assurance framework for Earth Observation
QC	Quality Control
SIOS	Svalbard Integrated arctic earth Observing System
SST	Sea Surface Temperature
SZA	Solar Zenith Angle

UN	United Nations
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
ZSL-DOAS	Zenith-scattered-light DOAS instrument

1 Introduction

1.1 Scope of the document

This document aims to map different existing ground-based and air-borne instrumented Cal/Val sites and networks acquiring measurements in a systematic manner, in Europe and worldwide. It does not include all available Cal/Val networks but only those that we interviewed or had enough information available online to include in this report. To meet the needs of satellite Cal/Val, measurements one must adhere to the definition for a Fiducial Reference Measurement (FRM)(Giuseppe Zibordi *et al.* 2014) and to the principles of the Quality Assurance framework for Earth Observation (QA4EO 2010).

An important distinction exists between networks that take measurements routinely (known as systematic in this document) and those whose measurements are made on an occasional, agreed timing (referred to as campaign based). Only the former are covered here with the latter being covered in Task 2.5. If sites or networks are doing both systematic and campaign-based measurements, then these are divided between this document and T2.5 report (REFERENCE) with the division decided on a case-by-case basis. In addition to listing activities already known to support Cal/Val, we also mapped activities that already fit the Cal/Val needs but are not used for Cal/Val and those that need only some modifications to be fit for this purpose. Also, it was important to map potential validation sites where measurements do not meet all the FRM requirements yet but which have a great potential to increase the amount of validation data.

Atmospheric composition measurements within the canopy cover and measurements related to air/surface exchange are different from other atmospheric composition measurements, as these are targeted only at the thin layer near the surface. These measurements are usually conducted by the same networks that collect data used for validating optical missions, therefore these air/surface interface measurements are covered in the optical missions' chapter.

As the number of systems that are dealing with Cal/Val exercises of radar and microwave missions is low, they are all covered within the T2.5 report to increase efficiency and readability.

The scope of this document is not to evaluate the quality or maturity of the networks/sites that were being interviewed. It only maps the current situation and serves as an input for a later stage of the project. The completed questionnaires that we used to collect the data assembled in this report are not added directly to the document but will be available for project partners for next stage analyses.

Table 2: Networks/Sites covered within this report

Network acronym	Network full name	Network Website
Optical		
AERONET-OC**	The Aerosol Robotic Network - Ocean Color	https://aeronet.gsfc.nasa.gov/new_web/ocean_color.html
Aquaspectus	Network of WISPstations	Water Insight

BOUSSOLE	BOUée pour l'acquiSition d'une Série Optique à Long termE	http://www.obs-vlfr.fr/Boussole/html/home/home.php
BSRN	Baseline Surface Radiation Network	https://www.bsrn.awi.de
Copernicus LAW	Copernicus Space Component for Land Surface Temperature, Aerosol Optical Depth and Water Vapour Sentinel-3 Products Project / LAW LST sites	https://law.acri-st.fr/home
DEMMIN & Moorfluxnet		https://www.moorflux.net/#Das%20Netzwerk
eLTER RI	European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure	https://www.lter-europe.net/elter-esfri
FLUXNET		Fluxnet.org
ICOS Ecosystem	Ecosystem part of the European infrastructure Integrated Carbon Observation System	www.icos-etc.eu www.icos-ri.eu
ICOS Ocean	Marine part of the European infrastructure Integrated Carbon Observation System	https://otc.icos-cp.eu/ www.icos-ri.eu
IMOS Ocean Colour Sub-facility	Integrated Marine Observing System – Ocean Colour Sub-facility	https://imos.org.au/facilities/srs/oceancolour http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/OC/LJCO/catalog.html http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/OC/BODBAW/catalog.html http://thredds.aodn.org.au/thredds/catalog/IMOS/SRS/OC/radiometer/VMQ9273_Solander/catalog.html http://coast-rs-1.it.csiro.au/
ISMN	The International Soil Moisture Network	https://ismn.earth/en/
FLARE		https://flare-network.com/
KIT LST	Karlsruhe Institute of Technology Land Surface Temperature	https://www.imk-asf.kit.edu/english/skl_surfacetemperature.php
LéXPLORE/Thetis		https://lexplore.info
MOBY	Marine Optical BuoY	https://mlml.sjsu.edu/moby
NASVF	North Australian Satellite Validation Facility	https://www.ozcalval.org/
NEON	National Ecological Observatory Network	https://www.neonscience.org/
PEN	Phenological Eyes Network	http://pen.envr.tsukuba.ac.jp/

PEP725	PEP725 PanEuropeanPhenology Data Base	http://www.pep725.eu/
RadCalNet**	Radiometric Calibration Network	https://www.radcalnet.org/#!/
SIOS	Svalbard Integrated arctic earth Observing System	https://sios-svalbard.org/
SMEAR	The Station for Measuring Earth surface - Atmosphere Relations	https://www.atm.helsinki.fi/globalsmear/index.php
TERN	Australian Terrestrial Ecosystem Research Network	https://www.tern.org.au/tern-observatory/tern-ecosystem-processes/
Altimetry		
AMAZON	Altimetry measurements at Amazon river	N/A
DBCP**	Buoys network	https://www.ocean-ops.org/DBCP/
DORIS	International DORIS service	https://ids-doris.org
FRM-BASS STRAIT**	Altimetry FRM site at Bass Strait (Australia)	N/A
FRM-CORSICA	Altimetry FRM site in Corsica (France)	N/A
FRM-CRETE	Altimetry FRM site in Crete (Greece)	https://www.frm4s6.eu/ https://www.frm4alt.eu/
FRM-HARVEST**	Altimetry FRM site ah Harvest oil platform (US)	N/A
FRM-ISSYKKUL	Altimetry FRM site at Issykkul lake (Kyrgyzstan)	N/A
GLOSS**	The Global Sea Level Observing System	https://www.gloss-sealevel.org
GRDC**	The Global Runoff Data Centre	https://www.bafg.de/GRDC/EN/01_GRDC/grdc_node.html
HYDRODATEN	Switzerland hydrological network	https://www.hydrodaten.admin.ch/fr/
IGS	International GNSS Service	https://www.igs.org
ILRS	International Laser Ranging Service	https://ilrs.gsfc.nasa.gov/
IMOS Ocean Colour Sub-facility	Integrated Marine Observing System	https://imos.org.au/facilities/nationalmooringnetwork/wave-buoys
INSTAC	Copernicus Marine Environment Monitoring Service In Situ Thematic Assembly Centre	http://www.marineinsitu.eu
LOCSS	Lakes Observations by Citizen Scientists & Satellites	https://www.locss.org/view-lake-data
NDBC**	National Data Buoy Center	https://www.ndbc.noaa.gov
OECS	Observations des Eaux continentales par des Citoyens et des Satellites	http://oecsmap.org/

REFMAR	Reseaux de reference des observations marégraphiques	http://refmar.shom.fr/en/home
Atmospheric composition		
AERONET	Aerosol Robotic NETwork	https://aeronet.gsfc.nasa.gov
AEROSPAN	AERONET Australian part	https://research.csiro.au/acc/capabilities/aerospan/aerospan-data/
AGAGE**	The Advanced Global Atmospheric Gases Experiment	https://agage.mit.edu
ARM	Atmospheric Radiation Measurement	https://www.arm.gov/
COCCON	Collaborative Carbon Column Observing Network	https://www.imk-asf.kit.edu/english/COCCON.php
enerMENA	enerMENA Meteo-Network	https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-8680/12865_read-32404/
EUBREWNET	European Brewer Network	http://www.EUBREWNET.org
GRUAN	GCOS Reference Upper Air Network	www.gruan.org
IAGOS	In-service Aircraft for a Global Observing System	https://www.iagos.org
ICOS Atmosphere	Atmospheric part of the European infrastructure Integrated Carbon Observation System	www.icos-atc.eu www.icos-ri.eu
Meteo-France	Meteo-France operational radiosonde network	http://www.meteofrance.fr/prevoir-le-temps/observer-le-temps/moyens/les-radiosondages
NDACC	Network for the Detection of Atmospheric Composition Change	http://www.ndacc.org
PGN	Pandonia Global Network	https://www.pandonia-global-network.org/
SHADOZ	Southern Hemisphere Additional Ozonesondes	https://tropo.gsfc.nasa.gov/shadoz/
SKYNET		http://atmos3.cr.chiba-u.jp/skynet/
SNO-IFA	SNO-IFA ICOS-France-Atmosphére	Under development
TCCON	Total Carbon Column Observing Network	http://www.tccon.caltech.edu/
TOLNet**	Tropospheric Ozone Lidar Network	https://www-air.larc.nasa.gov/missions/TOLNet/
WMO/GAW Ozone column and sonde profiles network	World Ozone and Ultraviolet Data Centre under Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO)	https://woudc.org/home.php

*Questionnaires were partially filled by information found online
**Questionnaires were fully filled by CCVS consortium member using information available online

2 Questionnaire

2.1 Questionnaire design

The Questionnaire was designed to get information on the following topics:

- General information – This includes basic information about name and website of the site/network, its coverage and ownership.
- Financing situation – To evaluate the sustainability of different measurements we gathered information about uniformity of financing within the networks and also about future prospects.
- Data handling – To fit the Cal/Val activities a network must fit the requirements of Fiducial Reference Measurements (FRM). At the same time there are number of measurements that might not have ideal documentation but which are essential to increase the amount of validation data available for Copernicus.
- Information how the data is collected, analysed and distributed and whether it is publicly available for a review (Measurement protocols, quality assurance, quality control, quality assessment metadata standards, data distribution rules)
- Planned or in progress developments including software, calculation, calibration/characterisation
- Detailed description about measured parameters: Device used, units used, measurement target, measurement frequency, calibration frequency, maintenance frequency, other characteristics measured about the instrument (in addition to standard calibration), uncertainty evaluation.

The full questionnaire template is available as Annex 1.1.1.1.1.1Annex A1.1.1.1.1.1A.1 and the full list of sites/networks who answered the questionnaire is available in Table 2.

The CCVS consortium acknowledges everyone who sent their feedback although due to COVID-19 restrictions the amount of working time available was very limited.

3 Optical satellite missions

3.1 Introduction

The measurements from fixed structures that are conducted to validate Copernicus optical missions benefit from the fact that the in-situ measurements can be themselves validated with additional measurements data (e.g. by campaigns to characterize the site, using instruments with different working prrinciples, laboratory vs field measurements). The benefit of these comparisons is that the quality of the measurements can be estimated with intercomparisons. However, this has also resulted in less development work in end product uncertainty estimations compared to for example atmospheric composition products. The drawback for the on-site measurements is that when the structures accommodating the sensors are bigger (e.g. fixed platforms on water), they influence strongly the pixel measured by the satellite and therefore when these measurements are used for comparison of satellite measurement a buffering area must be considered to exclude the effect of the structure itself. This is mainly an issue with radiometric measurements that have small FOV on sites (e.g. fluxes are integrated over a large area, SWC is measured in different places etc.). Using buffering zones automatically means that when measurements from these networks or individual sites are compared to satellite measurements for validation the targeted areas are different and must be spatially up or downscaled. This is not a big issue when the area is homogeneous but must be considered with more heterogeneous study areas. There is one exception (type of mooring stations) that is not sensitive for this issue and is covered in 3.1.2.

As optical satellite missions are extremely sensitive to cloud coverage then continuous measurements are essential to collect maximum amount of validation data as even carefully planned validation campaigns can be easily ruined by clouds that can form quickly and are often hard to predict.

Sites collecting optical measurements considered in this report were divided into two sub-groups: those located over land (mainly related to vegetation monitoring activities), and those located over water.

3.1.1 Vegetation measurements

The sites that are used to monitor vegetation are mostly not built for satellite validation purposes. The sites are usually designed for complex ecosystem evaluations which require many parameters, but some of these parameters are suitable to be used to validate satellite products. Sites are usually connected to the power grid or have an on-site generator that guarantees a continuous acquisition of measurements, which results in datasets having match-ups for all the satellites covering the area. These sites are usually also accessible independently of the weather, and gaps due to sensor failure can be addressed quickly. Regular maintenance trips are not as expensive as for on water sites. These sites/networks are of interest to many different parties, and are often related to national monitoring projects.

Most of these sites also measure gas fluxes within the canopy and therefore instruments have to be hosted on masts or towers higher than the local vegetation. This might not be an issue over lower canopies, but inside forests with higher trees (Figure 1), the need of tall towers can include cutting down some surrounding trees for logistic needs (safety cables). Luckily the tendency for these towers is to just find a natural hole, also because in this way it is possible to access the canopy for leaves level measurements. In the rare cases where cutting is need, the canopy closes the gap very fast. It is important to add, that most of the measurements on these towers are representative of the wider area and not the exact location of the tower.

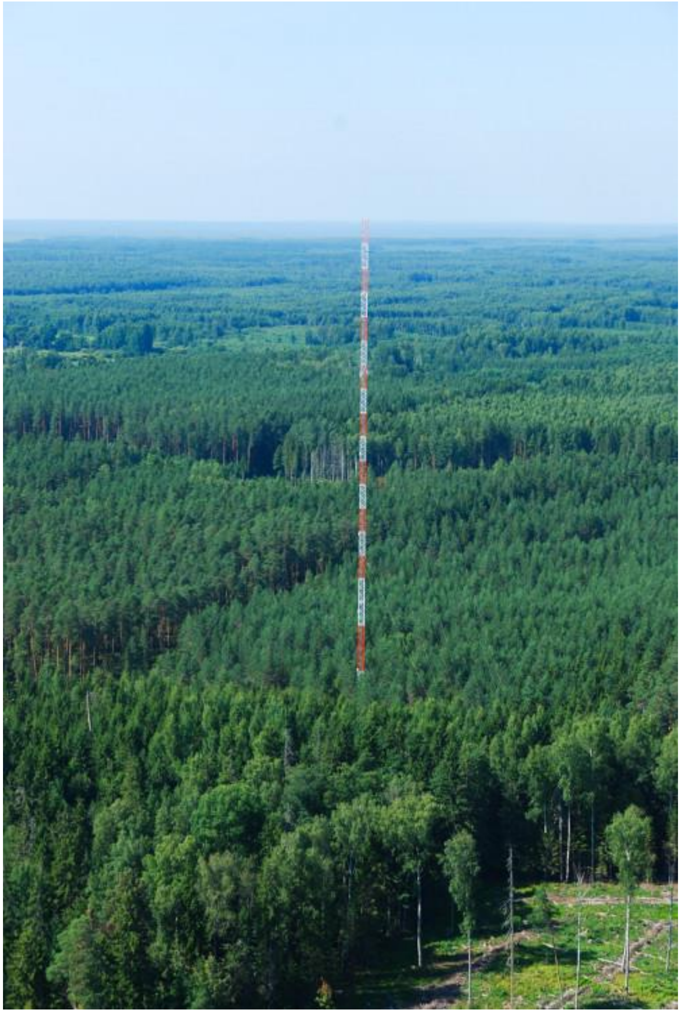

Figure 1. SMEAR tower in Estonia

3.1.2 Measurements over water

Measurements over water can be divided into three subgroups. A) Fixed position instruments usually on platforms or coastal structures. B) Floating measurement buoys. C) Moored stations. The campaigns conducted on research vessels are covered in task 2.5 (CCVS-DLR-D2.5 2021).

Only sensors from coastal structures can benefit from assured regular maintenance and quick access in case of sensor failure. Most of the on the water sites have access depending on the weather conditions, which means that any rapid response for sensor malfunction is hard to achieve, as often ships with cranes with an assistance of divers might be needed. On the other hand, the regular maintenance trips are planned together with additional measurements around the station that compile together as full set of parameters.

Moored stations that measure the full vertical structure of the water column have one key advantage that sets them apart from other fixed position measurements. The profiler can be set to be on the surface just before or after a satellite overpass (Figure 2). Therefore, it is possible to compare in-situ data with satellite measurements over exactly same location whereas structures are significantly brighter than the target (water) and not movable so buffer areas have to be considered.

One major issue with on water sites is that these have limited power supply. In order to increase battery life and the time between maintenance trips, the measurement frequency can be lower compared to land-based sites. This is especially the case with profiling measurements that are usually carried out hourly or a few times per day. Power supply gaps can affect any exact satellite overpass matches (± 30 minutes).

Figure 2. Profiling system breaching the surface minutes before satellite overpass

According to the feedback from the questionnaires, systematic optical measurements over water are usually funded by short term projects. National monitoring is usually interested in the data, but not enough to provide long term national funding for these sites. On water structures mostly have to be well optimized in the case of size and power consumption. Therefore, these sites usually cover limited set of instruments and are usually funded and managed by a small number of institutes whereas land-based sites (both for water and land measurements) can include different scientific fields for the same structure.

3.2 General information about the sites/networks

Table 3: General information of networks under investigation

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
AERONET-OC	NASA (and international federation)	Link	Global	Yes	To provide the additional capability of measuring the radiance emerging from the sea (i.e., water-leaving radiance) with CE-318 sun-photometers installed on offshore platforms like lighthouses, oceanographic and oil towers.
Aquaspectus	Site owners		Sites currently in Europe	Yes	Facilitate surface reflectance data collected with WISPstation instruments
Boussole	• Institut de la Mer de Villefranche (IMEV) • Sorbonne Université (SU) • Centre National de la Recherche Scientifique (CNRS) • Institut National des Sciences de l'Univers (INSU) • European Space Agency (ESA), • Centre National d'Etudes Spatiales (CNES)	7°54'E, 43°22'N	One location	Yes	Cal/Val activities for Ocean Colour satellites

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
BSRN	Sites are run by individual research institutes. The network is under the umbrella of GEWEX-GDAP, WCRP, GCOS	https://bsrn.awi.de/stations/listings/	Global	Yes, depending on site (example Dome-C, Antarctica)	The objective of the BSRN is to provide observations of the best possible quality for short- and long-wave surface radiation fluxes with a high sampling rate. These readings are taken from a small number of selected stations, in contrasting climatic zones, together with collocated surface and upper air meteorological data and other supporting observations.
Copernicus LAW	Copernicus LAW	https://law.acri-st.fr/sites	Global	Yes	This project aims to perform a more extensive and systematic validation against ground-based measurements of three Sentinel 3 datasets: The Integrated Water Vapor included in OL_2_LFR products, Aerosol Optical Depth included in SY_2_AOD products and Land Surface Temperature provided by SL_2_LST products
Demmin/Moorfluxnet	DLR and GFZ	https://www.moorflux.net/#Das%20Netzwerk	Regional	No	Collect data on exchange of climate gases between swamps and atmosphere to give recommendations for swamp management
eLTER RI	Various	https://www.lter-europe.net/lter-europe/infrastructure/networks https://deims.org/	Europe	eLTER RI is currently in its preparatory stage	establishing the integrated European Long-Term Ecosystem, critical zone and socio-ecological Research Infrastructure

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
FLARE	Labsphere	Demo site: Sioux Falls, South Dakota USA Planned operational site: Mauna Loa (Hawaii, USA).	Currently local	In progress	N/A
FLUXNET	Depending on site	https://fluxnet.org/sites/site-list-and-pages/	Global	Some site but not in an organized way	The Data Portal serving the FLUXNET community, collection of ecosystem-atmosphere fluxes
ICOS Ecosystem	Various, data co-owned by ICOS-ERIC	https://www.icos-cp.eu/observations/ecosystem/stations	Europe	Some site but not in an organized way	Long term measurement of the surface-atmosphere interaction. GHGs fluxes as primary measurement.
ICOS Oceans	ICOS Oceans is a network of more than 20 individual marine stations that are run by individual PI's.	https://otc.icos-cp.eu/station-network	Europe	Some stations have a little activity but nothing formal	The marine element of ICOS provides long-term oceanic observations, which are required to understand the present state and better predict future behaviour of the global carbon cycle and climate-relevant gas emissions.

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
IMOS Ocean Colour Sub-facility	CSIRO	Open Access to Ocean Data (aodn.org.au)	Regional	Yes	IMOS Ocean Colour Sub-facility provides access to ocean colour observations for satellite validation and algorithm development through following activities: 1) Continued acquisition of bio-optical data from the Australian research community to enhance the holdings of the IMOS Bio-Optical Database (BODB) 2) Continued acquisition of ship-borne above water radiometry using the DALEC sensor 3) Continued acquisition of radiometric, in-water optical measurements and discrete fortnightly water quality sampling at the Lucinda Jetty Coastal Observatory (LJCO)
ISMN	TU Wien	https://www.geo.tuwien.ac.at/insitu/data_viewer/	Global	Indirectly yes	The International Soil Moisture Network is an international cooperation to establish and maintain a global in-situ soil moisture database
KIT LST	Karlsruhe Institute of Technology	https://www.imk-asf.kit.edu/english/skl_stations.php	Europe and Africa	No; limited resources.	Enabling continuous validation of LST products over several years
LéXPLORE/Thetis	EPFL, Eawag, University of Lausanne, University of Geneva and CARRTEL	Lake Leman, Switzerland	One location	In progress	to assess the impacts from global changes and monitor the general health of Lake Leman
MOBY	Moss Landing Marine Lab	https://coastwatch.noaa.gov/cw/field-observations/MOBY.html	One location	Yes	Collect validation data for Ocean Colour satellites

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
NASVF	Maitech in collaboration with Charles Darwin University, Northern Territory Government, Terrestrial Ecosystem Research Network (TERN), University of Western Australia	Litchfield National Park, Northern Territory, Australia (centre E130.7895/S13.1805)	Regional	Yes, GBOV	On-going and long-term collection of on- and near-ground data for the validation of satellite products using automated and manually operating instrumentation in Northern Australia.
NEON	Sites are owned by a range of institutions (e.g., US Federal agencies, universities).	https://www.neonscience.org/field-sites/explore-field-sites	Regional	No	N/A
PEN	University of Tsukuba	http://pen.envr.tsukuba.ac.jp/	Global	No, but interested	PEN is a network of ground observatories for long-term automatic observation of the vegetation dynamics (phenology), vegetation's optical properties (such as spectral reflectance), and the atmospheric optical properties (such as aerosol optical thickness)
PEP725	The network is operated by ZAMG, the Austrian national weather service	http://www.pep725.eu/statistics.php	Europe	Yes	Establishing an open access database with plant phenology data sets for science, research and education.
RadCalNet		Baotou / China Gobabeb / Namibia La Crau / France Railroad Valley Playa / USA	Global	Yes	Provides satellite operators with SI-traceable Top-of-Atmosphere (TOA) spectrally-resolved reflectances to aid in the post-launch radiometric calibration and validation of optical imaging sensor data.
SIOS	Various members of SIOS consortium (link)	Various locations on Svalbard	Regional	There are a few activities but not in a structured way.	N/A

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
SMEAR	SMEAR I-III: University of Helsinki SMEAR IV: University of Eastern Finland SMEAR Estonia: Estonian University of Life Sciences SMEAR BUCT: Beijing University of Chemical Technology	https://www.atm.helsinki.fi/globalsmear/index.php/sta-tion-net-work/list-of-stations	Global	Yes, Thermal IR measurements for land surface temperature to be started at SMEAR II in autumn 2021	Concept offers an observation platform that provides continuous, comprehensive environmental information from local level up-to the global Grand Challenges
TERN	National Collaborative Research Infrastructure Strategy	Link1, link2, link3, link 4	Regional	Yes	Australia's Land Ecosystem Observatory measure key terrestrial ecosystem attributes over time from continental scale to field sites at hundreds of representative locations and openly provide model-ready data that enable researchers to detect and interpret changes in ecosystems.

3.3 Financing properties

Table 4: Summary of financing situation of Networks under investigation

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
AERONET-OC	Network (centrally)/ Individual sites separately (Both as it is a federation of partners)	Network – long term, Sites mostly project based	Depends on site	Network coverage from NASA is long term
Aquaspectus	Per site	Depends on site	Depends on site	Depends on site
BOUSSOLE	One site	Project based	Agency, National Funding is in form of ship time, personnel and infrastructure.	1 year
BSRN	Per site	Depending on the site	National funding / Own resources	N/A formally, sites are requested to commit for long term (10y+).
Copernicus LAW	Copernicus LAW finances central data processing and archiving facilities for LST, AOD and WV. Furthermore, LAW finances the acquisition of five standardized LST instrument packages and their deployment and initial operation at selected sites with pre-existing infrastructure.	Project based, but extension is expected	EC program	2 years (01.2020 - 12.2021). Extension program is expected
DEMMIN/Moorfluxnet	Centrally	Long term agreement	DLR, GFZ (in combination with 3rd party funding)	DLR – no limit GFZ – 2025
eLTER RI	Per site	Project based with long term commitment	National funding	5-years budget with commitments
FLARE	One site	Commercial initiative	Labsphere, NASA/USGS	N/A

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
FLUXNET	Mainly at site level, some activities at continental level. No funding for the global coordination	Depends on the site	National funding mainly, some continental	Highly variable
ICOS Ecosystem	Part network, part local	Long term agreement	National funding	next 5 years (plan 30 years)
ICOS OCEAN	Individual sites	Both	Depending on a station	Between 1 and 20 years, depending on the station
IMOS Ocean Colour Sub-facility	Network	N/A	National funding by the Australian Government provided to the IMOS. IMOS is enabled by the National Collaborative Research Infrastructure Strategy (NCRIS)	Until June 2023, Probable extension until 2028
ISMN	The ISMN has been and still is financed through different ESA programs centrally for building up the network as well as operational maintenance and inclusion of new updates and networks (currently QA4EO, formerly SMOS and IDEAS+) centrally. The Individual participating networks with individual numbers of sites, are financed separately through different organisations	Project based	ESA	ISMN operations: 1 year (End of April 2022) ISMN R&D: 2 years (End of April 2023)
KIT LST	KIT	Project based	Karlsruhe Institute of Technology	5 years (until 2025)
LéXPLORE/Thetis	One site	Long term agreement (platform) and project based (profiler)	National funding	September 2021 (Profiler) 2027 (Platform)

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
MOBY	One site	N/A	NOAA	2025, but planned to continue throughout the VIIRS era
NASVF	One site	Project based funding with long term agreement	The site is funded through a mix of sources.	ranges from 1-3 years with a longer term commitment
NEON	Network	Long term	US National Science Foundation	30 years
PEN	Centrally	Long term agreement	Agency and National funding	Depends on site
PEP725	Individual sites	Project based	Each of the PEP725 partners have their phenological observational networks financed. PEP725 itself is financed partly by EUMETNET and the Austrian Ministry of Education, Science and Research within the framework of the national weather service.	No time limit fot he network itself.
RadCalNet	Network			
SIOS	SIOS consortium has various components financed by various findings. Individual infrastructures are financed separately by member institutions	Both project based and long term	National funding and contribution from member institutions.	National funding until December 2021.
SMEAR	Individual sites	N/A	Depends on site	N/A
TERN	Centrally	Project based funding with long term agreement	Australian Government	Until 2023 and expected to continue

3.4 Data handling

Table 5: Data handling situation of Networks under investigation

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
AERONET-OC	Open access	Yes	Yes (link)	Yes (link), mostly automatic	Yes (link)	N/A
Aquaspectus	Open access	Yes	Yes, not yet published	Open access, not yet published, automatic	Depends on site	Harmonizing with MONOCLE in progress
BOUSSOLE	Open access (link1, link2, link3, link4, link5, link6, link7, link8, link9, link10)	N/A	Yes, links from measurement protocols and link1	Open access, previous links. Automatic and manual	Open access, previous links.	Internal standard
BSRN	Link – currently under complete review	No	Yes (Link)	Yes (Link1, Link2, Link3) Mixture of automatic and manual	Yes (Link1, Link2, Link3, Link4)	Pangea (link) AWI server: (link1, link2, link3)
Copernicus LAW	Open access	Yes	Yes (Link)	Yes (Link), automatic	No	Yes (Link)
Demmin/Moorflu xnet	Yes (link1, link2, link3)	Yes	Yes, Demmin planned to be published, Flux (link)	Yes, Demmin (automatic) planned to be published, Flux (manual) (link)	Demmin - No Flux (link)	Yes
eLTER RI	Will be open access	Yes	Once it is developed, it will likely be open access.	Once it is developed, it will likely be open access. (automatic)	Once it is developed, it will likely be open access.	INSPIRE conform and following ISO 19115/10139

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
FLARE	N/A	Yes	In progress	N/A	Uncertainties are provided	Format to be defined
FLUXNET	The network uses different protocols, not standardized. It is a global bottom-up self organized network.	Yes, at continental level where agreements on standards are discussed and reached	No, only on the last part of the processing	Only for the last part (automatic) of the processing it is centralized, as described in Pastorello et al. 2020. Previous steps highly variable function of the site.	no, only statistics on percentage of gaps	A FLUXNET standard is used (BADM)
ICOS Ecosystem	Open access (link)	Yes	Yes, In the protocols, that are validated by the ICOS ETC for each site	Yes. Function of the variable, there are procedures (in the protocols) and codes for the data evaluation and processing. Available in the ICOS ETC GitHub (some will be added soon). Almost all automatic	No, only statistics on percentage of gaps	A FLUXNET standard is used (BADM) currently in translation to RDF formats (DCAT probably)
ICOS Ocean	Open access (link)	Yes	N/A	Yes (link), both manual and automatic	N/A	Yes, not publicly documented
IMOS Ocean Colour Sub-facility	Open access	Yes	Open access	Open access	Yes, Round-robin experiments (link).	ACDD conventions

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
ISMN	No collection but data harmosation (link)	Yes	No	Yes (link1, link2), automatic	No	Yes (link)
KIT LST	Open access (link)	Yes	Yes (not open access)	Yes, automatic	No	Yes (link)
LéXPLORE/Thetis	In work	N/A	Yes, reference in progress.	Yes, reference in progress. Automatic	Yes, reference in progress.	NetCDF
MOBY	Open access (link)	N/A	Yes (link)	Yes, manual (link)	Yes (link)	Own standard
NASVF	varies	Yes	In development	Mixture of automatic and manual, not yet published	In development	NETCDF CF

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
NEON	Open access (link)	Yes	Yes (link)	Yes. Specific data QC procedures tests for instrumented data are described in the Algorithm Theoretical Basis Document for each data product and other documents referenced therein. These documents are downloadable in data packages and from each data product's landing page on the NEON Data Portal (link). Almost all automatic. Science review flags can be raised manually based on Scientists' assessment.	Yes (link)	Yes (link)
PEN	Open access	Yes	Not sure	Not sure	N/A	No
PEP725	No centralised protocol	Yes	No	A QC procedure is being developed by PEP725. To some degree such QC is done by the contributing partners. Mixture of both, manual checking and automatic procedures.	N/A	Link
RadCalNet		Yes	Yes	Yes	Yes	

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
SIOS	depends on the partners (link1, link2, link3, link4, link5)	N/A	Yes, but this can vary from partner to partner (link1, link2, link3)	This may vary from partner to partner and depends on the type of data (meteorological)	No	Discovery metadata: GCMD DIF, ISO19115 Darwin Core Archive (link) Climate and Forecast convention (link) GeoJSON, XML (link1, link2)
SMEAR	Partly yes ICOS, ACTRIS measurement protocols for measurements that are part of those infrastructures	Yes	Yes	Yes, automatic for near real time data, for most parameters periodic manual QC	Yes, for some ICOS/ACTRIS related atmospheric variables, otherwise no.	Administrative metadata yes, technical/descriptive metadata no
TERN	Open access (Link1, Link2)	Yes	Partly Yes (link1, link2, link3), partly pending	Yes, more detail in the questionnaire (link1, link2, link3). Mixture of manual and automatic	Yes (link1, link2, link3),	Yes (link)

Table 6: Data distribution of Networks under investigation

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
AERONET-OC	Open access	Yes	https://aeronet.gsfc.nasa.gov/new_web/data.html	First site was set up in 2002	Depends on site
Aquaspectus	Depends on site	Yes	support@waterinsight.nl	First site was set up in 2018	The timeseries are only measured when there is enough light so there are no night-time measurements. Wintertime measurements depend also on light availability (sun far enough above the horizon: in principle solar elevation should be above 30O). Since the system is solar powered, there may be periods when there is not enough solar energy to charge the internal battery, in which case there will be gaps.
Boussole	(link1, link2) The catalogue search is not currently functional online, and this is performed by the team on request	No, some variables are not visible online due to lack of development of the website. However, the access through direct contact is obviously the same.	enzo@imev-mer.fr david.antoine@imev-mer.fr	20 years	Time series from buoy measurements is quasi continuous from 2003 to 2017 included. There is a 6-month gap in 2018, and no data in 2018 and 2020. Time series from ship measurements is continuous with punctual cruises canceled for bad weather, ship technical issues or military ban.

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
BSRN	Link	Yes	WRMC Archive Director: amelie.driemel@awi.de BSRN Project manager/deputy: christian.lanconelli@ec.europa.eu , laura.riihimaki@noaa.gov	Since 1992	Link
Copernicus LAW	Free distribution of matchups between Sentinel-3 SLSTR products and in-situ; on request access to time series of in-situ LST at 1-minute temporal resolution (Link).	Yes	contact-law@acri-st.fr	Since 2021	Just started
Demmin/Moorfluxnet	Open Access TERENO data portal / data publications GFZ data services / European Fluxes Database Cluster	Yes	Demmin (link) Fluxes (link)	Demmin 2009 Flux 2007	DEMMIN: yes, sensor specific problems and gaps Fluxes: no, typical instrument gaps, filled by standard procedures
eLTER RI	The eLTER data policy will be established in two years and will follow the FAIR data principles	Yes	deims.org	Partly more than 30 years	During the Operative Phase (estimated to start 2026) of the RI the aim is to get continuous data sets. The gaps of the historical data sets are unclear, data sets/time series are currently being checked. In several places the observations have been going on for decades without major gaps.

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
FLARE	Data is provided as part of a commercial service. There is not restriction on further redistribution of the data	Yes	cdurell@labsphere.com	2020	Follows contract period
FLUXNET	CC4-BY	Not yet (under construction)	https://fluxnet.org	Since 1996	Depend on site
ICOS Ecosystem	CC4-BY	Yes	www.icos-ri.eu	2018	No
ICOS Ocean	Data will be made public at the ICOS Carbon portal (link)	Yes	rsan@norcereserach.no or link		Yes. Due to the nature of the stations (limited access) it can always happen that instruments fail and it takes some time until a station visit is possible.
IMOS Ocean Colour Sub-facility	Open access	N/A	Thomas.Schroeder@csiro.au	IMOS Lucinda Jetty Coastal Observatory and Shipborne Radiometry started in 2013. IMOS Bio-optical Database first data entry 1996	Yes

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
ISMN	Open access (link) Non-commercial use only! No distribution to third party! Not only the ISMN has to be cited but also each individual network used for the study!	Yes	ismn@tuwien.ac.at	Since 1952	Yes, especially for data before 2000: measurements taken irregularly (once per month). In general data time series vary between hourly timestamps (for most networks available) and daily average timestamps per station. Furthermore, data gaps appear due to the variability of natural (e.g., loss of sensor to soil contact since soil is to dry, etc.) and technical (e.g., new sensor instalment, etc.) influences. Also, some network providers erase untrustworthy data rather than flagging it. Furthermore, due to the variability of different network providers and their individual contract situations and maintenance cycles, data provision is on a voluntary basis and can occur irregularly. Once a network cannot provide data any longer, the status of this network changes to inactive but the data records are kept.
KIT LST	Data sharing on request and within co-operations	Yes	Frank.goettsche@kit.edu	Since 2008	Depends on individual station; generally high continuity during a station's lifetime.
LéXPLORE/Thetis	Free and open once we finished the first publications, probably this summer.	Not yet	www.datalakes-eawag.ch	Since 2018	Missed about half the time due to maintenance/repair.
MOBY	Open access (link1, link2)	Yes	kvoss@miami.edu	Since 1997	Short episodic gaps, primarily due to instrument failure. One extended (many month) gap due to funding limitations in the pre-VIIRS era (2011).

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
NASVF	Free and open access, special data on cost-recovery basis	No	stefan.maier@maitec.com.au	June 2011	No, some instruments have been installed later
NEON	Open data (link)	Yes	https://www.neonscience.org/data-samples	Since 2016	Generally, no
PEN	Contact if needed	Yes?	Depends on station. General contact: pen-ml@aist.go.jp (http://pen.envr.tsukuba.ac.jp/)	Depends on site	Depend on site
PEP725	Link	Will be	Markus Ungersböck, markus.ungersboeck@zamg.ac.at	Mostly from 1951, some from 1868	No
RadCalNet	Free and open access	Yes	https://www.radcalnet.org/#!/		
SIOS	Link	No	https://sios-svalbard.org/Staff	Since 2018	Depends on the data type. Most of the meteorological data collected by automatic stations are complete. The oceanographic data series from moorings may have some interruptions due to equipment failures or difficulties in retrieving equipment. Data acquired during fieldwork may have some gaps. Data gaps are also possible due to the pandemic situation.

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
SMEAR	https://smear.avaa.csc.fi/terms-of-use	Yes	pasi.kolari@Helsinki.fi	First station 1991	Depends on parameter
TERN	Open data (link1, link2)	Yes	https://portal.tern.org.au/#/5d2ee8fe	Until beginning of site	Varies from site to site.

3.5 Uncertainty evaluation

The situation with uncertainty evaluation is versatile and needs additional investigation. Firstly, there is the matter of terminology as terms like uncertainty, accuracy and precision are used for the same parameter by different providers, although there are thorough reports available that explain this topic (e.g. IOCCG 2019). Furthermore, the level of uncertainty calculation is different. There were several networks that did not provide any uncertainty estimation for their products (or only provided it for some products). However, this does not mean, that the uncertainty estimation is missing but it can be that it is just not known to our contact person. Other networks provided uncertainty estimations that are just instrument uncertainties received from the manufacturer. Complete uncertainty budgets (documented and published) are mostly not available for the networks validating satellite optical missions. However, this is currently a new topic that is being actively developed with several ongoing/just finished projects that aim to create the necessary rules to make this calculation achievable for all who are interested. At the same time, the optical missions benefit from ground truthing. This, combined with years of expertise means that the optical measurements with well-defined quality control and quality flags are vital part for satellite validation, but it is important to note that this does not make up for lacking uncertainty estimations. Table 9 lists the information available for each variable.

3.6 Future and current developments

In this table only answers with certain plans are shown. Several networks stated, that when needed and possible they will make changes. These answers were excluded from this table.

Table 7: Future or current developments of Networks under investigation

Network	Planned changes
Aquaspectus	Water insight is developing a “semi-portable” WISPstation and a new handheld system. Water insight plans to expand our current quality control and include additional options for applying different water quality algorithms.
BOUSSOLE	BOUSSOLE is one of the in-situ sites selected by EUMETSAT as potential candidate for the development of the future Copernicus OC-SVC infrastructure.
BSRN	Upwelling measurements should be expanded, especially in area of major interest for satellite and model validation. Synergy with other collocated networks should be reinforced. Value added products (VAP) such as temporal averages, cloud screening, radiative cloud effects, possibly gap filling will be investigated within the upcoming BSRN working group on VAP. This is meant to deliver product other than original QC data to the community, by taking advantage of the well-developed routines used within the BSRN community. WRC-PMOD is working on the review of WISG offset with respect new technologies for the determination of longwave reference. Studies to apply the offset retrospectively to the whole archive is object of current investigations.
Demmin/Moorfluxnet	Spectral sensors planned: HYPSTARR radiometers on 10 masts
eLTER RI	Instrumentation will be standardized among sites and only differ in the monitored number of eLTER SOs (monitored variables). Quality control is also standardized and currently developed. Once the system has been established we expect no changes within the next 10 years Calibration will be standardized and follow an exact protocol. Both will be set up once the eLTER SOs and monitoring design/strategy are defined. Since eLTER RI is in its developing phase, there is still the option to include further instrumentation needed for Cal/Val activities.
FLARE	Additional sites foreseen. A “low resolution” version with a large number of mirrors is under study. Use of MODTRAN for the estimating the upwelling path transmission is foreseen in the future.
ICOS Ecosystem	Data evaluated when the station is labelled as ICOS. After this the data are continuously checked. It is possible to change the protocols in case new and better methods are available always pre-checking the compliance with the previous methods. It is possible to include new variables.
ICOS Ocean	ICOS evaluates data quality when a station joins. After that as long as modifications are minor no large scale reevaluation is done. But a continual QC on data is undertaken by the Ocean Thematic Centre
IMOS Ocean Colour Sub-facility	Hyperspectral data added to LJCO in 2020. Data will be available mid 2021 then on quarterly basis.

Network	Planned changes
ISMN	We are part of the recently started ESA Fiducial Reference Measurement for Soil Moisture (FRM4SM) program and will focus on R&D efforts in that respect. ISMN data is used in a variety of products and services (Dorigo et. al 2021). A special case is the the Quality Assurance for Soil Moisture service (QA4SM) focusing on the validation of satellite soil moisture data against modelled and in-situ soil moisture data -also heavily involved in ESA´s FRM4SM program.
LéXPLORE/Thetis	We consider testing a flow-through system instead of the profiler, using the same instruments. We had huge calibration issues during the pandemic, when estimated transfer times to the US increased to almost a year, and made periodic calibration impossible. We would be interested to find a calibration facility in the EU, especially for the ACS.
MOBY	We are currently developing a completely new optical system, buoy structure, and control system. This is being done under both NOAA support (MOBY-Refresh) and NASA support (MarONet). NASA supported MarONet may provide an additional site in Perth, Australia, in collaboration with David Antoine (Curtin University).
NASVF	Further additions of instrumentation are under way/planned
NEON	Modifications in calculations are part of a data product revisioning process. For example, some data products are slated for revision based on quality assessment. Development of drift quantification & correction procedures ongoing.
PEP725	PEP725 is just negotiating with various European phenological networks for joining and/or updating their contributions. QC is being further developed. Within the HR-VPP project there are Cal/Val activities going on.
SIOS	Instrumentations modifications as part of the InfraNOR project and SIOS partners' projects and strategies. For calculations and calibration procedures part of our work on SIOS core data (link) and the optimization report (link), we conduct workshops and activities to harmonize procedures
SMEAR	Aim towards more frequent and systematic calibrations. Working hours of technical staff limit modifications or new installations
TERN	Overstorey Phenocam cameras being deployed across the network in 2021. We are installing Photosynthetically Active Radiation sensor arrays at 3 of our sites in Western Australia.

Table 8: Readiness for modifications for non Cal/Val sites to become Cal/Val sites

Network	Instrumentation	Calculation	Calibration/characterisation
Demmin/Moorfluxnet	Welcome, if they fit to topics of research of the involved centers	Needs to be discussed	Needs to be discussed
LéXPLORE/Thetis	N/A	N/A	N/A
eLTER RI	Since eLTER RI is in its preparatory phase, there is still the option to include further instrumentation needed for Cal/Val activities or change monitoring designs/strategy to meet EO needs. We would need to discuss what would be needed and what can be realized.		Calibration/characterisation purposes can be discussed before being in place. We may find common ground to satisfy eLTER RI and EO Cal/Val needs.
FLARE	N/A	N/A	N/A
FLUXNET	Possible	Yes	Possible
ICOS Ecosystem	Possible	Yes	Possible
ICOS Ocean	This might be a matter of financial support. Stations can't afford to invest in new sensors.	Yes	Yes
ISMN	Speculating: Honestly, with budget boosts, some of them might be able and willing to add or change their instrumentations … without - how should they afford this or be motivated to do so? Also due to the variety of different network providers and their different objectives for taking these measurements in the first place, they simply might not be interested (since it does not fit their purpose).	Efforts in ESA's FM4SM program will determine this within the next two years.	Efforts in ESA's FM4SM program will determine this within the next two years.

Network	Instrumentation	Calculation	Calibration/characterisation
NEON	Possible	Possible	Possible
PEN	N/A	N/A	N/A
SIOS	Possible	Possible	Possible
SMEAR	If working hours of technical staff allow	OK	If working hours of technical staff allow

3.7 Parameters measured

Some sites/networks have additional measurements that are only conducted as campaigns or during regular maintenance. This is the reason some parameters have low frequency measurements.

Table 9: Distribution of measured parameters in Optical missions

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Biomass	FLUXNET, ICOS Ecosystem	1 year – 5 years			
Canopy cover / LAI	NASVF	30 minutes		1	
Canopy foliar traits: LMA, chlorophyll, Carbon, Nitrogen, lignin, isotopes	NEON, ICOS Ecosystem	Yearly - 5 years			
Canopy temperature	FLUXNET	Continuous			
Carbon dioxide flux	DEMMIN/Moorfluxnet, FLUXNET, ICOS Ecosystem, NEON	Continuous – 30 minutes	6 – 48	0.5 – 1	FLUXNET, ICOS Ecosystem (link)
CDOM absorption	BOUSSOLE, IMOS Ocean Colour Sub-facility	14 days – 1 month	12	1	
Chlorophyll-a concentration	Aquaspectus, LéXPLORE/Thetis, ICOS Ocean	1 minute – 1 month	12 – 18	1 – 15	

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Chlorophyll-a fluorescence	BOUSSOLE, IMOS Ocean Colour Sub-facility	15 minutes – 1 month	12-24	0.5	
C-Phycocyanin concentration	Aquaspectus	4 minutes - …	12	1	
Diffuse radiation	FLUXNET, ICOS Ecosystem, NEON	Continuous	6 – 24	0.5	
Dissolved oxygen	LéXPLORE/Thetis, ICOS Ocean, IMOS Ocean Colour Sub-facility	1 minute – 1 month	12-24	0.5 – 15	ICOS Ocean: 2 µmol/kg
Green Area Index	ICOS Ecosystem	2 months – 4 months			
Gross Primary Production	FLUXNET, ICOS Ecosystem	Continuous	24	0.5	FLUXNET (link) ICOS Ecosystem (link)
Land Surface Temperature	Copernicus Law, ISMN, KIT LST	1 minute	12	6 – 12	Copernicus Law: 0.5K KIT LST: 0.3 K – 0.8 K
Leaf Area Index	FLUXNET	variable			
Leaf fall rates	NASVF	1 month		1	
Leaf wetness	DEMMIN/Moorfluxnet	15 minutes		1-3	
Methane flux	DEMMIN/Moorfluxnet	30 minutes	24-48	1	
PAR	BOUSSOLE, DEMMIN/Moorfluxnet, LéXPLORE/Thetis, FLUXNET, ICOS Ecosystem, NASVF, NEON	Continuous – 5 minutes	24	0.5 – 1	NEON: ~±5% of measurement
PAR (under canopy)	FLUXNET, ICOS Ecosystem, NEON	Continuous	24	0.5	NEON: ~±5% of measurement

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Partial pressure of CO2 (pCO2)	ICOS Ocean	1 minute – 1 month	1-8 times per day	1 – 15	ICOS Ocean: 2-10 µatm
Particle absorption	BOUSSOLE, IMOS Ocean Colour Sub-facility	1 month		Continuous	
Phenology	FLUXNET, ICOS Ecosystem, NEON, PEP725	Continuous – 1 week		0.5	
Phytoplankton pigments	BOUSSOLE, IMOS Ocean Colour Sub-facility	14 days – 1 month	6 – 12	1	BOUSSOLE (link)
Precipitation	DEMMIN/Moorfluxnet, FLUXNET, ICOS Ecosystem, NEON	15 minutes - 30 minutes		1-3	
Radiation	DEMMIN/Moorfluxnet, FLUXNET, ICOS Ecosystem, NEON	1 minute - 30 minutes	24	1	
Riparian composition and structure	NEON	1 year			
Shortwave downwelling diffuse component	BSRN	1 minute	12-24	1-4	Manufacturer/ISO/secondary standards
Sky irradiance	AERONET-OC, Aquaspectus, BOUSSOLE, FLUXNET, ICOS Ecosystem, IMOS Ocean Colour Sub-facility, NEON, TERN	Continuous – 1 month	12 - 24	0.5 – 12	BOUSSOLE (link) AERONET-OC (link)

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Sky radiance	AERONET, AERONET-OC, AEROSPAN, Aquaspectus, BSRN, IMOS Ocean Colour Sub-facility	1 minute – 1 hour	12 – 24	0.25 – 18	AERONET-OC (link) Sinyuk et al., 2019.
Snow depth	ISMN	From irregular to near real time			
Snow water equivalent	ISMN	From irregular to near real time			
Soil heat flux	DEMMIN/Moorfluxnet, FLUXNET, ICOS Ecosystem, NEON	1 minute - 30 minutes			
Soil moisture	DEMMIN/Moorfluxnet, ICOS Ecosystem, ISMN, FLUXNET, NASVF, NEON	Continuous – 15 minutes	12 – 24	0.5 – 3	NEON: typically ~0.03 cm3 cm-3
Soil suction	ISMN	From irregular to near real time			
Soil temperature	DEMMIN/Moorfluxnet, ICOS Ecosystem, ISMN, FLUXNET, NASVF, NEON	Continuous – 15 minutes	24	0.5 – 3	NEON: ~0.1 °C
Solar radiation	DEMMIN/Moorfluxnet, FLUXNET, ICOS Ecosystem, NEON	15 minutes - 30 minutes		1 – 3	
Sun radiance	BOUSSOLE	1 month			
Surface elevation	NEON	1 year	12	12	
Surface irradiance	BOUSSOLE, FLUXNET, IMOS Ocean Colour Sub-facility, NEON	Continuous – 1 month	12	0.5 – 1	

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Surface radiance	AERONET-OC, Aquaspectus, BOUSSOLE, BSRN, IMOS Ocean Colour Sub-facility, MOBY, TERN	1 second – 3 times/day	4-24	0.5 – 12	AERONET-OC (link) BOUSSOLE (link)
Surface reflectance	AERONET-OC, Aquaspectus, BOUSSOLE, IMOS, FLARE, NEON, PEN, RadCalNet	30 minutes – 1 year	12	0.5 – 12	AERONET-OC (link)
Terrestial Laser Scans	ICOS Ecosystem	Once	24		
TOA radiance	RadCalNet	30 minutes			
Total backscattering coefficient	IMOS Ocean Colour Sub-facility		12-24	0.5	
Total Suspended Matter	Aquaspectus, BOUSSOLE, LéXPLORE/Thetis, IMOS Ocean Colour Sub-facility	4 minutes – 1 month	12	1	
Transmittance	BOUSSOLE	15 minutes – 1 month	12	0.5	
Tree density, diameters, heights and health status	FLUXNET, ICOS Ecosystem, NEON	1 years – 5 years			
Understorey cover / LAI	NASVF	30 minutes		1	
Vegetation nutrients content	ICOS Ecosystem	4 months – 1 year			
Volume scattering function	BOUSSOLE, IMOS Ocean Colour Sub-facility	15 minutes – 1 month	12	0.5	

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Water absorption	BOUSSOLE, LéXPLORE/Thetis, IMOS Ocean Colour Sub-facility	3 hours – 1 month	12	0.5	
Water attenuation	Aquaspectus, LéXPLORE/Thetis, IMOS Ocean Colour Sub-facility	4 minutes – 3 hours	12	1	
Water level	DEMMIN/Moorfluxnet	30 minutes			
Water pressure	IMOS Ocean Colour Sub-facility		12-25	0.5	
Water salinity	BOUSSOLE, ICOS Oceans, IMOS Ocean Colour Sub-facility	1 minute – 1 month	12-18	0.5-18	ICOS Ocean: 0.01 – 0.1 PSU
Water temperature	BOUSSOLE, LéXPLORE/Thetis, ICOS Oceans, IMOS Ocean Colour Sub-facility	1 minute – 1 month	12-18	0.5-15	ICOS Ocean: 0.05 – 0.1 degC
Water turbidity	BOUSSOLE, IMOS Ocean Colour Sub-facility	15 minutes	12-24	0.5	

4 Altimetry

4.1 Introduction

As explained in previous Work Packages, the altimetry missions are constituted of three main instruments (radar altimeter, microwave radiometer and POD instruments). The principal objective is a characterization of the ocean surface topography. But the mission's objectives cover also other ocean variables (significant wave height, wind speed, roughness, etc.) and other surfaces (hydrology with rivers and lakes surface height, glaciology and sea ice thickness, snow depth and land ice elevation over major glaciers and ice caps). These instruments do not require any specific hardware tuning after the satellite launch. The commissioning phases aim at checking their good health and correcting the ground processing. But very few parameters can be changed on-board and they are generally minor changes, except for the on-board DTM used to get signals on hydrological and glacier / land ice sloppy targets. This DTM is enriched throughout the mission, benefiting from the Cal/Val activities to determine new target or correct actual target heights.

In-situ measurements are used to better characterize some errors of the instruments and, mostly, to qualify the products. The ground algorithms are improved by comparing their results with the in-situ measurements. They also play an important part for climate monitoring. For this topic, the bias and uncertainty determination is a key issue.

The in-situ networks, used for Cal/Val of altimetry sensors, are of many types:

- In-situ facilities deployed specially to characterize instrumental defaults (for instance, transponders for altimeters),
- In-situ facilities deployed specially to qualify the altimetry products, deployed under satellite tracks, mainly with multi-missions' coverage (for instance, tide gauges or GNSS-based instruments for Sea Surface Height),
- In-situ facilities dedicated to other purposes and used as opportunities (this is the case for many of the networks cited here).

The completeness of last type of network cannot be evaluated. We have tried to list the major ones and all variables which are important and available to validate altimetry products.

4.1.1 Fiducial Reference Measurements sites

Several key sites have been identified around the world. They are located on cross-overs of altimetry mission tracks and often overflown by more than 2 different missions (see Figure 3). Most of them are designed for ocean variables but there are also hydrological ones (see Figure 4) such as the Parintins (Brazil) site over the Amazon river (Figure 4) and the Issykkul site (Kirghizstan) which has been used for over 15 years. These sites are "FRM sites for altimetry". Note that an ESA project, FRM4ALT, covers the CRETE site.

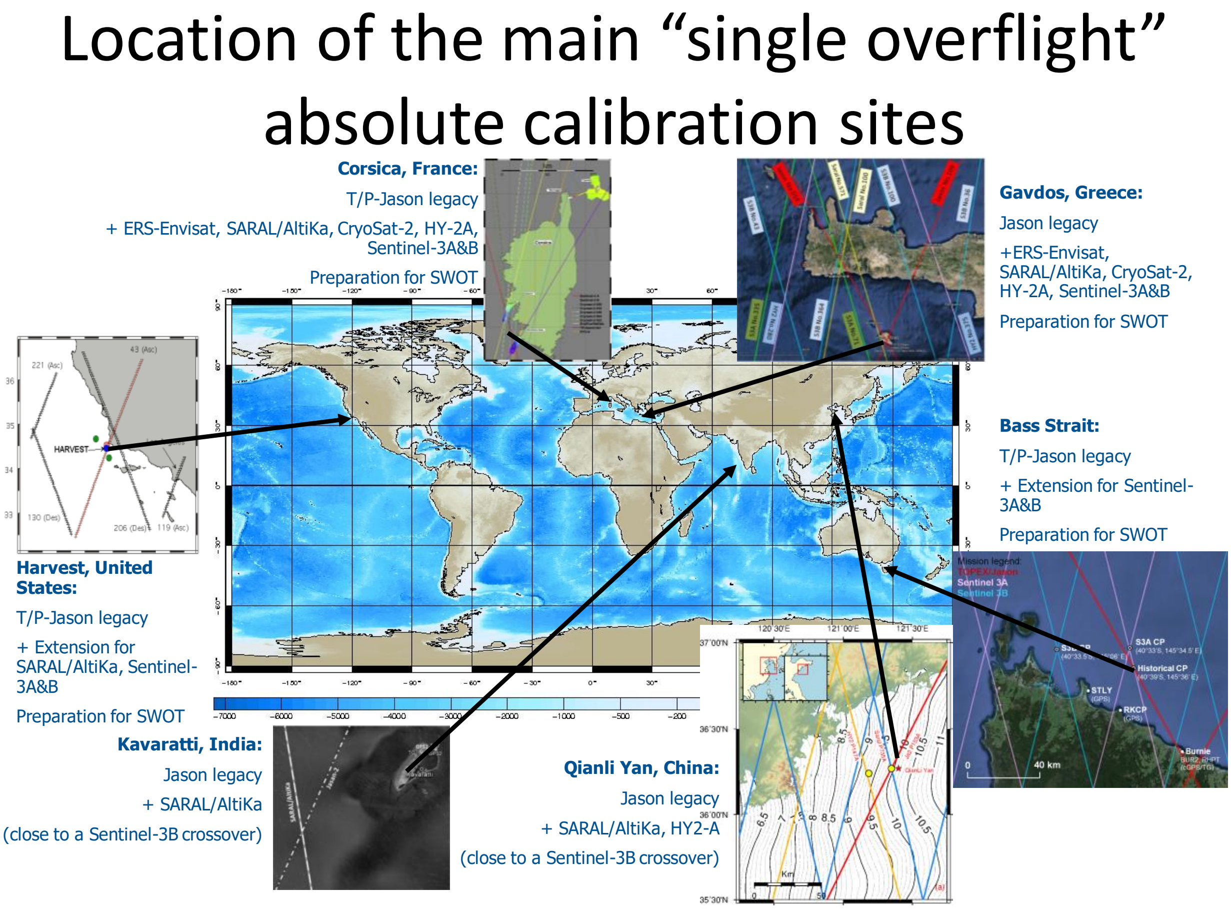

Figure 3. Main altimetry FRM sites for absolute calibration (courtesy P. Bonnefond). Each site are multi-missions as noted directly in the viewgraph.

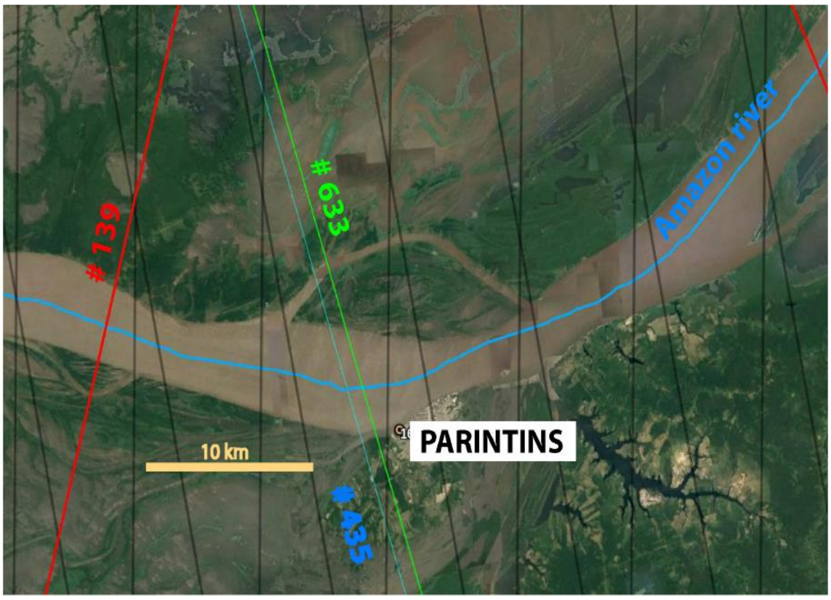

Figure 4. Amazon (Parintins, Brazil) site. Courtesy S. Calmant. Ground tracks are plotted around Parintins. Altimetry missions are sorted here by orbit revisit duration. Red = 10-day family, blue = 35-day family missions, green = 27-day family missions, black = Cryosat-2.

All these sites undertake surface height monitoring (either sea level, or water surface height). This requires a device to measure the water surface (such as tide gauges or GNSS-based instruments) and also a very fine knowledge of the local geoid and the atmospheric conditions. Therefore, these sites are all equipped with GPS receivers and weather stations. The weather stations are used to get the atmospheric vapor content and dry tropospheric content. Supplementary campaigns are also conducted to better qualify the geoid (with GNSS-based instruments) and add measurements along satellite tracks through other instruments (boats, buoys, etc.).

These sites are hosted by different organizations (Universities, Research Labs, etc.) and receive funding from national agencies, space agencies or European entities. They often rely on national partnerships to support in-situ equipment (one country provides the equipment; another hosts them). The processing is performed by the entities in charge of the sites but collaborative efforts have been made over many years to homogeneize the processing systems into a standard system (e.g. considering geodetic corrections etc) even though realized at best effort (Bonnefond *et al.* 2011). The space agencies in charge of the satellite and/or the ground segment have privileged access to these in-situ measurements, as they provide very valuable information for processing improvements.

All these sites contribute to the global Cal/Val knowledge of altimetry missions. They could also be of great interests for other missions as their instruments can also provide information for atmospheric or optical/SAR imagery (pending on other missions' coverage).

Eventually, the ESA project ST3TART (Sentinel-3 topography mission Assessment through Reference Techniques) will bring new overviews and solutions to this topic, addressing all kinds of surfaces.

4.1.2 Active measurements: signals sent to the satellites

A few sites use active ground sensors pointing at the satellite to calibrate some physical measurements.

In the altimetry field, we can identify the following:

- The ILRS (laser reflectometry) network which provides very accurate measurements on satellite orbits, a great validation for the POD solutions.
- Radar transponders designed especially for the altimeters.

The transponders have very specific design adapted to each altimeter. Located at the nadir below the satellite, they re-emit the altimeter waveforms once received. This requires an adapted antenna and RF chain for each instrument. Knowing the precise location of the transponders, all its internal path delay, the transponders offer a unique mean to estimate the radar range. Its own calibration remains tricky but it is operational for several missions (JA3, S3, S6-MF) and ESA aims at having a new position to complement the CRETE site.

The backscatter from a radar altimeter σ0 is a measure of the surface roughness at scales of a few radar wavelengths; over the ocean, this is used to infer wind speed, which is an essential parameter used in weather forecasting. Over ice, it gives information about ice characteristics, which are crucial for understanding the dynamics of the sea-ice and ice-sheets. The Ice Community is ideally requesting an accurate absolute knowledge of the backscatter coefficient to within 0.1 dB. Some discrepancies have been also observed between different satellites for the open ocean backscatter σ0 coefficient.

In order to cover both points, ESA/ESRIN decided to refurbish the Envisat σ0 transponder so that it can be used operationally for current and future altimetry missions. CNES followed the same track by refurbishing the Ku-band transponder used for Jason missions to calibrate the SWIM instrument (on-board CFOSAT). The requirement around knowing σ0 knowledge accurately is a very strong requirement on the transponder design and its monitoring in temperature. This is more challenging than the transponder designed for range.

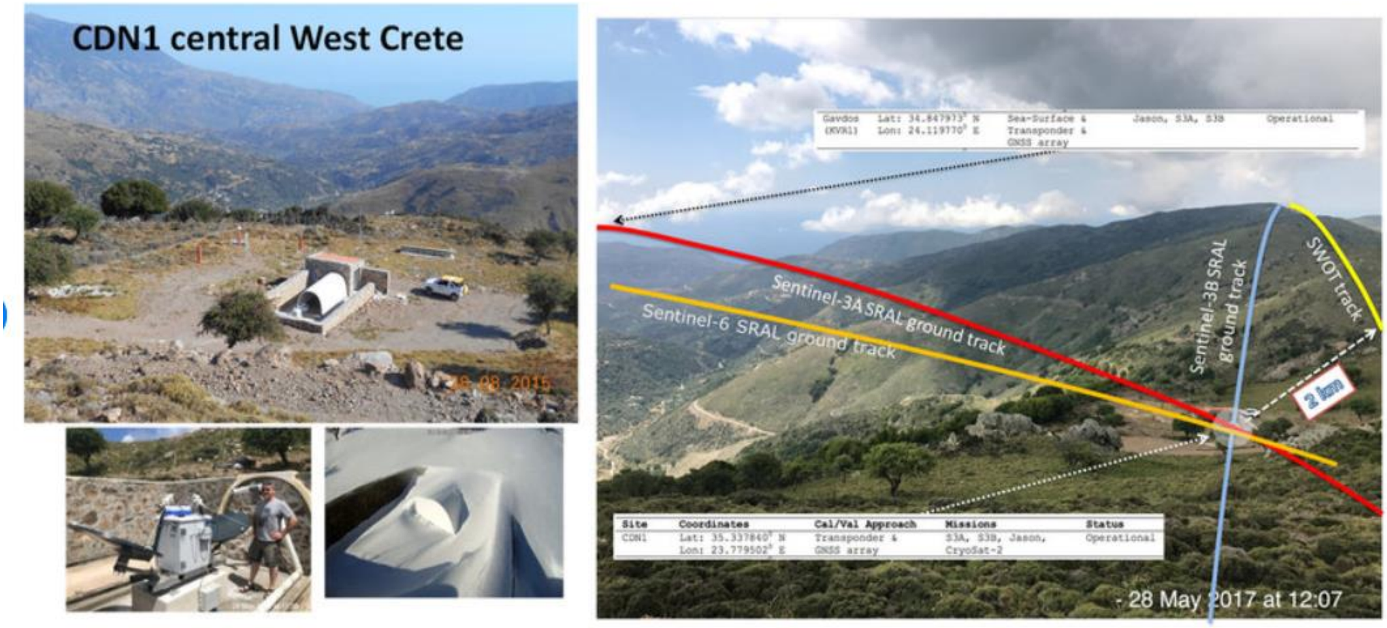

Figure 5. Ku-band transponder at CDN1 central West Mountains, Crete. (Mertikas et al. *2019)*

4.1.3 Opportunity networks

At large scale, the Cal/Val of altimetry missions rely mainly on "opportunity networks" where *in-situ* data which are not collected for space purposes become key data for Cal/Val activities.

The in-situ networks are often gathered in "networks of networks". Countries aggregate their in-situ facilities, often under the UN aegis. The data are open access but the processing may depend on each country, as well as the design of the sensors and the calibration process. Some national entities gather the available data and use their own harmonized process (for instance, the CMEMS in-situ TAC for all oceanic observations or the NDBC for buoys). Some confusion can result from the same original measurements being accessible via several routes and with different processing pathways. The buoys network is a good example of how tricky the access to in-situ data can be. In this framework, the CMEMS in-situ TAC (INSTAC) initiative is very important. It is definitely satellite orientated with the willingness of gathering in a single portal all the data we need. Nonetheless, the data are not corrected by CMEMS INSTAC. Suspicious data are flagged to avoid usage by non-specialist users. INSTAC synchronized with the best version provided by the platform data manager or the network portal if exists (example Argo GDAC) and those updated data overwrite the data received previously. CMEMS INSTAC doesn't have the capacity to correct from bias.

The main in-situ data which are involved in altimetry Cal/Val are listed below.

- For ocean variables:

  The validation of ocean estimations is a difficult task as the ocean is very large and uninhabited. The meteorological and oceanography networks provide observations of altimetry variables and others oceanic variables (Sea Level, Sea Surface Salinity and Temperature, Chlorophyll etc.). The fixed instruments (tide gauges, moored buoys) are often near the coasts or at least, in shallow waters. The density is higher in North Hemisphere, with hopefully a contribution of Australia to get precious observations in the Southern oceans. The drifting instruments can cover all the oceans.

- Tide gauges: these instruments, some complemented by GNSS receivers, provide sea level near the coasts. The GLOSS network gathers national tide gauges worldwide. National networks are only partially taken into account in GLOSS. For instance, the French REFMAR has some site additional to GLOSS.

- Buoys: buoys provide sea state information, as well as atmospheric conditions. The DBCP gather national moored buoys under WMO aegis. The buoys can have different properties: some measure only the significant wave height, others provide access to the directional wave spectrum. The measurements are not all equivalent. The NDBC, NOAA network, delivers access to the US buoys, but also to part of the DBCP ones.

  In addition to moored buoys, there are many drifting buoys. Among them, the ARGO buoys play an important part in the altimetry budget closure. ARGO is a fleet of robotic instruments that drift with the ocean currents and move up and down between the surface and a mid-water level. ARGO has been built in partnership with the JASON missions. The data are transmitted to process centers though satellite links.

- Global portal for in-situ data over ocean: the CMEMS INSTAC aims at gathering all the oceanic observations (not only for altimetry, water quality parameters are also available as well as atmospheric observations). This includes the ARGO measurements.

Figure 6. REFMAR and partners tide gauges along the French coasts. One tide gauge in Corsica is placed in the in-situ FRM site.

- For hydrology variables: the networks provide observations on water level and, sometimes, on river discharge.

  The in-situ coverage is very irregular spatially. Some regional basins are very well instrumented (e.g. Europe, North America), other are sparsely covered (e.g. Africa). Good examples include the French and Swiss hydrological networks. River discharge data is gathered in the GRDC network, described in this document.

  The LOCSS and OECS initiative are developed in the framework of the SWOT program, relying on citizens' involvement to collect the measurements (also described in this report).

Figure 7. LOCSS (Lake Observations by Citizens Scientists and Satellites) and OECS (Observations des Eaux continentales par des Citoyens et des Satellites) in-situ rules for citizen contributions: lakes and rivers levels are sent to the project by the citizens.

- For geodesy, the IGS network of GNSS receivers provide dense in-situ observations of the vertical reference and its variation. The DORIS ground network and IDS play also an important part in geodesy and complement GNSS. These techniques (GNSS, DORIS, ILRS and VLBI) and combined to support, the ITRF (International Terrestrial Reference Frame which is the absolute reference of all orbiting and terrestrial objects). This is a crucial work for referencing and thus for quality and monitoring.

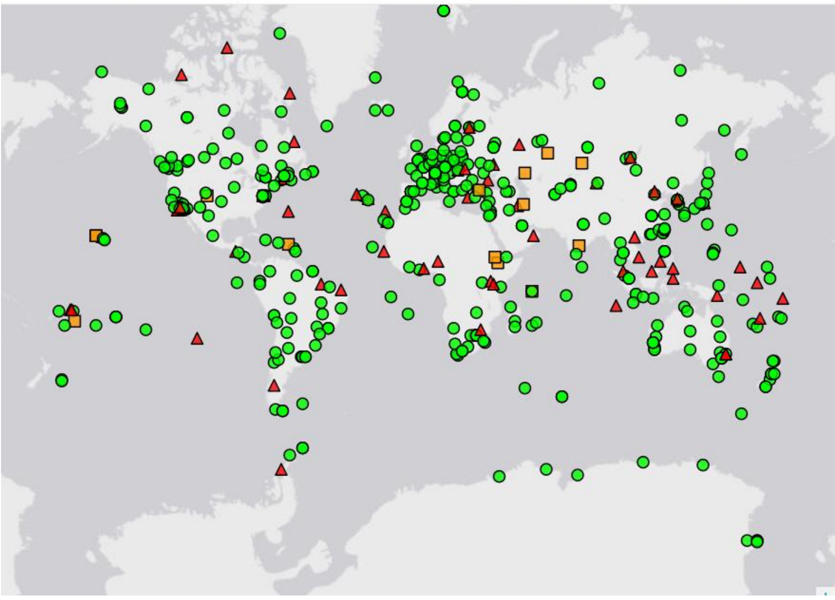

Figure 8. IGS network: location of the 507 GNSS stations all over the world.

For glaciology many campaigns have been undertaken to get in-situ data (e.g. the CryoVeX campaigns detailed in D2.11 report) however there are relatively few permanent measurements. The Sea Ice CCI gathers information on this topic. In addition, the Ice T-buoy (developed by LOCEAN labs (UPMC, France) can provide long term information on ice and current in the Polar Regions.

4.2 General information about the sites/networks

Table 10: General information of networks under investigation

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
AMAZON	CPRM and ANA (Brazil)		One location	Yes	Altimetry range determination and water level height
DBCP*	National ownerships	https://www.ocean-ops.org/dbcp/	Worldwide (mostly North hemisphere coasts)	Yes (indirectly)	Buoy network for sea state monitoring
DORIS	CNES with support of IGN	https://ids-doris.org/doris-system/tracking-network/maps.html	60 DORIS stations around the world	Yes	Orbit determination and reference frame
FRM - BASS STRAIT*	IMOS, University of Tasmania, CSIRO	http://imos.org.au/srscalval.html	One location (Tasmania, Australia)	Yes	Altimetry range determination and sea level height
FRM - CORSICA	CNES, CNRS	https://www.aviso.altimetry.fr/en/data/calval/in-situ/absolute-calibration/corsica-calibration-sites.html https://doi.org/10.1016/j.asr.2019.09.049	2 sites on Corsica Island	Yes	Altimetry range determination and sea level height
FRM - CRETE	Space Geomatica & the Geodesy and Geomatics Engineering Lab, Technical University of Crete	https://www.frm4s6.eu/ https://www.frm4alt.eu/	4 sites on the Crete Island	Yes	Altimetry range determination and sea level height

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
FRM - HARVEST*	JPL/NASA	https://sealevel.jpl.nasa.gov/documents/1583/?list=projects https://doi.org/10.1016/j.asr.2020.08.013	One location (Harvest oil platform, off the coast of central California)	Yes	Sea level height
FRM - ISSYKKUL	Tien Shan High Mountain Scientific Centre National Academy of Sciences of the Kyrgyz Republic , CNRS, CNES	https://doi.org/10.3390/rs10111679	One location	Yes	Altimetry range determination and water level height
GLOSS*	WMO / JCOMM based on national contributions (90 nations) GLOSS has labelled a core network worldwide which is enriched by national contributions	https://www.gloss-sealevel.org	Worldwide (290 sea level stations along the coasts)	Yes (indirectly)	Tide gauge network for sea level height
GRDC*	WMO / National Hydrological Services	https://www.bafg.de/GRDC/EN/01_GRDC/grdc_node.html	Worldwide (with irregular densities)	Yes (indirectly)	Hydrology network for river discharges
HYDRODATEN	Swiss federal office for the environment FOEN	Basic monitoring network: water levels and discharge in surface waters (admin.ch)	Countrywide (Switzerland)	Yes, lake water levels are used.	Hydrology network for water height surveillance
IGS	International organization	https://www.igs.org	Worldwide	Yes	Orbit determination and reference frame
ILRS	International organization	https://ilrs.gsfc.nasa.gov/network/stations/index.html	Worldwide (mostly North Hemisphere)	Yes	Orbit determination and reference frame

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
IMOS	IMOS, BOM, NCRIS, University of Tasmania (as lead of other research labs)	http://www.bom.gov.au/products/IDT65091.shtml http://www.bom.gov.au/products/IDD65028.shtml	Two locations	Not yet (new deployment)	Buoy network for sea state monitoring
INSTAC	UE (CMEMS framework)	http://www.marineinsitu.eu	Worldwide	Yes	Gathering of in-situ observations of ocean parameters
LOCSS	NASA and local partners, OMP (for France)	https://www.locss.org/view-lake-data	US (~50 lakes), France (14 lakes), India (2 lakes), Bangladesh (4 lakes)	Yes (indirectly)	Hydrology network for water height surveillance
NDBC*	NOAA (US)	https://www.ndbc.noaa.gov	Worldwide (mostly North hemisphere coasts)	Yes (indirectly)	Buoy network for sea state monitoring
OECS	CNES	http://oecsmap.org/	Mainly in South West of France. Sites are still under discussions.	Yes (in the near future)	Hydrology network for water height surveillance
REFMAR	SHOM (France)	data.shom.fr	Along French coasts	Yes	Tide gauge network for sea level height

*table filled with internet information / no contact with experts

“Indirectly” in the fifth column means that the site or network has not been designed for CalVal purposes. It is use as opportunity data by the remote sensing community. These site and network owners are more or less aware of the use of their data in Copernicus Cal/Val.

4.3 Financing properties

Table 11: Financing situation of Networks under investigation

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
AMAZON	One site	Long term agreement	CNES, IRD, CPRM	4 years (for the present contract – OSTST (FOAM) project) started 10 years ago, secured for long term - as long as necessary for altimetry- on the Brazilian side. Secured for 4 years on the French side
DBCP*	Network	Long term agreement	National contributions + WMO aegis	On-going (meteorological network)
DORIS	Network	Long-term agreement	French Space Agency (CNES) is supporting most of the costs. Local sites are provided and maintained by hosting partners. For some of them a CNES financial support exists.	Network is needed for satellites until 2025 at least. Long term agreements are also in place with local sites for hosting the ground stations.
FRM - BASS STRAIT	One site	Long term agreement	National funding (Australia)	On-going
FRM - CORSICA	Centrally	Long term agreement	CNES, CNRS, French Minsitry of Research, ESA	4 years (for the present contract – OSTST (FOAM) project)
FRM - CRETE	Centrally	Long term agreement	UE, ESA	Until end of 2021. Contract to be renewed.
FRM - HARVEST	One site	Long term agreement (but the Harvest oil platform is not exploited since 2011)	US national funding (NOAA, University of Colorado, NASA)	4 years (for the present contract – OSTST project)
FRM - ISSYKKUL	One site	Long term agreement	Agency (CNES, ESA) + National funding (Kyrgyzstan)	4 years (for the present contract – OSTST (FOAM) project)

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
GLOSS*	Network	Long term agreement	WMO / JCOMM based on national contributions (90 nations)	No end date
GRDC*	Network of individual sites	Project based agreement	National hydrological services	Nation/Station-dependent
HYDRODATEN	Network	Long term agreement	National funding	Permanent
IGS	Network of individual sites	Long term agreement	National fundings	Station-dependent
ILRS	Network of individual sites	Long term agreement	National fundings	Station-dependent
IMOS	Centrally	Long term agreement	IMOS, BOM, NCRIS, University of Tasmania	Contract in place until June 2022. Currently in negotiations to extend to June 2023, then likely further funding until June 2028.
INSTAC	Network	Long term agreement	UE	On-going
LOCSS	Network	Project based agreement (SWOT framework)	NASA, OMP for France	Followed y OECS in for French contribution.
NDBC*	Network	Long term agreement	NOAA (US)	On-going (meteorological network)
OECS	Network	Project based agreement	Local water agency ‘Agence de l’eau Adour Garonne”	Up to August 2023 for the current contract, extension is envisaged if the project goes smoothly
REFMAR	Network	Long term agreement	SHOM + partnerships	4 years

4.4 Data handling

Table 12: Data handling situation of Networks under investigation

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
AMAZON	Restricted access except for GNSS data (link)	Partially	Yes (not public)	Yes, manual	Yes (not public)	N/A (but could be done)
DBCP*	Depends of the data providers and the parameters. link1 link2	No (network dependent)	Yes (network dependent)	Yes, automatic	Yes (network dependent)	Yes
DORIS	Open access at CDDIS (link) and IGN (link)	Yes	Yes (not public)	Yes, automatic (not public)	Yes (not public)	
FRM - BASS STRAIT	Restricted access					
FRM - CORSICA	No but some details are published (publications)	Yes	Yes (publications)	Yes (publications)	Yes (publications)	Yes (NetCDF) (link)
FRM - CRETE	Restricted access	Yes	Yes (not public)	Yes, manual and automatic	Yes (not public)	Yes (ESA ICD)
FRM - HARVEST	Restricted access					

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
FRM - ISSYKKUL	Restricted access except for GNSS data (link)	No	Yes	Yes	Yes	N/A
GLOSS*	Dependant on each national owner. Shared with the network. Sharing of "good behaviors" for installation, processing and checking: link	No Each station process its data.	Not very well documented. Done by each country independently with recommendations of the group (link) Calibration of instruments during manufacturing			
GRDC*	Yes (national services dependent)	N/A (national services dependent)	Yes (national services dependent)	Yes (national services dependent)	Yes (national services dependent)	Yes
HYDRODA TEN	Yes (no open access)	Yes	Yes (no open access)	Yes (no open access, both manual and automatic)	Yes (no open access)	No (however metadata is collected according to a fix protocol)
IGS	Open access (link)	Yes	Yes (link)	Yes, manual	Yes	Yes (link)
ILRS	Open access (link)	Yes	Yes (link)	Yes, manual	Yes	Yes (link)
IMOS	Not open access, since processing of raw data uses proprietary TRIAXYS methods	Yes (on-board each buoy). QC is undertaken for all buoys by a contractor.	Not open access	Yes. Real-time-data QC is automatic. Delayed mode (annual) is manual.	Yes	No

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
INSTAC	Measurement are made by the owner of the observing systems not by CMEMS INSTAC	Raw processing is made by the owner of the observing systems not by CMEMS INSTAc The data integration is performed by a distributed network of 6 regional centers and one global center (link)	The whole process is described in the different Product User Manual distributed through the CMEMS catalogue for each of the INSTAC product (link)	Yes, automatic for NRT products and manual for REP	Yes (link)	SeaDataNet P09 physical parameters and linked with P01 and P06 vocabularies managed (link)
LOCSS	Yes	N/A	Yes (No procedures, this is done by an operator)	Yes, manual	Yes (No procedures, this is done by an operator)	N/A
NDBC*		Yes		Yes, automatic	Yes (link)	Yes
OECS	Yes	N/A	Yes (No procedures, this is done by an operator)	Yes, manual	Yes (No procedures, this is done by an operator)	N/A
REFMAR	Open access for RONIM (link)	Yes for RONIM	Yes. Open access for RONIM (link)	Yes, manual	No	No

Table 13: Data distribution of Networks under investigation

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
AMAZON	Specific altimetric measurements accessible on-demand. Gauge readings in open access. GNSS data on demand	Yes	stephane.calmant@ird.fr daniel.moreira@cprm.gov.br	Since early 90's	No
DBCP*	Open access	Yes	https://www.ocean-ops.org/dbcp/community/contacts.html	Since 1985	No (buoy dependent)
DORIS	Open access	Yes	ids.central.bureau@ids-doris.org		No
FRM - BASS STRAIT	Restricted access				
FRM - CORSICA	Open access (link)	Yes	pascal.bonnefond@obspm.fr	Since 1998	No
FRM - CRETE	Restricted access. Data used by ESA experts and its Mission Performance Center and in the Mission Advisory Groups	Yes	admin@spacegeomatica.com and mertikas@mred.tuc.gr	Sentinel-3A&B, Sentinel-6 & Jason-3 entire missions.	No
FRM - HARVEST	Restricted access				
FRM - ISSYKKUL	Restricted access	Yes	jean-francois.cretaux@legos.obs-mip.fr	Since 1927	No

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
GLOSS*	Open access (link)	Yes	t.aarup@unesco.org	Since 1985	No at the global level (depending on the stations at local level)
GRDC*	Open access for research (link)	Yes	grdc@bafg.de	Depending on stations (some since 1900)	Stations dependent.
HYDRODATEN	Open access (on demand).	Yes	hydrologie@bafu.admin.ch	Measurements since the 1850ies to present, thus for about 170 years.	Depending on the station, there are some significant periodical gaps.
IGS	Open access (link)	Yes	https://www.igs.org/wg/infrastructure-committee/	Since 1994	Stations may have gaps in data acquisition
ILRS	Open access (link)	No	https://ilrs.gsfc.nasa.gov/about/contact_ilrs/index.html	Since 1998	Station-dependent (seasonal, during holidays, new station positions). No gap in the global network.
IMOS	Open access (link)	Yes	diana.greenslade@bom.gov.au	Coming soon (new facility)	N/A
INSTAC	Open access with CMEMS licence (link)	Yes	cmems-service@ifremer.fr	Depends on products (link)	None
LOCSS	Open access	Yes	lakelevel@unc.edu	Since 2019	Depends on citizens' contributions
NDBC*	Open access	Yes	webmaster.ndbc@noaa.gov	Since 1995	No (buoy dependent)

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
OECS	Open access	Yes	Nicolas.picot@cnes.fr	No archive (project start)	N/A
REFMAR	Open access (link)	Yes	refmar@shom.fr	Since 1846!	Gaps exist where data do not exist or where data are outliers.

4.5 Uncertainty evaluation

The uncertainty evaluation of in-situ measurements is hard to evaluate as it strongly depends on the ground instruments and on the methods to correlate their measurements to the satellite measurements. The quality and uncertainties of the ground measurements are well known, but the methodologies may differ from one network to another. But mostly, the link between the in-situ measurement and the qualification of an altimetry product is not straightforward. For instance, the use of transponder measurements to qualify the altimetry range accuracy relies on many things: the processing of the transponder signal in the altimetry signal, the knowledge of the exact positioning of the transponder, the knowledge of the internal transponder delay, etc. Each contributor has its own uncertainty budget, which is not so easy to determine. At the end, the ground instruments have their own uncertainties which can be of same magnitude to the ones of the satellite instruments. The uncertainty budget has to be very well known (including the processing impact) to be able to validate space missions. This is not always well documented - the Table 16 lists the information available for each variable. This is clearly a topic which should be investigated further. Note that great efforts have been done for the altimetry FRM sites on these subjects (Bonnefond et al., 2011; Mertikas et al., 2019).

4.6 Future and current developments

Table 14: Future or current developments of Networks under investigation

Network	Planned changes
AMAZON	In the framework of the SWOT Cal/Val, some new instruments will be added: • New permanent GNSS station (including GALILEO) • ADCP sounder • CalNaGeo device (Calibration), • Drone surveys (possibly) • Pressure gauge to duplicate gauge readings • According to funding, GNSS station in reflectometry mode to access to independent estimates of height and slope • Website to distribute the raw and processed data, reports, etc. Part of this instruments will be for dedicated campaigns and not installed permanently.
DORIS	Orbit measurements: any new satellite launched with a DORIS instrument on board, there is a new set of measurements. If a satellite is decommissioned, date is interrupted. Data from the ground stations are independent from satellites. Time series are available as long as the station is operated.
FRM - CORSICA	Improvements to be taken into account the new SWOT mission. A new GNSS receiver has been installed at Senetosa in February 2021 to allow multiple constellation acquisition (GPS, Galileo, GLONASS, …) A radar couple with a GNSS is currently in development and test.
FRM - CRETE	The new ESA transponder Cal/Val facility is ready to be installed at GVD1 Cal/Val site in CRETE island, Crete. A DORIS beacon will be installed at GVD1 Cal/Val site in CRETE island, Crete, Greece in summer 2021.
FRM - HARVEST	Transponder developed at JPL, which could be added on the Harvest platform.
FRM - ISSYKKUL	New GNSS receivers, new radar station for water height measurement and new weather station
GLOSS*	Maintenance of the tide gauges, improvement of the instruments, addition of new sites
HYDRODATEN	For discharge measurements: use of PIV systems (photrack) for measuring the flow velocity and calculating the discharge).

Network	Planned changes
IGS	Improvement of the satellite payload quality, new ground stations, improvements in acquisition and processing. Tracking new GNSS signals and constant improvements of the services. Alternative monumentation, mitigate multipath effects, improved receiver technology…
ILRS	New missions to be taken into account, new ground stations, improvements in processing (range biases better modelled)
IMOS	Work on QC and format
INSTAC	It will integrate new platforms/sensor measuring the parameters managed by CMEMS INSTAC when available. The NRT and REP products QC procedures are improved to take into account the recommendations provided by the scientific community. New methods are tested and goes through the CMEMS “Request For Change” process before being implemented.
LOCSS	Enrolment of new lakes.
OECS	Network currently under deployment.

Table 15: Readiness for modifications for non Cal/Val sites to become Cal/Val sites

Network	Instrumentation	Calculation	Calibration/characterisation
IMOS	Unlikely	Possible	Unlikely

4.7 Parameters measured

The table below links variables which are calibrated and validated for altimetry missions. These variables are detailed in the report (CCVS-CLS-D1.2 2021). The in-situ networks and sites described in the current report may supply other variables. In particular, water quality variables are available in CMEMS INSTAC or with buoy networks (NDBC, DBCP). The complete list of instruments and measured variables are provided in the Questionnaire files, annexed to this report. We focus here only on the variables in the framework of the altimetry Cal/Val.

The in-situ measurements do not always provide directly the key variables. Some require additional processing specific to Cal/Val to compare to and validate the mission products. We do not detail this in this report. But the reader should keep this important point in mind. The in-situ networks should be used cautiously to validate the satellite missions.

Table 16: Distribution of measured parameters in Altimetry missions

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Altimere Range	AMAZON, FRM-BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, FRM-ISSYKKUL	Continuous measurements. Except for transponder at FRM-CRETE: only at satellite overflights	1	1/month	FRM-CORSICA (link) FRM-ISSYKKUL (link)
Altitude (Orbit)	DORIS, IGS, IRLS	Continuous for IGS At satellite overflights for IRLS and DORIS	Station-dependent	Station-dependent	ILRS (link)
Ionospheric Correction	DORIS, IGS	Continuous for IGS At satellite overflights for DORIS	Station-dependent	Station-dependent	

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Rain flag/Rain rate	AMAZON, FRM-BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, FRM-ISSYKKUL, GLOSS, INSTAC, REFMAR	Continuous measurement by weather stations	Station-dependent	Station-dependent	
Sea Surface Height	FRM- BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, GLOSS, INSTAC, REFMAR	Continuous	1	1/month	FRM-CORSICA (link)
Signifigant Wave Height	DBCP, FRM-BASS STRAIT, FRM-HARVEST, IMOS, INSTAC, NDBC	Continuous	Station-dependent	Station-dependent	Link1, Link2
Water Level Height	AMAZON, FRM-ISSYKKUL, GRDC, HYDRODATEN, LOCSS, OECS	Continuous	Station-dependent	Station-dependent	FRM-ISSYKKUL (link) LOCSS (link) AMAZON (link)
Water Vapor	FRM-BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, FRM-ISSYKKUL, INSTAC	Continuous measurement by weather stations	Station-dependent	Station-dependent	
Wet Tropospheric Delay	FRM-BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, FRM-ISSYKKUL, INSTAC	Continuous measurement by weather stations	Station-dependent	Station-dependent	

Continuous means here several times per hours. Each instrument has its own rhythms. But the data are acquired very regularly along the day.

5 Atmospheric composition

5.1 Introduction

Sentinel satellites targeting atmospheric composition use remote sensing spectrometric techniques for measuring spectra from which concentrations of atmospheric constituents (gases and aerosol) are derived using spectral inversion techniques, also called retrieval algorithms, involving radiative transfer modelling; these concentrations are the targeted data products of the 'atmospheric composition satellites'.

To achieve a good quality of the target data products, the measured spectra must be well calibrated, and the data derived or retrieved from these calibrated spectra (the so-called L1 data) data must be verified (validated) against comparable data from reference networks. Therefore, there are two types of ground-based networks that are discussed in this section 'atmospheric composition': (1) the networks that deliver data that are useful for the spectral calibration or as ancillary data in the retrieval algorithms, and (2) the networks that deliver data that can be compared to the target retrieved products (the so-called L2 data) for their validation. In some cases, like AERONET, which provides information about the aerosol content in the atmosphere, the data can be used for the validation of a satellite aerosol data product, but they can also be used as ancillary data product in the validation of a satellite data product for another atmospheric constituent in case the retrieval of that constituent's concentration is influenced by the presence of aerosol in the airmass observed by the satellite.

Among the second category of networks (networks for validation of the L2 satellite data), we distinguish between the networks that perform in-situ measurements at the surface or in the air to provide local concentration measurements, and the networks that perform ground-based remote sensing measurements. The latter typically provide 'smoothed' vertically and/or horizontally integrated information, like total or partial column abundances of the target constituents or vertical profiles at limited vertical resolution, with a sensitivity to the true local concentrations that varies with altitude and with a certain horizontal representativeness. The in-situ data better represent the truth, but since the satellite data product is also a remote sensing data product, it is often more easily comparable to reference data from a remote sensing network. It is especially difficult to compare the satellite data products to in-situ data recorded at the surface or at one specific altitude in the atmosphere. The in-situ surface concentration data are therefore mostly used as ancillary data in the validation process.

The last column in the table below (Table 17) therefore distinguishes between the different uses of the network data for satellite calibration (C) or Validation (V), directly or as ancillary data product (VA). For completeness, we add between brackets the distinction between in-situ (IS) and remote sensing (RS) networks if relevant.

Most networks have their own data handling facilities but often distribute their data also through other data portals with which they have agreements about data or metadata exchanges.

Thorne et al. (Thorne *et al.* 2017) proposed a distinction between reference networks, baseline networks and comprehensive networks according to their degree of 'maturity', the latter being evaluated along the lines of a maturity matrix. The networks classified as reference networks provide access to metrologically trace-able observations, with quantified uncertainty, known as Fiducial Reference Measurements (FRM). For many of the networks listed in the Table below, the purpose is, and efforts are ongoing to deliver FRM data, but often this objective is reached for a limited number of data products or at a limited number of sites only – depending on the available resources. Efforts towards FRM data quality have been supported by the Space Agencies and in the context of the European Research Infrastructures like ICOS and ACTRIS (currently in the implementation phase) and should be continued. Because the data quality is not necessarily fully homogeneous throughout the networks, it is difficult to assign the different reference-quality labels to the networks as a whole.

It must also be noted that – apart from some like TCCON that have been designed from the start to support satellite validation – many networks started off as collaborative initiatives for research, not specifically targeting satellite validation; a good example is NDACC. This means that neither the observation sites, nor the schedules of the observations have been optimised for supporting satellite validation. For example, data from high-mountain sites are not necessarily optimal for validation of tropospheric satellite products with large footprints, or ozone sonde launches are not routinely targeted towards satellite overpass times. Also, the delivery times of the data are not necessarily short enough to satisfy the needs of quick satellite data quality monitoring. Nevertheless, networks like NDACC are used very successfully for the validation of atmospheric composition data from many different satellites as well as for the validation of Copernicus Atmosphere Monitoring Service products, and have demonstrated that they are willing to adapt to specific requirements like rapid data delivery, provided that sufficient resources are made available.

5.2 General information about the sites/networks

Table 17: General information of networks under investigation

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
AERONET	NASA	https://aeronet.gsfc.nasa.gov/	Global	Not directly but different sites are	V, VA (RS)
AEROSPAN	CSIRO	https://aeronet.gsfc.nasa.gov/cgi-bin/draw_map_display_aod_v3	Regional	YES	Australia's component of AERONET, provide data about Atmospheric Composition & Chemistry V, VA (RS)
ARM	United States Department of Energy (DOE)	https://www.arm.gov/capabilities/observatories/	6 ground-based observatories that each provide extensive measurements of a small area (though one observatory, in the US state of Oklahoma, does have a surrounding network of supporting measurements). Three of the observatories are moved to new locations periodically so that to date ARM has provided measurements at approximately 25 locations over the past 29 years. Most of these deployments were at least a year in duration. Five exceeded 10 years in duration.	No. Don't see a reason why this couldn't be done.	To conduct ground-based observations advancing atmospheric and climate research

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
AGAGE	Massachusetts Institute of Technology	https://agage.mit.edu/global-network	Global. 13 active stations (10 primary, 3 affiliated)	N/A	To measure globally, at high frequency, and at multiple sites all the important species in the Montreal Protocol and all the important non-carbon-dioxide (non-CO2) gases assessed by the Intergovernmental Panel on Climate Change
COCCON	Sites are run by individual research institutes	Worldwide (Link)	Global	Yes	V (RS)
enerMENA	Sites are run by individual research institutes	https://www.dlr.de/sf/en/desktopdefault.aspx/tabid-8680/12865_read-32404/	North Africa Active stations: Tataouine (Tunisia), Ma'an (Jordan), Quijda (Morocco), Cairo (Egypt), Missour (Morocco), Erfoud (Morocco), Zagora (Morocco) Deactivated stations: Adrar (Algeria), Ghardaia (Algeria), Tan-Tan (Morocco)	Yes, in CAMS2_73 project	The enerMENA network aims to supply reliable meteorological data of the MENA region, especially those of the Direct Normal Irradiance (DNI) that are necessary for the implementation of concentrated solar power (CSP) technologies.
EUBREWNET	All observatories (stations; instruments) of the network belong to and are operated by individual organisations/ research institutes / PIs	http://www.eubrewnet.org/?map=1	Global	Yes, the network is a contributor to validation of TROPOMI, EUBREWNET also contributes data to C3S	The purpose of EUBREWNET is to harmonise observations, data processing, calibrations and operating procedures so that a measurement at one station is entirely consistent with measurements at all the others.

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
GRUAN	Network governance: GCOS & GRUAN Lead Centre. Individual sites by national agencies or institutions	GRUAN Homepage: Sites	Global	Yes, depending on the site	V, VA (IS and RS)
IAGOS	European Research Infrastructure. It's a distributed network of commercial aircraft belonging to international airlines.	IAGOS aircraft (today: 7, objective: 15) visit ~300 airports (hubs are more frequently visited), providing vertical profiles over this perimeter: 65° N – 44° S, 172° W – 175° E (for the airports).	Global	No	IAGOS is contributing to CAMS-84 (EU project): validation of regional and global models – 2015-end of 2021. V (IS)
ICOS Atmosphere	Various, data co-owned by ICOS-ERIC	https://www.icos-cp.eu/observations/atmosphere/stations	Mainly in Europe	Some site but not in an organized way	Mission is to produce standardised, high-precision and long-term observations and facilitate research to understand the carbon cycle and to provide necessary information on greenhouse gases
Meteo-France	Meteo-France	http://www.meteofrance.fr/prevoir-le-temps/observer-le-temps/moyens/les-radiosondages	Global	No, but some exercises exist	V, VA (IS)
NDACC	Site based	www.ndacc.org/	Global	Yes	C, V, VA (IS and RS)
PGN	All sites have their own	https://www.pandonia-global-network.org/	Global	N/A	V (RS)

Network	Ownership	Location link	Coverage	Participating Copernicus Cal/Val	Purpose of the network
SHADOZ	NASA-sponsored project with NOAA partnership	https://tropo.gsfc.nasa.gov/shadoz/Archive	Global	Yes	V (IS)
SKYNET	Chiba University	http://atmos3.cr.chiba-u.jp/skynet/	Global	N/A	Observation network dedicated for aerosol-cloud-radiation interaction research. V, VA (RS)
SNO-IFA	LSCE (Laboratoire des Sciences du Climat et de l'Environnement)	18 sites: 10 in France, 2 in Europe, 6 in tropical and subtropical areas. 5 sits are labelled in ICOS-ERIC	Global	No	
TCCON	Site based	Worldwide (Link)	Global	Yes	V (RS)
TOLNet	Site based, supported by NASA	https://www-air.larc.nasa.gov/missions/TOLNet/	6 stations in USA, 1 in Canada	Yes	To provide time/height ozone measurements from near the surface to the top of the troposphere to describe in high-fidelity their spatio-temporal distribution. V (RS)
WMO/GAW Ozone column and sonde profiles network	Stations operated under the auspices of the Global Atmosphere Watch (GAW) programme of the World Meteorological Organization (WMO)	https://oscar.wmo.int/surface/#/search/station#stationSearchResults	Global	More than 500 stations globally distributed	Yes

5.3 Financing properties

Table 18: Summary of financing situation of Networks under investigation

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
AERONET	Both	Depends on site	Depends on site	NASA side it is long term, ACTRIS also long term, NEON 30 years other contributor are highly variable
AEROSPAN	Centrally	Project based	CSIRO	Year to year funding
ARM	DOE funds the entire network as one facility, but observatories are managed by several institutions and funds are split out from the main facility budget to those institutions	The project is funded year by year but there is on-going long-term planning with DOE.	United States Department of Energy (DOE)	Funding is provided by DOE on an annual basis; however, the ARM facility has been funded for 30 years and we have plans extending out at least seven years.
AGAGE	Some funding centrally, and each site separately	N/A	Many different (e.g., NASA; grants; BEIS UK; NOAA; CSIRO, DoEE, Bureau of Meteorology (Australia); NERC; Ministry of Environment of Japan, NIES, FOEN, MIT CGCS)	N/A
COCCON	Per site	Project based	Depending on site	Short term
enerMENA	Per site	Partly via CAMS2_73, partly via different EU / German projects (site-specific)	EC & national funding	~2 years
EUBREWNET	Per site	Project based	Most of the stations are funded by Metrological Nacional Services. Database / network management is financed by AEMET	Depends on site, no long term guaranteed financing

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
GRUAN	Site dependent	Long term agreement	The network's sites are financed locally, e.g. by national weather service or research institutions GCOS secretariat is financed by WMO. GRUAN Lead Centre is financed by DWD.	N/A
IAGOS	Centrally financed via national funding from institutes (FR, DE, UK)	Long term agreement	France: CNRS and Meteo-France GermanY: MPI-Jena, FZJ- Julich, DLR, TROPOS-Leipzig, KIT UK: University of Manchester	Until 2028 for CNRS
ICOS Atmosphere	Part network, part local	Long term agreement	National funding	Next 5 years (plan 30 years)
Meteo-France	Centrally	Long term agreement	Meteo-France	No end date set
NDACC	Site dependent	Project based	Depend on site	Generally no long-term commitment; site-dependent
PGN	Individual sites are separately funded, while the overall network operation and management are funded centrally.	Project based	Network: NASA and ESA. ACTRIS will contribute in the near-future. At individual sites, funding comes from national agencies or own resources, or a mixture of all	Depends on site, mostly no guarantee
SHADOZ	Centrally	Project based	NASA-sponsored project with NOAA partnership; sponsors at 14 international stations and 4 nations in Europe and Japan	NASA and NOAA funding cycles are 3-4 years and international commitments to support SHADOZ data-taking are typically renewed on a 3-5 year basis
SKYNET	Centrally	Long term agreement	Agency and National funding	Depends on site

Network	Network/Centrally	Project based/long term agreement	Financer	Current agreement length
SNO-IFA	Network	Long term agreement	National funding (MESRI, CEA, CNRS, UVSQ, ANDRA, IPEV, CNES)	5 years
TCCON	Site based with network support	Mostly project based	N/A	N/A
TOLNet	N/A	N/A	N/A	N/A
WMO/GAW Ozone column and sonde profiles network	Site dependent	Long term agreement	Essentially national funding	Site-dependent

5.4 Data handling

Table 19: Data handling situation of Networks under investigation

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
AERONET	Open access (link)	Yes	Open access (Holben et al, 1998)	Open access (Giles et al 2019) Automatic for data, hybrid for calibration	N/A	https://aeronet.gsfc.nasa.gov
AEROSPAN	See AERONET	See AERONET	See AERONET	See AERONET	See AERONET	See AERONET

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
ARM	N/A	Yes	Yes (link)	Yes (link), automatic and manual	No	Yes. ARM uses Climate and Forecast (CF) where it is applicable. For distribution of metdata, ARM uses FGDC (Federal Geographic Data Committee –link) and ISO 19115 standards.
AGAGE	N/A	Identical in each station	N/A	Yes	Yes	N/A
COCCON	N/A	Yes, for now	Yes (link1, link2)	Yes (link). Mostly automatic, remaining in progress of automation	Yes, the precision of the data is calculated and archived together with the data. The codes used for archiving (which include this step) will be published as open source under CC license in the near future.	GEOMS compatible HDF files. Data will be hosted by EVDC and so meet EVDC standard
enerMENA	No	N/A	No	Yes (link)	Yes	No
EUBREWNET	Open access (link)	Yes	Yes (link)	Mostly automatic, the manual qc through a data exclusion list defined by the operators (link)	Yes	WOUDC extCSV (link) GEOMS HDF (link) NDACC AMES (link)
GRUAN	N/A	Yes	Yes (TD5 & TD6)	Automatic (TD5 & TD6)	Yes (TD5 & TD6)	N/A

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
IAGOS	Open access (link)	No – details in questionnaire	Yes, publication planned	Mixture of automatic and manual – planned to be open access	Not yet open access Standard operating procedure (link), QA per instrument (O3-CO, CO2-CH4, Aerosols, NOx, clouds, humidity, intercomparison)	ISO 19115
ICOS-Atmosphere	Open access (link)	Yes	Yes, in the protocols	Automatic and manual (link)	No, under development	Current work to provide consistent format with WDCGG and OBSPACK SPARQL tool is also available in the Carbon Portal

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
Meteo-France	Yes (link)	No	There is no formal data quality management plan for the whole measurement process. Nevertheless, required measurement characteristics are fully specified in the call for tender when buying sondes, and a verification of suitability is performed upon acceptance of the sondes. Each anomaly detected by the quality assessment process is tracked through a formal process.	Automatic (EOSCAN software)	Quality assessment is performed by monitoring: comparison to best estimate from Numerical Weather Prediction models, and computation of various metrics (mean or median bias, standard deviation, etc.). This is done at different places	No
NDACC	Yes (link)	Depends on the parameter	Yes (link1, link2)	Partly manual, partly automatic (link)	Yes (link)	GEOMS standard (link)
PGN	Yes (link)	Yes	Yes (link1, link2)	Partly manual, partly automatic (link)	Yes (link1, link2)	GEOMS (link)

Network	Measurement protocol	Centralised processing of raw data (Yes/No)	Quality Assurance for the whole measurement process	Quality Control for the measurements after their acquisition	Quality Assessment of the measurements	Does metadata follow a standard
SHADOZ	Yes (link) inproved publication in summer 2021	Yes	Yes, open access to the degree that the QA procedure adheres to WMO/GAW (2021) and supporting papers by Sterling et al. (2018), Witte et al. (2017; 2018), Thompson et al. (2017).	Yes, open access to the degree that the QA procedure adheres to WMO/GAW (2021) and supporting papers by Sterling et al. (2018), Witte et al. (2017; 2018), Stauffer et al. (2020).	Yes, total uncertainties for ozone are given in the v6 SHADOZ data (Witte et al., 2018). The current procedure is not open access, but follows the guidelines of the ASOPOS 2.0 (2021) report mentioned above.	Metadata is provided within the individual data files and is similar to WOUDC and NDACC specifications. SHADOZ is creating additional metadata files to be used with the WMO GAW OSCAR database that will follow the WMO XML standard.
SKYNET	Open access	Yes	Yes	mostly automatically, partially manual	Yes	No
SNO-IFA	Open access. Following ICOS-ERIC recommendations	Yes	Yes, not open access	Yes, not open access. Following ICOS-ERIC recommendation. Both manual and automatic	No	No
TCCON	Open access (link)	No	Yes (link)	Yes (link1, link2). Partly automatic, partly manual	link	CF standard
TOLNet	N/A	N/A	N/A	N/A	N/A	N/A
WMO/GAW Ozone column and sonde profiles network	Open access (link)	Had in the past but not currently	Yes (link1, link2, link3, link4, link5, link6, link7, link8, link9)	Yes (link1, link2, link3, link4, link5, link6, link7, link8, link9)	Yes (link1, link2, link3)	Link1, link2, link3, link4

Table 20: Data distribution of Networks under investigation

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
AERONET	https://aeronet.gsfc.nasa.gov/new_web/data_usage.html	Yes, but there are several ways to access the data.	Brent.n.holben@nasa.gov	Up to 28 years	Yes, depending on the sites
AEROSPAN	See AERONET	See AERONET	See AERONET	Up to 21 years	Some instruments have experienced failures which have spanned several months before the site could be visited and the instrument repaired. Particularly during 2020 and 2021 (Covid-19 travel restrictions). Typically, a newly calibrated instrument is swapped in for an existing instrument on an annual to 18-month basis, with only a day or two gaps in data occurring.
ARM	openly available to anyone upon registration with the ARM data center (link)	Yes, however, there are a few data sets provided by organizations external to ARM that have limited access.	Giri Prakash: palanisamyg@ornl.gov	Since 1993	Generally, once deployed at an observatory, instruments operate continuously for the duration of the period that observatory is active. Most deployments have a duration of approximately a year or more but there have been several shorter deployments. However, ARM operates approximately 400 instruments and does experience significant gaps at times. This is most common for the more complex instruments such as scanning radars, which may be off-line for extended periods.
AGAGE	Available to the scientific community (link)	No	Depends on station. General contact: agage@mit.edu	Depends on station and measurements	N/A

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
COCCON	Link	Yes	darko.dubravica@kit.edu	The data archive is in the development phase	Solar absorption measurements require direct sunlight (so no observations during night, polar night, overcast sky)
enerMENA	To share the data of one of the stations of the network, all network partners have to agree.	Yes	natalie.hanrieder@dlr.de	See website. Most active sites have been installed between 2010 and 2013.	Site-dependent due to sensor failures, sensor calibrations or communication problems.
EUBREWNET	Link	Yes	eubrewnet@aemet.es	Since 1988	Brewer raw observations previous to 1995 are in different format and are slowly incorporating to the database.
GRUAN	Link – NOTE being modified to reflect the new WMO resolution 42	In principle yes, being implemented	Gruan.lc@dwd.de	From 2008	Yes. For each radiosonde type a separate data product is developed. The available data for each data product depends on the deployment at the individual sites.

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
IAGOS	link	Yes, for L2 (fully calibrated) data. Data are available between 6 and 1 year after acquisition (depending on the maintenance of the instrument – flight period of 6 months). There is a direct access only for operational services (CAMS) regarding NRT and L1 (which means only validated by PI supervision) data.	Damien.boulanger@obs-mip.fr	Since 1994 for O3 & H2O (RH/T), 2001 for CO, 2011 for NOx, 2020 for CO2-CH4.	Yes, in case of instrument failures, and depending on operations of commercial fleets (2020-2021 lockdowns for example).
ICOS Atmosphere	CC4-BY	Yes	www.icos-ri.eu	Mos sites started between 2016-2020	No
Meteo-France	Etalab Open Data License. Source attribution ("Météo-France") is required by the license.	Before 1996 – on request. Afterwards (link). Additional details in the questionnaire	vd@meteo.fr	Since 1950	The stations of Le RAIZET and SAINT-DENIS are currently performing two launches/day during the cyclonic season and one launch/day during the other six months of the year.
NDACC	Link1, link2	Yes	jeannette.wild@noaa.gov Gao.Chen@nasa.gov	Since 1963	For some instrument techniques, data can be collected only under certain meteorological conditions, only during day- or nighttime etc. The dependence on sunlight for some techniques (FTIR, UVVIS) causes seasonal (local winter) gaps in the time series at high latitudes.

Network	General data policy	Data policy same for the entire archive?	Lead contact for the data	Archive depth	Gaps in the time series
PGN	Link	Yes	alexander.cede@luftblick.at	Since 2015	Very variable from one data record to another. Direct-sun measurements require cloud-free conditions at least at proximity of the sun's position in the sky.
SHADOZ	Open access. DOIs for data within 1-2 years	Yes (link)	Debra.E.Kollonige@nasa.gov	Since 1998	Six stations have data gaps in the 1998-2020 period, ranging from a few months to several years.
SKYNET	Personal contact	Yes?	Depends on station. General contact: hitoshi.irie@chiba-u.jp (http://atmos3.cr.chiba-u.jp/skynet/)	Depends on site	Depends on site
SNO-IFA	The open access is under development at AERIS-France	Yes	Michel.ramonet@lsce.ipsl.fr	Since 1981	No
TCCON	Link	Yes	https://tccondata.org/	Since 2004	Gaps are possible in case of instrument failure at the respective sites, and due to absence of sunlight necessary for measurements.
TOLNet	Open access. Link	Yes	Different for each site	Different for different sites	N/A
WMO/GAW Ozone column and sonde profiles network	Use of the WOUDC data are governed by the WMO data policy and WMO GAW data use policy. More information about WOUDC's data policy can be found online	Yes, near real time data provision is provided within different domains	https://woudc.org/contact.php?lang=en ec.woudc.ec@canada.ca	Earliest since 1926	Site dependent

5.5 Uncertainty evaluation

FRM data quality requires a comprehensive uncertainty evaluation, including the traceability to metrological standards. Most of the networks have laid out procedures and guidelines for evaluating the uncertainties, to a more or lesser level of comprehensiveness, but these efforts must be continued. In particular, the evaluation of the horizontal smoothing errors is lacking. Also, in many validation exercises, the uncertainties and in particular the uncertainties due to the smoothing effect, both in the satellite and the reference data (if these are also remote sensing data), are not well accounted for.

For remote sensing data, the traceability to metrological standards, like the WMO standards, is almost impossible, although TCCON has achieved it at several sites and specific times (Messerschmidt *et al.* 2011) albeit with considerable effort. The COCCON network calibrates the spectrometers with respect to reference TCCON station and therefore linking its measurements to the WMO standards (Frey *et al.* 2019, Sha *et al.* 2020). The most important is that the whole network uses a commonly agreed traceable standard.

Apart from the uncertainty associated with each individual data set, it is important to have a proper evaluation of possible site-to-site biases in the network, especially when the network is used for global validation exercises. Currently, several networks are deploying standard travelling instruments for calibration of the individual sites (e.g., COCCON), or have designed a calibration procedure (e.g., cell measurements in the NDACC Infrared Working Group) that must be performed regularly at each site, or deliver a centralised calibration service (e.g., PGN, AERONET), to ensure minimal site-to-site biases. Table 23 lists the information available for each variable.

5.6 Future and current developments

Table 21: Future or current developments of Networks under investigation

Network	Planned changes
AERONET	Slight modifications to the equipment have occurred over and new modifications particularly in the firmware are occurring.
AEROSPAN	Move away from the aging CE318-N units to CE318-T units has begun. Increasingly the older CE318-N units are wearing out and are harder to calibrate than the newer instruments. CSIRO is investigating moving away from using its own data loggers (weekly download) to sending the data at regular (hourly) intervals to CSIRO for collation and QC before sending to AERONET. We are currently working on reimplementing the in-house processing of the Aerosol Optical Thickness (Depth) calculation for Australian conditions (Set up by Ross Mitchell and Susan Campbell) which needs to be ported over to new code. Currently we are reliant on NASA GSFC for calibration, but would like to implement in-house QC of instruments prior to deployment. This would involve measurements with calibrated integrating spheres.
AGAGE	Continuous software developments for data processing, quality control and visualization. Also, stations software developments for oversight and drift.
ARM	There are not specific changes coming that are pertinent to the parameter interest list; however, I will note that approximately annually, observatories are moved to new locations so we obtain measurement sets at that new location (typically for a year). We will be deploying for a more extended period in the southeast United States in 2023. That deployment may include additional parameters relevant to land-atmosphere interactions such as leaf area index (LAI). Over the next year, we also expect to embark on an initiative that will allow us to make calibration information more readily accessible by users of ARM data.
COCCON	There are only peripheral / incremental upgrades concerning instrumentation ahead. There is a substantial upgrade on the COCCON trace gas retrieval code foreseen, including e.g. improved spectroscopic line lists (to be realized in the framework of an upcoming ESA project, planned start in autumn 2021). A COCCON travel standard is in preparation. It will visit TCCON sites around the globe and thereby contribute to further improving the consistency between COCCON and TCCON. We expect it will be highly useful for further reducing site-to-site biases between TCCON stations.
enerMENA	Regular re-calibration and exchange of sensors.
EUBREWNET	Improve Stray Light characterization include new cut-off filter. Updated total ozone algorithm, with the inclusion of the Bremen ozone cross section and Rayleight coeffients, also updated airmasss calculation and inclusion of the ozone cross section temperature dependence. Implemetation of the uncertainty of the total ozone measurements (link). The implementation of the error budget requires characterization of the uncertainty on the instrumental parameters that is not included on current calibration protocol. NO2 observation for Brewer MKIV instruments.

Network	Planned changes
GRUAN	Yes, data products are being developed for (raman) lidar and MWR, as well as for additional radiosonde types. For some radiosonde data products (e.g. Vaisala RS92, Meise RS-11G) updates of the data processing are foreseen.
IAGOS	Current: increase the number of aircraft equipped with additional GHG, Aerosols, NOx measurements. Current and Future: increase the number of aircraft equipped to increase the global coverage, and the number of visited European airports thanks to new aircraft/airlines (for profiling during take off and landing).
Meteo-France	It is planned that the station of Nîmes will switch from using M10 radiosondes to M20 radiosondes mid-2021. Tahiti Faa'a will soon start implementing the probe preparation and checking procedure following GRUAN's specification. No precise date is set, because of travel restrictions due to the COVID epidemic.
NDACC	Additional wind data from lidar and microwave instruments and H2O sonde data are being added to the archive. Depending on funding it is planned to add ground based spectral radiance (UV-visible-IR) data. Starting point of data submissions not known yet. NDACC has agreed to make different versions of a same dataset available on its public archive, for different applications, including datasets dedicated to satellite validation at the global scale. Several data products are progressing towards full FRM (Fiducial Reference Measurement) quality, e.g., the NDACC FTIR HCHO data product has been added to the list of FRM data since the publications by Vigouroux et al., 2018 (https://doi.org/10.5194/amt-11-5049-2018) and Vigouroux et al., 2020 (https://doi.org/10.5194/amt-13-3751-2020)
PGN	The PGN network is based on two instruments, the Pandora-1S and the Pandora-2S. Ongoing developments include the addition of polarisation channels.
SHADOZ	The basic ECC ozonesonde-radiosonde configuration and procedures are little changed over the SHADOZ period and the same is expected going forward. This is because the SOP that SHADOZ stations follow are based on ASOPOS WMO/GAW 201 (2104) and ASOPOS 2.0 (2021). These SOP have been tested and re-evaluated since 1996 in lab tests (the JOSIE series, Smit et al., 2007; Thompson et al., 2019) and found to be accurate and increasingly precise over time. Both ECC ozonesonde instrument type (manufacturer) and radiosonde models and manufacturer have changed at individual stations over the 23 yr record of SHADOZ data (Sterling et al., 2018; Witte et al., 2017; 2018). Radiosonde manufacturers continually modify instrumentation over time, having a small but quantifiable impact on the ozone profile (Stauffer et al., 2014). A goal of ongoing reprocessing of SHADOZ ozonesonde profiles (Smit & O3S-DQA guidelines, 2012; Deshler et al., 2016) is to homogenize the ozone data to avoid artifact discontinuities in the ozone measurement (Witte et al., 2017; 2018; Thompson et al., 2017; Smit and Thompson, 2021). The ASOPOS process is set up to communicate ongoing modifications to calculation of the ozone concentration, QC practices and uncertainty across the global ozonesonde community and to publish updates in the standard literature and in period Report. There are no major changes in data processing anticipated for SHADOZ but the procedures have evolved in the past 6-7 years to improve measurement accuracy and precision (to ~5%) as documented in the reprocessing articles cited above. Recommendations in the new ASOPOS 2.0 (2021) will lead to a second major reprocessing of SHADOZ data that will include new data quality flags and, it is anticipated, slightly revised ozone profiles with uncertainty estimations.

Network	Planned changes
SNO-IFA	Uncertainty estimates under development
TCCON	Addition of species measured with InSb detector in the mid-infrared spectral range. Improvements of retrieval algorithm. Improvements in tying TCCON to the WMO scale, and reduction of site-to-site bias. Retrievals of partial column profiles (e.g., CO2, CH4), retrievals of CO2 windows that are sensitive to different altitudes.
WMO/GAW Ozone column and sonde profiles network	Planned evolutions: - new stations; stations that stop measurements - changes in data products and data quality (e.g., implementation of new O3 absorption Xsections) - data reprocessing All modifications are agreed network-wide, with advice from SAG, GAW Expert Teams, Int'l O3 Commission (IO3C), etc

Table 22: Readiness for modifications for non Cal/Val sites to become Cal/Val sites

Network	Instrumentation	Calculation	Calibration/characterisation
AERONET	N/A	N/A	N/A
ARM	We are willing to consider additional needs; however, those will need to be weighed against needs expressed by other stakeholders and consider impact on the broader community. We do add new measurement capabilities on a somewhat regular basis.	We are open to considering new data processing procedures and welcome feedback regarding what would be most useful. As with measurements, we will need to weigh any recommendations against competing requests.	Same Response as for modifications in calculations.
AGAGE	N/A	N/A	N/A

Network	Instrumentation	Calculation	Calibration/characterisation
BSRN	Broadband albedo should be estimated from higher mast (at least 10mt)	The uncertainty is not provided though it can be assessed from cross comparison of redundant measurements, at least for the downwelling global radiation. The BSRN Uncertainty WG is working to move forward towards the implementation of a full uncertainty budget for the different components. Flagging system is available indirectly through the BSRN-Toolbox (https://bsrn.awi.de/software/bsrn-toolbox/).	All instruments are traceable with respect to the World Radiometric Reference (WRR, shortwave) and World Infrared Standard Group (WISG, longwave) maintained by the PMOD World Radiation Centre (PMOD-WRC, Davos, Switzerland).
WMO/GAW Ozone column and sonde profiles network	Instrumentation, procedures, protocols for ozone are generally reviewed by SAG on Ozone and UV radiation (chaired by Dr. Matt Tully) and since 2021 in coordination with GAW Expert Team on Atmospheric Composition Measurements Quality (ET - ACMQ) (chaired by Dr. Herman Smit). Ozone sonde communities are also providing advice and recommendations to operators. WOUDC is not involved.	Not at the data center by this moment. Such are discussed, approved by SAG on O3 and UV radiation and ET-ACMQ and their implementation is guided and ensured by ET-ACMQ and implemented by individual station or network PIs. Discussions are ongoing on how to deal with past records if O3 absorption xs is changed as recommended and on how to harmonize Brewer and Dobson records. Some Ozonesondes' records might also have needs for changes.	Not at the data center. Such are discussed, approved by SAG on O3 and UV radiation and ET-ACMQ and their implementation is guided and ensured by ET-ACMQ
IAGOS	Not flexible	Not flexible	Not flexible
ICOS Atmosphere	Possible	Possible	Possible
Meteo-France	Extra launches are possible	N/A	N/A
SKYNET	N/A	N/A	N/A
SNO-IFA	N/A	N/A	N/A

5.7 Parameters measured

Table 23: Distribution of measured parameters in Atmospheric composition missions

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Aerosol absorption	AERONET, AEROSPAN	5 min	12 – 24	0.25-18	
Aerosol extinction	IAGOS	1 sec			
Aerosol Layer Height	ARM				
Aerosol Optical Depth	AERONET, AEROSPAN, ARM, EUBREWNET, SKYNET	Continuous – 5 min	12-24	0.25-18	EUBREWNET (link)
Aerosol Partical size distribution	AERONET, AEROSPAN, IAGOS, SKYNET	1 sec - 5 min	12 – 24	0.25-18	(IAGOS) CPC#1: +/-10 cm-3 CPC#2: :+/-10 cm-3 OPC: +/-5 cm-3
Aerosol total concentration	IAGOS	1 sec			
Aerosols vertical profile	ARM, NDACC		1-3		NDACC (link1, link2)
Air relative humidity	DEMMIN/Moorfluxnet, enerMENA, FLUXNET, IAGOS, ICOS Atmosphere, ICOS Ecosystem, IMOS Ocean Colour Sub-facility, NASVF, NEON, TERN	Continuous – 5 minutes	2 – 48	1 – 12	enerMENA: 2-4% IAGOS: Precision: +/- 1% Uncertainty: +/- 6%
Air temperature	DEMMIN/Moorfluxnet, enerMENA, IAGOS, ICOS Atmosphere, ISMN	Continuous – 5 minutes	2 – 24	0.5 – 12	IAGOS: Precision: +/- 0.2K Uncertainty: +/- 0.5K enerMENA: +-0.3 - 0.9°C

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Air temperature vertical profile	ARM, GRUAN, Meteo France, NDACC/Lidar	1-4 profiles/day			Meteo-France: 0.3K NDACC (link1, link2)
Ammonia column	NDACC/FTIR	Clear-sky/daytime	1		NDACC (link)
Atmospheric pressure	enerMENA, DEMMIN/Moorfluxnet, ICOS Atmosphere, NASVF, FLUXNET, ICOS Ecosystem, IMOS Ocean Colour Sub-facility, NEON, RadCalNet	Continuous – 5 minutes	24	1 – 12	enerMENA: +-0.3 - 2.5 hPa
Atmospheric pressure Vertical profile	ARM, GRUAN, Meteo France	1-4 profiles/day			Meteo-France: 1% of the measured value.
Bromine monoxide total column	NDACC/UV-VIS ZSL-DOAS	Continuous			NDACC (link)
Chlorine dioxide total column	NDACC/UV-VIS ZSL-DOAS	Continuous			NDACC (link)
Cloud particles: concentration and Effective Diameter (ED) subset*	IAGOS	4 sec	6	6-12	Concentration dependent – typical uncertainty ± 20%
Carbon monoxide (in-situ)	IAGOS, SNO-IFA, AGAGE	Continuous – 1 minute	1 – 24	2 – 24 or as required	IAGOS: +/- 5 ppb +/- 5% SNO-IFA: ±3 ppb
Carbon monoxide total column	COCCON, ICOS Atmosphere, NDACC/FTIR, TCCON	Continuous	0.5 – 24	0.5 – 24 or as required	COCCON: < 3% until 75° SZA NDACC (link) TCCON: <4% and decreases with SZA (link)

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Carbon monoxide vertical profile	NDACC/FTIR	Clear-sky/daytime	1	as required	NDACC (link)
Carbon dioxide (in-situ)	IAGOS, SNO-IFA	Continuous – 1 minute	Daily – 24	2-24	IAGOS: Precision (4s, 1 sigma): CO2: ±0.04 ppm; Uncertainty (100s, 1 sigma): CO2: ±0.13 ppm; SNO-IFA: ±0.1 ppm
Carbon dioxide total column	COCCON, ICOS Atmosphere, NDACC/FTIR, TCCON	Continuous	0.5 – 24	0.5 – 24 or as required	COCCON: < 0.2% until 75° SZA NDACC (link) ICOS Atmosphere: ± 0.1 ppm TCCON: 0.25% until 82° SZA (link)
Dew point vertical profile	Meteo-France	1-2 profiles/day			
Diffuse horizontal solar irradiance	enerMENA	1 Hz	~24	~6	1-2% (Pyrheliometer) 2-4% (Rotating Shadowband Irradiometer)
Direct normal solar irradiance	enerMENA	1 Hz	~24	~6	1-2% (Pyrheliometer) 2-4% (Rotating Shadowband Irradiometer)
Direction and intensity of winds	ARM	2-4 profiles/day			

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Formaldehyde total column	NDACC/FTIR NDACC/UV-VIS MAX-DOAS PGN	Clear-sky/daytime	12	as required	PGN (Link), NDACC (link)
Formaldehyde vertical profile	NDACC/FTIR NDACC/UV-VIS MAX-DOAS	Continuous		as required	NDACC (link)
Geometric cloud mask	ARM, CLOUDNET				
Global horizontal solar irradiance	enerMENA	1 Hz	~24	~6	1-4%
Glyoxal total column	NDACC/UV-VIS MAX-DOAS	Continuous			
Isotopes of: CO2, CH4, CO, N2O, SF6, H2,	ICOS Atmosphere	1 week		0.5 – 1	
Methane (in-situ)	IAGOS, SNO-IFA, AGAGE	Continuous – 1 minute	Daily - 24	2 – 24	IAGOS: Precision (4s, 1 sigma): CH4: ±0.4 ppb; Uncertainty (100s, 1 sigma): CH4: ±1.3 ppb; SNO-IFA: ±1 ppb AGAGE: 0.2%
Methane total column	COCCON, ICOS Atmosphere, NDACC/FTIR, TCCON	Continuous	0.5 – 24	0.5 – 24 or as required	COCCON: < 0.25% until 75° SZA ICOS Atmosphere: ± 1 ppb NDACC (link) TCCON: <0.5% until 85° SZA (link)
Methane partial columns	NDACC/FTIR	Clear-sky/daytime	1	as required	NDACC (link)

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
MWR Brightness Temperature	ARM				
Nitrogen dioxide (in-situ)	SNO-IFA	Continuous – 1 minute	1-12	2	SNO-IFA: ±2 ppb PGN: (Link)
Nitrogen dioxide stratospheric column	NDACC/UV-VIS ZSL-DOAS	All weather/twilights (sunrise and sunset)			Link
Nitrogen dioxide total column	ICOS Atmosphere, NDACC/FTIR NDACC/UV-VIS ZSL-DOAS	Continuous – 3 minutes	0.5 – 12	0.5 – as required	ICOS Atmosphere: ± 0.2 ppb NDACC (Link)
Nitrogen dioxide tropospheric column	NDACC/UV-VIS MAX-DOAS PGN	Continuous	12		PGN (Link), NDACC (link)
Nitrogen dioxide Vertical profile	NDACC/UV-VIS ZSL-DOAS				Link link
Nitric acid total column	NDACC/FTIR	Clear-sky/daytime	1	as required	NDACC (link)
NO/NOx (in-situ)	IAGOS	1 sec – 4 sec	6	6	Precision: NO: ±5% or ±25 ppt (4s, 1 sigma); NOx: ±5% or ±35 ppt (4s, 1 sigma) Uncertainty: NO: ±7% or ±25 ppt (1 sigma); NOx: ±15% or ±40 ppt (1 sigma)
Nitrous oxide total column	NDACC/FTIR, TCCON	Clear-sky/daytime	1	12 – 24 or as required	NDACC (link) TCCON: ~ 1% and reasonably independent of SZA (link)

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Ozone (in-situ)	IAGOS	4 sec	6	6	+/- 2 ppb +/- 2%
Ozone total column	Brewer network, Dobson network, EUBREWNET, GAW-WOUDC, NDACC/UV-VIS ZSL-DOAS, PGN, WMO/GAW Ozone column and sonde profiles network,	Clear-sky/daytime Twilight, all weather Continuous	1 - 72	12 - 72	EUBREWNET (link2) NDACC (Link1, link2, link3, link4) PGN (Link) WMO/GAW reports n°s 176, 180, 201, 225, ASOPOS 2.0 report (2020)
Ozone tropospheric column	NDACC/ozonesonde, NDACC/FTIR, WMO/GAW Ozone column and sonde profiles network	Ozonesonde launch usually at noon, station dependent frequency Clear-sky/daytime	Every launch 1	As required	NDACC: Link1, link2, link3 WMO/GAW: reports n°s 176, 180, 201, 225, ASOPOS 2.0 report (2020)
Ozone vertical profile	NDACC/FTIR, NDACC/Lidar, NDACC/ozonesonde, TOLNet, WMO/GAW Ozone column and sonde profiles network	Clear-sky/night-time Ozonesonde launch usually at noon, station dependent frequency Continuous – 3 days	1 Every launch 1	1 -3	NDACC: Link1, link2, link3, link4, link5 WMO/GAW reports n°s 176, 180, 201, 225, ASOPOS 2.0 report (2020)
Planetry boundary layer depth	ARM	2-4 profiles/day			
Radiative forcing	AERONET, AEROSPAN	5 minutes	12-24	0.25-18	
Radiometric Cloud Fraction	ARM, CLOUDNET				
Rain Rate	ARM, ISMN				
Refractive index	AERONET, AEROSPAN, SKYNET	5 minutes	12-24	0.25-18	

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Single scattering albedo	AERONET, AEROSPAN, SKYNET	5 minutes	12-24	0.25-18	
Sulfur dioxide total column	NDACC/UV-VIS MAX-DOAS PGN	Continuous	12		PGN (Link), NDACC (Link)
Soil water content	ARM				
Solar spectral irradiance	ARM				
Spectral Albedo of surface	ARM				
Spectral flux	AERONET, AEROSPAN	5 minutes	12-24	0.25-18	
UV irradiance	NDACC/UV, EUBREWNET	30 minutes	12	1	NDACC (link1, link2)
Water vapour (in-situ)	GRUAN	1 minute – 15 minutes	24	24	
Water flux	AERONET, AEROSPAN, DEMMIN/Moorfluxnet	5 min – 30 min	12-48	0.25-18	
Water vapour total column	ARM, COCCON, NDACC/FTIR, TCCON	Clear-sky/daytime (FTIR)	1 – 24	12 – 24 or as required	COCCON: < 2% until 75° SZA NDACC (link1, link2) TCCON: <1.3% below ~85° SZA (link)
Water vapour vertical profile	ARM GRUAN NDACC/Lidar NDACC/MW	1-4 profiles/day			

Parameter	Networks measuring this parameter	Measurement frequency	Calibration frequency (in months)	Maintenace frequency (in months)	Uncertainty evaluation references
Wind direction	DEMMIN/Moorfluxnet, enerMENA, ICOS Atmosphere, IMOS Ocean Colour Sub-facility	Continuous	24	1 – 12	enerMENA: +-1.6 - 2.5°
Wind direction vertical profile	Meteo France	1-2 profiles/day			1°
Wind speed	AMAZON, DBCP, DEMMIN/Moorfluxnet, enerMENA, FLUXNET, FRM-BASS STRAIT, FRM-CORSICA, FRM-CRETE, FRM-HARVEST, FRM-ISSYKKUL, ICOS Atmosphere, ICOS Ecosystem, IMOS Ocean Colour Sub-facility, INSTAC, NDBC, NEON, TERN	Continuous	24	12	enerMENA: ~ +-0.14 - 0.45m/s
Wind speed vertical profile	GRUAN, Meteo France	1 profile/day			Meteo France: 0.15 m/s

6 Conclusions

The scope of this document was not to evaluate the investigated networks, but to map the current situation as an input for the second phase of the project. Therefore, it is important to point out that the conclusions below are meant to be starting points for the second phase and not as recommendations for Copernicus program or for the networks in question.

- Still a lot of networks rely on site specific and/or manual quality control.
- Uncertainty estimations are often missing, partial or are not well documented. This is not uniform over the field and the situation for atmospheric composition measurements is better than for optical and altimetry missions. However, it is under development and at the same time there are well established quality control procedures and quality flags already in place for most networks.
- Although sites/networks have made large investments and have established nice facilities with experts managing the measurements and the instruments could run for years with proper calibration/maintenance, only few sites/networks have long term financial assurance.
- Metadata format is often site/network specific which makes it harder to include the data in a more automated way into bigger Cal/Val activities.

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Annex A Sample Questionnaire

A.1 Questionnaire template

Questionnaire for CCVS project T2.4 – Ground based systematic measurements.

This interview is part of the H2020 project "CCVS – Copernicus Cal/Val Solutions" under task 2.4 "Ground based systematic measurements". The aim of the project is to map the current situation and to set guidelines of how the Copernicus program should handle the calibration and validation of satellite measurements during all phases of the ongoing/future missions.

Under current task we map how different networks are conducting and analysing measurements that are related to calibration and/or validation activities of Copernicus satellites. We are also analysing the readiness level of the contacted networks to meet requirements of the fiducial reference measurements. In order to initiate discussion we invite all the providing networks to our project workshop were we provide feedback according to the analyses carried out during the project.

PS If you don't have an answer to a question in the questionnaire just put N/A.

Interviewer:

Interviewee:

I. General Information:

1. Name of the site/network:
2. Site/network website:
3. Ownership of the site/network:
4. Site/network location (link to info):
5. Is it Global/Regional/Smaller area?
6. Is the network currently involved in Copernicus Cal/Val activities (if no – are there any KNOWN obstacles why it can't be done)?

II. Financing

7. Is the network/site financed:

Network (centrally)/ Individual sites separately

Project based/long term agreement

If financing system is similar for the entire network then answer following 2 questions:

8. Who is financing the site/network?

Agency / EC program / National funding / Own resources / Other. Comment:

9. For how long is the financing currently agreed (in years)?

III. Data handling

10. Is the Measurement protocol open access? If yes – provide link or reference

11. Has the network capacity to perform centralised processing of the raw data? (Yes/No)

12. Is there a Quality Assurance (data quality management) for the whole measurement process? (Yes/No)

    a. Is the Quality Assurance procedure open access? If yes – provide link or reference.

13. Is there a Quality Control for the measurements after their acquisition? (Yes/No)

    a. Is the Quality Control procedure open access? If yes – provide link or reference.

    b. Is the Quality Control procedure automatic or manual?

14. Is there a Quality Assessment (derivation of ex-post quality indicators) of the measurements? (Yes/No)

    a. Is the Quality Assessment procedure open access? If yes – provide link or reference.

15. Does metadata follow a standard? If yes – provide link or reference.

16. What is the general data policy? Please provide link to applicable terms of reference.

    a. Is the procedure to access the data the same for the entire archive?

17. Lead contact for the data (e-mail or link).

18. For how long period is the archive available?

19. Are there significant gaps in the time series (also periodical/seasonal?)

IV. Future or current developments

20. Are there development changes in progress regarding:
    a. Additions/changes in instrumentations?
    b. Modifications in calculations (quality control, uncertainty estimations...)?
    c. Modifications in calibration/characterisation procedures?
    d. Testing/developing merging technologies that are potential addition to Cal/Val activities?

21. If the network site/series of campaigns is currently not suitable for Cal/Val site, how willing/flexible are they for modifications in:
    a. Additions/changes in instrumentations?
    b. Modifications in calculations (quality control, uncertainty estimations...)?
    c. Modifications in calibration/characterisation procedures.

V. Product description

22. Describe the details of measured parameters:

Measured parameter	Device	Units	Measurement target (Land/Water/Atmos.)	Measurement frequency	Calibration frequency (in months)	Maintenance Frequency (in months)	Measured instrument characteristics	Uncertainty evaluation

End of Document

/