Copernicus Cal/Val Solution

D2.5 - Field and Aerial Campaigns

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1 Introduction

1.1 Scope of the document

This document is a compilation of existing campaigns, which were or will be conducted to validate or calibrate satellite mission requirements and/or satellite-based products (particularly Copernicus products). In contrast to the systematic measurements, which are described in CCVS-TAR-D2.4 (Systematic Ground-Based Measurements), campaign-based measurements can be considered as event-based activities (e.g., data acquisition during a satellite overpass or a certain incident). Typically, campaigns require advance planning, specific instruments and are often realized within the framework of a research project.

Information about field and aerial campaigns have been collected within a 3-month survey and documented in a systematic manner. As a result, we got a variety of platforms, instruments and objectives involved in the different data acquisitions. Of course, this survey makes no claim to be complete, but shall represent the intention and nature of campaigns in conjunction with Copernicus Cal/Val. In this context, we would also like to refer to the ESA supported ground-based, ship-borne, balloon-borne, and airborne campaigns that validate orbiting ESA EO satellites and support future mission development:

https://earth.esa.int/eogateway/search?text=&category=Campaigns&year=2001&sortby=RELEVANCE

In addition to the collection of campaigns, we also considered the infrastructures and networks supporting the campaigns. Here too, we do not claim to be complete, but show some examples which indicate the possibilities in Europe and abroad.

The filled questionnaires and surveys are not added directly to the document but will be available for project partners for next stage analyses.

1.2 Structure of the document

The first part of the document (Section 1) contains general information. Section 2 comprises the systematic listing of all recorded campaigns, ordered by the related mission. Networks and infrastructures are described in Section 3. Within the last part (Section 4) we give a résumé on possibilities and limitations concerning campaigns for Cal/Val purposes. The list of campaigns, networks and infrastructures with the information on the corresponding documents can be found in the Annex.

1.3 Acronyms

The list of the acronyms and acronyms of institutions used in our technical proposal is provided hereafter:

Table 1: Acronyms

Acronym	Definition
ADF	Auxiliary Data File
AOP	Atmospheric Optical Properties
AOT	Aerosol Optical Thickness
APEX	Airborne Prism EXperiment
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BOA	Bottom of Atmosphere
Cal/Val	Calibration and Validation
CHIME	Copernicus Hyperspectral Imaging Mission
CDOM	Colored Dissolved Organic Matter
CH_4	Methane
Chl-a	Chlorophyll-a
COCCON	Collaborative Carbon Column Observing Network
CO_2	Carbon dioxide
CO	Carbon monoxide
DESIS	DLR Earth Sensing Imaging Spectrometer
DOAS	Differential Optical Absorption Spectroscopy
EnMAP	Environmental Mapping and Analysis Program
FLEX	FLuorescence EXplorer (FLEX) mission
GCAS	GEO-CAPE Airborne Simulator
GEMS	Geostationary Environmental Monitoring Spectrometer
GeoTASO	Geostationary Trace gas and Aerosol Sensor Optimization
GOES	Geostationary Operational Environmental Satellite
GOSAT	Greenhouse Gases Observing Satellite
HCHO	Formaldehyde
HISUI	Hyperspectral Imager Suite
IASI-NG	The Infrared Atmospheric Sounding Interferometer New Generation
IOP	Inherent Optical Properties
KdPAR	Diffuse attenuation coefficient
Kd490	Diffuse attenuation coefficient at 490 nm
LAI	Leaf Area Index
LSTM	Land Surface Temperature Monitoring (LSTM) mission
LWIR	Long Wavelength Infrared
L7	Landsat 7
L8	Landsat 8
MERLIN	Methane Remote Sensing Lidar Mission
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
MSI	Multi Spectral Instrument
NIR	Near Infrared
NO_2	Nitrogen dioxide
OCO-2/3	Orbiting Carbon Observatory-2/3
OLCI	Ocean and Land Colour Instrument
OMI	Ozone Monitoring Instrument

PC	Phycocyanin
PE	Phycoerythrin
PRISMA	Hyperspectral Precursor and Application mission
RI	Research Infrastructure
ROV	Remotely Operating Vehicle
RV	Research vessel
SBG	Surface Biology and Geology (SBG) science mission
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SLSTR	Sea and Land Surface Temperature Radiometer
SMAP	Soil Moisture Active Passive
SMOS	Soil Moisture and Ocean Salinity (SMOS) mission
SO_2	Sulphur dioxide
SPM	Suspended Particulate Matter
SWIR	Short-wave Infrared
S-1	Sentinel-1
S-2	Sentinel-2
S-3	Sentinel-3
S-5P	Sentinel-5 Precursor
SWING	Small Whiskbroom Imager for trace gases monitoriNG
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TIR	Thermal Infrared
TSM	Total Suspended Matter
UAV	Unmanned Aerial Vehicle
VENµS	Vegetation and Environment monitoring on a New Micro-Satellite
VIIRS	Visible Infrared Imaging Radiometer Suite

Table 2: Acronyms of institutions

Acronym	Institustion
AEMET	Agencia Estatal de Meteorología
AGH	University of Science and Technology Krakau
AIST	Advanced Industrial Science and Technology
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
AWI	Alfred-Wegener -Institut
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
CEA-LSCE	Commissariat à l'énergie atomique - Laboratoire des sciences du climat et de l'environnement
CESBIO	Centre d'Etudes Spatiales de la Biosphère (Center for the Study of the Biosphere from Space)
CNES	Centre national d'études spatiales
CNR	Consiglio Nazionale delle Ricerche
CNRS	Centre national de la recherche scientifique
CNRM	Centre National de Recherches Météorologiques
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center)
EMI	Estonian Marine Institute
ESA	European Space Agency
EUFAR	The EUropean Facility for Airborne Research
FAAM	Facility for Airborne Atmospheric Measurements
FZJ	Forschungszentrum Jülich
GFZ	Deutsches Geoforschungszentrum (German Research Center for Geoscience)
INCAS	National Institute for Aerospace Research "Elie Carafoli"
INOE	National Institute for Research and Development in Optoelectronics INOE 2000
INPE	Instituto Nacional de Pesquisas Espaciais (National Space Institute of Brazil)
INTA	Instituto Nacional de Técnica Aeroespacial
IUP	Bremen Institute of Environmental Physics, University of Bremen
KIT	Karlsruher Institut für Technologie
LATMOS	Laboratoire atmosphères, milieux, observations spatiales
LERMA	Laboratoire d'Etudes du Rayonnement et de la Matière en Astrophysique et Atmosphères
LMD	Laboratoire de Météorologie Dynamique
NASA	National Aeronautics and Space Administration
NIER	National Institute of Environmental Research
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
ONERA	Office national d'études et de recherches aérospatiales
PML	Plymouth Marine Laboratory
RAL	Rutherford Appleton Laboratory
RHUL	Royal Holloway, University of London
RUG	RUG Rijksuniversiteit Groningen
SNSA	Swedish National Space Agency
SNU	Seoul National University
SYKE	Suomen ympäristökeskus (Finnish Environment Institute)
TUM	Technische Universität München
UFZ	Helmholtz-Zentrum für Umweltforschung (Centre for Environmental Research)
UHEI	Heidelberg university
VITO	Vlaamse Instelling voor Technologisch Onderzoek (Flemish institute for technological research)
MRI KU	Marine Research Institute of Klaipeda University
UTARTU	University of Tartu

2 Campaigns

2.1 Design of campaign survey

2.1.1 Preliminary consideration

Overall Goal: Get an overview about the past / present / future dedicated Cal/Val campaigns.

In order to get an overview of the different types of campaign we are dealing with an initial attempt was made to systematically map the situation. Figure 1 illustrates this approach. Campaigns are mapped to the different missions, mission phases and platforms. Furthermore, details on the instrumentation and data acquisition as well as on the campaign organisation help to describe the campaign.

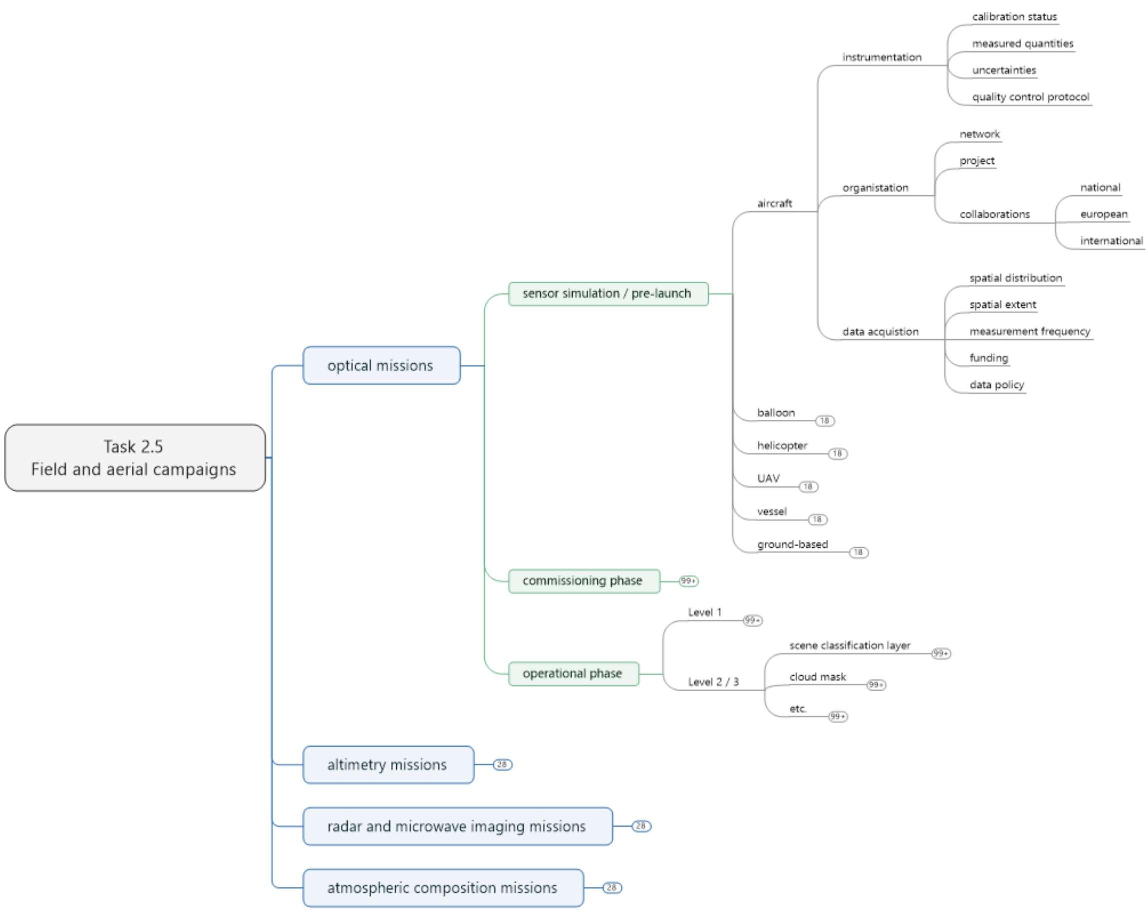

Figure 1 : Classification of Cal/Val campaigns

This preliminary consideration helped to elaborate a template to record the campaigns within our survey. First, campaigns of different CCVS project partners were recorded to assess the usability of the survey template and to adapt it if necessary. Afterwards, the survey has been expanded outside CCVS.

2.1.2 Survey template

The survey template helped to collect the most important features describing the diversity of campaigns. The different aspects are explained in more detail below.

General Information

- Campaign name: clear project identifyer
- Campaign objective/topic: short description of the campaign's objective
- Campaign website: link to the campaign's website (if available)
- Related satellite mission(s): which satellite mission data is concerned within the campaign
- Related thematic field: choice between optical, altimetry, radar and microwave and atmospheric composition mission (along the lines of CCVS WP1)
- Related mission phase: choice between pre-launch, commissioning and operational phase
- Calibrated/validated data/product: which satellite products are considered for validation
- Principle investigator (e.g., name/organization): PI of the campaign
- Related project/network/collaboration (e.g., S-2 MPC): was the campaign carried out as part of a project or initiative? Are there connections to infrastructures or networks ?

Data Acquisition

- Used platform: choice between ground-based, UAV/drone, aircraft, balloon
  - Specification (e.g., DO-228): specification of platform
  - Operator (e.g., DLR-FX): platform operator
- Measured quantity (e.g., radiance): what has been measured?
- Instrumentation (e.g., imaging spectrometer): which type of instruments were used?
  - Specification (e.g., HySpex): specification of the instruments
  - Calibration status (e.g., annual calibration): instrument calibration status
  - Uncertainties (e.g., uncertainty evaluation available): knowledge about measurement uncertainty
  - Quality control protocol (e.g., ISO-certified service): quality control of measurements
  - Operator (e.g., DLR's OpAiRS): instrument operator
  - Related website(s): link to instrument webpage (if available)
- Spatial distribution (e.g., Demmin, Germany): campaign location
- Spatial extent (e.g., 1000km²): extent of survey area

- Measurement frequency (e.g., summer on a yearly basis): how often do the campaigns take place

Financing

- Funding (e.g., ESA): which entity is financing the campaign?

Data Handling

- Data availability (e.g., freely available): Is the data available for everybody?
- Data access (e.g., data portal): How can the data be accessed?
- Data processing (e.g., used software/codes): How was the data processing done?

Cal/Val Methods / Data Analysis

- Cal/Val methods (e.g., vicarious Cal/Val on natural target): description of the validation method (if applicable)
- Related publications: publications detailing the campaigns/results (if available)

Future Developments

Further developments (e.g., instrumentation, methodologies…): are any further developments foreseen to improve the results?

2.1.3 Summary and evaluation of the survey

The completed forms do vary in terms of size and level of detail. This is partly due to the different complexity of campaigns but also to the willingness of the interviewee to complete the form. For the presentation of the campaigns in this report, we have rearranged or merged some sections of the campaign form and harmonized entries as much as possible for better comparison and understanding. For further details we do refer to the filled survey forms.

The campaigns are sorted according to their related thematic field (e.g., optical missions). At the end of each section, we draw conclusions about the campaigns listed within and highlight the major findings.

Remark: All campaigns are sorted alphabetically by name.

2.2 Remark on uncertainty indications

Using field and aerial campaigns to validate satellite-based products involves uncertainties for both the satellite and the auxiliary measurements. The uncertainties of the validation measurements must be smaller than the target uncertainty of the satellite product to be validated. There are instrument uncertainties, processing uncertainties but also uncertainties concerning the representativity (esp. concerning the spatio-temporal coverage of the measurements). Critical points include also the natural variability and characterization of the covered target area with respect to the different footprints of satellite observations and measurements performed during campaigns.

Within our survey, we tried to capture these different aspects. Although in many cases there was no concrete information on the uncertainty budget available, we received information on the quality of the sensors used (calibration status), existing measurement protocols, and the spatial and temporal coverage of the campaign.

In order to understand and characterize the uncertainty of the validation process, a full uncertainty budget would be necessary. This is rarely implemented. This is done more frequently in the field of atmospheric physics than in the other fields. Throughout the different thematic fields, the sensor error budget is quite always performed, with specific calibration scheme. This is less true for the processing error budget. For atmospheric and “land” parameters, good examples are the traceability chains developed within the QA4ECV initiative (http://www.qa4ecv.eu/ecvs), which include showcases for satellite as well as for ground reference measurements.

If information on uncertainty evaluation was provided within the survey form, it is included in the tables about “used instrumentation”. Sometimes, this is also just a link to the networks presented within the task2.4 deliverable CCVS-TAR-D2.4, where the uncertainty estimates are given in details for the respective networks.

2.3 Survey results

2.3.1 Optical missions

General Information

Table 3: General information about campaign

Campaign name	Satellite mission	Mission phase	Cal/Val data	PI affiliation	Funding
AMT	S-1 S-3	operational	BOA reflectance radiances water constituents (Chl-a, TSM) Sea Surface Roughness gas fluxes	PML	national funding
ASTER/HISUI vicarious calibration	Terra ASTER HISUI	operational	BOA reflectance	AIST	national funding
Australian continental surface reflectance validation	S-2 L8	operational	BOA reflectance	CSIRO in collaboration with UQ, U Adelaide, U Woollongong, U Melbourne & Maitec	Digital Earth Australia
AWI-Lake_Constance	EnMAP DESIS S-2 S-3	pre-launch commissioning operational	BOA reflectance IOP water constituents (Chl-a, TSM)	AWI	DLR national funding
AWI-Polarstern	SeaWiFS/OrbView MERIS/ENVISAT	pre-launch commissioning	BOA reflectance IOP (diffuse attenuation)	AWI	AWI national funding

	MODIS/AQUA MODIS/TERRA VIIRS OLCI SCIAMACHY/ENVISAT GOME-2/METOP OMI/AURA S-3/TROPOMI	operational	water constituents (Chl-a) phytoplankton functional types		
CHIME-SBG	CHIME SBG PRISMA	pre-launch operational	BOA reflectance higher-level priority products (L2B)	ESA NASA University of Zurich (UZH)	ESA NASA UZH
DLR-DESIS	DESIS	operational	BOA reflectance L3 fractional cover	DLR Earth Observation Center	DLR
DLR-Sentinel2	S-2 L8 DESIS	operational	BOA reflectance water leaving reflectance vertical column AOT spectrum vertical column water vapour and ozone contents	DLR Earth Observation Center	DLR
DLR-Shipborne field campaigns	S-2 S-3 DESIS PRISMA EnMAP	operational pre-launch	BOA reflectance vertical column aerosol optical thickness (550 nm) vertical column water vapor (WV) ozone concentration bathymetry water constituents (Chl-a, TSM)	DLR Earth Observation Center	national funding DLR

			IOP (CDOM absorption (440 nm))		
UTARTU-EMI	S-2 S-3	commissioning	radiance irradiance absorption attenuation backscattering water constituents concentration	EMI	variable
FlexSense	FLEX S-3	pre-launch operational	BOA reflectance solar induced fluorescence	FZJ	ESA
ForDroughtDet	S-2 ZiYuan-3	operational	BOA reflectance	TU Munich	national funding
INPE-Validation of Satellite Detected Vegetation Fires	Aqua and Terra MODIS S-NPP and NOAA-20 VIIRS NOAA-18, NOAA-19, METOP-B, AVHRR GOES-16, ABI MSG-03, SEVIRI.	operational	radiance (TIR)	INPE	INPE NOAA
JECAM	S-1 RadarSat-2 S-2 L7 L8	operational	LAI wet biomass dry biomass (of leaves = leave, haulm, ears) leaf area leave water content dry matter plant height	Halle Univ. (D) DLR GFZ Wuerzburg Univ. (D) Jena Univ. (D)	national funding DLR

			fractional vegetation cover proportion of senescent material leaf chlorophyll content phenological stage orientation of planting rows soil moisture soil samples soil roughness aerosol optical thickness column of water vapor absolute spectral reflectance factors		
MRI KU	S-1 S-2 S-3 L8 PRISMA VENµS	operational commissioning	BOA reflectance cyanobacteria bloom index	Klaipeda University	EU H2020, 7FP ESA national funding
MONOCLE	S-2 S-3	operational	L2a water-leaving reflectance / drone-based water-leaving reflectance	PML VITO	EU H2020
MOSES-REEBUS Eddy Hunt	S-3 OLCI & SLSTR Aqua MODIS VIIRS	operational	BOA reflectance Radiance, irradiance, remote-sensing reflectance IOP (CDOM absorption (440 nm)) water constituents (Chl-a) S-3-SLSTR Level-2 sea surface temperature	Helmholtz-Zentrum Hereon	Helmholtz Association (MOSES, REEBUS)

NASVF	S-2	operational	BOA reflectance radiance	maitec	various
PRIMEWATER	S-3 OLCI	commissioning operational	BOA reflectance	CNR-IREA	EU H2020
Priscav	PRISMA	operational	BOA reflectance	CNR	ASI
PRISCAV-water Garda	PRISMA	commissioning operational	BOA reflectance	CNR-IREA	ASI CNR
PRISCAV-water Trasimeno	PRISMA S-2 MSI S-3 OLCI	commissioning operational	BOA reflectance	CNR-IREA	EU H2020 CNR
Sen3Exp	S-3	pre-launch	Instrument configuration and processing algorithms	Brockmann Consult	ESA
SU	S-2 S-3	commissioning operational	radiance irradiance turbidity IOP (attenuation, backscattering, CDOM absorption) water constituents (Chl-a, TSM) transparency	Stockholm University	SNSA ESA EU
SurfSense	LSTM	pre-launch	Land Surface temperature (LST) Land Surface Emissivity (LSE)	FZJ	ESA
SYKE	S-2 S-3 L8	operational	water leaving reflectance water constituents temperature total absorption	SYKE	national funding EU H2020

			total scattering		
UTARTU-TO	S-2 S-3	operational	water leaving reflectance water constituents (Chl-a, TSM, CDOM)	University of Tartu, Tartu Observatory	national funding
Western States UAS Fire Imaging Missions	NASA Aqua-MODIS and Terra-MODIS; NOAA Suomi NPP-VIIRS	Operational	BOA reflectance and emitted energy in 16-channels thermal emittance in MWIR & LWIR (high & low gain) for fire energy rates	NASA-Ames Research Center & CA. State University	NASA
WSN Sentinel-2 Val	S-2	operational	BOA reflectance	UFZ	UFZ

Used platform

Table 4: Information about used platform

Campaign name	Platform	Operator	Related network / infrastructure
AMT	research vessel	depends on the campaign	
ASTER/HISUI vicarious calibration	ground	AIST	
Australian continental surface reflectance validation	ground	CSIRO in collaboration with UQ, U Adelaide, U Woollongong, U Melbourne & Maitec	TERN
AWI-Lake_Constance	boat	Institut für Seeforschung/ Landesanstalt für Umwelt Baden-Württemberg (ISF/LUBW)	
AWI-Polarstern	research vessel	AWI for RV Polarstern and RV Heincke; Leitstelle Deutsche Forschungsschiffe: RV Sonne and RV Maria S. Merian;	S3VT-OC (2013-) DFG-project with Transregio 172 $(AC)^3$ "Feedback of Arctic Amplification on ocean color" (2016-2023)

		Murmansk Marine Biological Institute for RV "Dalnie Zelentsy"	HGF infrastructure project FRAM - Task 4.3 "Remote Sensing and Biooptics" (2014-2022) ESA project S5POC (2019-2021) EU-CSA project PORTWIMS (2018-2021) ACRI-ST-project OLCI-PFT (2018-2020) DFG project PHYSYN (2015-2019) CSC PhD project "Assessing the impact of climate change on Arctic phytoplankton" (2015-2019) ESA project SynSenPFT (2014-2016)
CHIME-SBG	aircraft ground	Dynamic Aviation Group Inc	ARES EUFAR CHIME MAG
DLR-DESIS	aircraft	DLR	OpAiRS EUFAR
DLR-Sentinel2	aircraft ground boat	DLR	OpAiRS
DLR-Shipborne field campaigns	research vessel boat	diverse	TypSynSat MONEO-WET Collaboration: AWI, LUBW, CENAT (Costa Rica)
UTARTU-EMI	boat	EMI	
FlexSense	aircraft	CzechGlobe	FLIS EUFAR
ForDroughtDet	aircraft	DLR	

		Uni Trier	
INPE-Validation of Satellite Detected Vegetation Fires	drone	INPE	NOAA NESDIS OSPO Laboratório de Aplicações de Satélites Ambientais (LASA)
JECAM	ground	Halle Univ. (D) DLR GFZ Wuerzburg Univ. (D) Jena Univ. (D)	AgriSens - DEMMIN 4.0 DEMMIN (Durable Environmental Multidisciplinary Monitoring Information Network)
MRI KU	ircraft boat	DLR depends on campaign	
MONOCLE	drone	VITO	Geo Aquawatch
MOSES-REEBUS Eddy Hunt	aircraft research vessel	Aachen University of Applied Sciences University of Hamburg	
NASVF	drone	maitec	Digital Earth Australia - DEA Analysis Ready Data Phase 1 Validation Project
PRIMEWATER	aircraft boat	CNR-IREA CGR Italy	H2020-PRIMEWATER
Priscav	aircraft	CzechGlobe	FLIS EUFAR
PRISCAV-water Garda	boat	CNR-IREA	ASI-PRISCAV
PRISCAV-water Trasimeno	ground	CNR-IREA	ASI-PRISCAV, H2020 EOMORES
Sen3Exp	aircraft	INTA	INTA_ARS
SU	research vessel	Stockholm University	

SurfSense	aircraft	CzechGlobe	FLIS EUFAR
SYKE	boat	SYKE and consultants	
UTARTU-TO	boat	University of Tartu	
Western States UAS Fire Imaging Missions	aircraft	NASA Armstrong Flight Research Center (AFRC)	USDA Forest Service National Infrared Operations (NIROPS) National Interagency Fire Center AMS-Wildfire data in Operational Fire and Smoke Applications
WSN Sentinel-2 Val	ground	UFZ	

Used instrumentation

Table 5: Information about employed instrumentation

Campaign name	Instrument type	Specification	Measured quantity	Quality information / uncertainty evaluation	Operator
AMT	spectrometer	Satlantic Hyper-OCR	radiance	Calibrated yearly, with temperature dependency and angular response	PML
ASTER/HISUI vicarious calibration	field spectrometer	ASD	reflectance		AIST
Australian continental surface reflectance validation	field spectrometer	ASD	DN radiance surface reflectance	Protocol endorsed by CEOS WGCV, see link at http://calvalportal.ceos.org/methods-guidelines-good-practices and https://doi.org/10.25919/5c9d0ba9e9c12	CSIRO in collaboration with UQ, U Adelaide, U Woollongong, U Melbourne & Maitec

AWI-Lake_Constance	radiometer flow cell for absorbance measurements Integrating Cavity Absorption Meter	TriOS Ramses LWCC (Liquid Waveguide Capillary Cell) QFT-ICAM (Quantitative Filter Technique – Integrating Cavity Absorption Meter)	remote sensing reflectance absorption of phytoplankton, non-algal particles, colored dissolved organic matter, total absorption Chlorophyll-a concentration Total Suspended Matter concentration	IOCCG protocols for radiometry and LWCC, QFT as in Röttgers et al. (2016)	n.a.
AWI-Polarstern	radiometer flow cell for absorbance measurements Integrating Cavity Absorption Meter ACS transmission and absorptionmeter HPLC fluormetry	TriOS Ramses LWCC (Liquid Waveguide Capillary Cell) QFT-ICAM (Quantitative Filter Technique – Integrating Cavity Absorption Meter) ACS transmission and absorptionmeter HPLC fluormetry	remote sensing reflectance absorption of phytoplankton, non-algal particles, colored dissolved organic matter, total absorption chlorophyll-a concentration distinct phytoplankton groups' chlorophyll-a concentration Diffuse Attenuation	IOCCG protocols for radiometry, ACS transmissiometer, and LWCC, QFT as in Röttgers et al. (2016)	n.a.
CHIME-SBG	imaging spectrometer	AVIRIS-NG	radiance	regular calibration	NASA/JPL
CHIME-SBG	field spectrometer	ASD Field Spec Pro + others	reflectance	annual calibrations in laboratory	Site PIs
DLR-DESIS	imaging spectrometer	HySpex	radiance	calibrated at least 1/year uncertainties based on laboratory calibration	DLR
DLR-Sentinel2	imaging spectrometer	HySpex	radiance	calibrated at least 1/year	DLR

				uncertainties based on laboratory calibration	
DLR-Sentinel2	field spectrometer	SVC HR1024i	radiance	White disk	DLR
DLR-Sentinel2	field spectrometer	MCS3	radiance	annual calibration	DLR
DLR-Sentinel2	sun photometer	Microtops Calitoo	direct solar irradiance	every 3 years	DLR
DLR-Shipborne field campaigns	spectrometer sun photometer	Ocean Optics Spectrometer System (OOSS): Self-developed measurement system consisting of three Ocean Optics STS-VIS miniature spectrometers Microtops II sun photometers	upwelling radiance downwelling irradiance remote sensing reflectance vertical column aerosol optical thickness, water vapour and ozone content secchi depth CDOM absorption AOT spectra vertical column water vapour content vertical column ozone content	ISO-certified laboratory at DLR radiometric calibration before each campaign spectral calibration is checked before each campaign (is usually stable) Quality control protocol from manufacturer, uncertainty evaluation available	DLR
UTARTU-EMI	spectrophotometer	TriOS Ramses WET Labs AC-s, BB3, VSF-3 Perkin Elmer Lambda 35 UV/VIS	radiance irradiance absorption attenuation backscattering water constituents concentrations	annual calibration	EMI

FlexSense	imaging spectrometer	HyPlant	radiance	annual calibration	FZJ
FlexSense	imaging spectrometer	TASI-600	Radiance (TIR)	annual calibration	CzechGlobe
FlexSense	laser scanner	Riegl LMS Q780	Vegetation structure	annual calibration	CzechGlobe
ForDroughtDet	imaging spectrometer	HySpex	radiance	annual calibration	DLR Uni Trier
ForDroughtDet	digital camera system	3K system	aerial image Digital elevation model (DEM)	Accuracy assessment of the DLR 3K camera system (Kurz F.)	DLR
INPE-Validation of Satellite Detected Vegetation Fires	thermal camera	FLIR portable cameras (FLIR Zenmuse XT); home-built radiometers	emitted radiance	NA	INPE-Wildfire Program
JECAM	LAI measuring devices chlorophyll measuring devices soil moisture measuring device sun photometer field spectrometer	LAI 2000 (LiCor) LAI 2200 (LiCor) LI3100 (LiCor) SPAD-502+ Chlorophyllmeter HH2 moisture meter Microtops Sunphotometer II ASD FieldSpec 3, SVC HR1024	Leaf Area Index Chlorophyll content Soil moisture Atmospheric composition reflectance	Measurement protocols calibration by manufacturer	Halle Univ. (D) DLR GFZ Wuerzburg Univ. (D) Jena Univ. (D)
MRI KU	imaging spectrometer	The Airborne Prism Experiment (APEX)	water leaving reflectance	annual calibration	VITO
MRI KU	Field spectrometer	WISP-3 Spectral Evolution SE	radiance		WaterInsight b.v, Quantum Design s.r.l.

		Satlantic			CNR-IREA
MONOCLE	RGB and multispectral frame camera	DJI Phantom 4 pro RGB camera Micasense RedEdge-M + DLS-1 (Downwelling Light Sensor)	radiance	calibrated in 2018 NERC FSF lab	VITO
MOSES-REEBUS Eddy Hunt	imaging spectrometer thermal camera	HySpex FLIR Thermal Camera TriOS-Ramses Cubert Camera HPLC-Pigment of discrete water samples	radiance sea surface temperature inherent optical properties of water samples concentrations of water constituents	Rrs estimates and HPLC according standard protocols uncertainty evaluation available calibration regular	
NASVF	point spectrometer	Ocean Insight STS-VIS spectroradiometer	Ocean Insight STS-VIS spectroradiometer	annual calibration	maitec
PRIMEWATER	hand-held spectroradiometer	WISP-3 on boat	radiance irradiance sky-radiance SpectralonTM radiance	annual, from the instrument provider	WaterInsight b.v.
PRIMEWATER	hand-held spectroradiometer	Spectral Evolution SE 3500 on boat	radiance	annual, from the instrument provider	Quantum Design s.r.l.
PRIMEWATER	Fixed autonomous JB-hyperspectral spectroradiometer	JB-Hyperspectral ROX on platform (Flame spectrometer from Ocean Optics (350- 950 nm))	radiance	annual, from the instrument provider	JB Hyperspectral Device GmbH

PRIMEWATER	imaging spectrometer	Hyspex VNIR 1800 on aircraft	radiance	several times a year prior to acquisition campaigns, from the instrument provider	Compagnia Generale Riprese Aeree s.p.a. Italy
Priscav	imaging spectrometer	CASI-1500	radiance	annual calibration	CzechGlobe
Priscav	imaging spectrometer	SASI-600	radiance (SWIR)	annual calibration	CzechGlobe
PRISCAV-water Garda	field spectrometer	WISP-3 400-800 nm Spectral Evolution SE 3500, 350-2500 nm	radiance irradiance sky-radiance spectralonTM radiance	annual calibration, from the instrument provider annual calibration, from the instrument provider	WaterInsight b.v Quantum Design s.r.l.
PRISCAV-water Trasimeno	fixed position autonomous radiometers	WISPStation	radiance irradiance sky-radiance	annual, from the instrument provider	WaterInsight b.v.
Sen3Exp	imaging spectrometer thermal multispectral scanners	AHS CASI SASI	radiance	Specific laboratory calibration for the campaign	INTA
SU	spectrophotometer sonde fluorometers	TACCS WET Labs AC-9 WET Labs VSF-3 Hach Lange 2100QIS LICOR SAIV/AS CTD, SeaPoint turbidity sonde TriLux Fluorometer sonde (Chelsea Instruments) Perkin Elmer 650S	radiance irradiance Kd490 absorption attenuation backscattering turbidity kdPAR PE, PC & Chl-a	annual calibration, uncertainties follow MERMAID protocol	Stockholm University, Baltic Sea Centre, Swedish Coast Guards and Umeå University, SLU

			concentrations of Chl-a & CDOM SPM		
SurfSense	imaging spectrometer	TASI-600	radiance (TIR)	annual calibration	CzechGlobe
SYKE	field spectrometer flow-through devices	ASD Pro Jr, AC-9 fluorometers, turbidity meter, fDOM, RFLEX system (Trios spectrometers) onboard an Alg@line ship	Water leaving radiance downwelling irradiance sky radiance water samples for lab analyses water constituents based on flow-through sensors temperature atot and btot	ASD: last calibration in 2017 AC-9: last calibration in 2017	ASD, RFLEX: SYKE, AC-9: Luode Consulting
UTARTU-TO	spectrophotometer	TriOS Ramses Hitachi U-3010	radiance irradiance absorption attenuation water constituents' concentrations	Calibration twice per year for TriOS RAMSES	University of Tartu
Western States UAS Fire Imaging Missions	multispectral imaging spectrometer	Autonomous Modular Scanner – Wildfire multispectral scanner (Dadaelus AADS-1268); Spectral Range: 412nm - 11.5µm (Center Wavelength); Resolution: 5m - 50m (variable with altitude)	VIS/NIR/MWIR/LWIR spectral and emitted radiance	Multiple spectral / thermal calibrations annually. Application of NIST-traceable characterizations of airborne imaging devices	NASA (Ames) Airborne Sensor Facility

WSN Sentinel-2 Val	mobile wireless sensor network	developed system of UFZ; 4 channel sensor (665nm, 710nm, 740nm, 865nm => comparable to S-2 channels)	reflectance	annual laboratory calibration	UFZ

Cal/Val site

Table 6: Information about Cal/Val sites

Campaign name	Location	Spatial extent	Acquisition date	Measurement frequency
AMT	Atlantic Ocean	12 000 km transect	autumn	yearly
ASTER/HISUI vicarious calibration	Railroad Valley Playa	90mx60m	summer	yearly
Australian continental surface reflectance validation	Pinnacles, WA Lake George Dookle Blanchetown, SA Lake Lefroy, WA Fowler's Gap, NSW Winton, QLD Warrabin, QLD Mitchell Downs/ Longrreach, QLD Lake Hume Lucinda Jetty Turmbarumba, NSW	100m x 100m on each site	throughout the different seasons	yearly? 2018/2019 (50+ datasets)

	Dharawal Nature Reserve, NSW Narrabundah Oval, ACT Litchfield, NT JF O'Grady Memorial Park, QLD			
AWI-Lake_Constance	Lake Constance		March and September 2020	one-time
AWI-Polarstern	Global Ocean		Since Nov. 2007	yearly
CHIME-SBG	Across Europe	different depending on campaign	May-June	yearly
DLR-DESIS	Camarena, Spain	110 km²	08/2020	one-time
DLR-Sentinel2	States Brandenburg and Mecklenburg-Vorpommern (Germany)	Up to 100 km2	04.05.2018 22.08.2019 01.08.2020 06.08.2020	yearly
DLR-Shipborne field campaigns	2018: Terraba Sierpe river system (Costa Rica) 2019: Terraba Sierpe river system (Costa Rica) 2020: Lake Constance (Germany)	2018: ~100 km² 2019: ~100 km² 2020: 10 km²	2018: 3 subsequent days in November 2019: 7 days within 2 weeks in March 2020: 4 subsequent days in March, 3 subsequent days in September	one-time
UTARTU-EMI	Estoanian coastal areas and lakes	variable	variable	project-dependent
FlexSense	Italy, Grosseto; Germany, Julich; France, OHP; Spain, Majadas; Switzerland, Laegeren	20 km²	summer	one-time

ForDroughtDet	KROOF Kranzberger Forst Freising Gramschatzer Wald Traunsteiner Stadtwald	50 km²	20150917, 20160824, 20180508; 20180605; 20180820 20180507 20180508	one-time
INPE-Validation of Satellite Detected Vegetation Fires	Central and Southeast Brazil	plots of a few km2 in different biomes of the country	fire season	biannual
JECAM	Demmin, Germany	Variable (multiple agricult. Fields)	Since 2018	yearly 4-5 time per vegetation period
MRI KU	Lithuanian coastal waters and lakes	various	March-October	yearly
MONOCLE	Lake Balaton, Hungary	+/- 32km² (approximated)	One week of data acquisition at different locations around Lake Balaton (Hungary) in 2019	one-time
MOSES-REEBUS Eddy Hunt	Sea area around the Cape Verde Islands, North Atlantic Ocean		November-December 2019	one-time comparable campaigns are planned in future
NASVF	North Australian Satellite Validation Facility (NASVF) - Savanna Supersite, Litchfield National Park, Northern Territory, Australia	0.01 km2	2018, 2019, on-going, bi-monthly capture planned	yearly bi-monthly planned
PRIMEWATER	Lake Mulargia, Italy	124 km²	24 September 2020	one-time
Priscav	Italy, Grosseto	20 km²	summer	yearly

PRISCAV-water Garda	Lake Garda, Italy	370 km^2	on PRISMA overpass scheduling basis	about tri-monthly
PRISCAV-water Trasimeno	Lake Trasimeno, Italy	128 km^2	since April 2019 from sunrise to sunset	every 15 minutes
Sen3Exp	Specific test sites in San Rossore (IT), Acqua Alta Buoy (IT), Boussole Buoy (FR), Barrax (ES)	San Rossore (IT): ≈350 km2 Acqua Alta Buoy (IT): ≈600 km2 Boussole Buoy (FR): ≈480 km2 Barrax (ES): ≈160 km2 Total: ≈1600 km2		one-time
SU	Swedish Coast, Baltic Sea	350 000	variable	biannual
SurfSense	Italy, Grosseto	20 km^2	Summer, 10 days	one-time
SYKE	Finnish coast; Baltic sea between Finland and Germany	10-20km transects; 1100 km transects	Variable; Twice per week May-September	Random dates from 2017 onward; Yearly
UTARTU-TO	30 lakes in Estonia	20 000	2018-2020	yearly Minimum 3 times per vegetation period
Western States UAS Fire Imaging Missions	Western United States	Random-located fires in western U.S. ranging from (N-S) Canada border to Mexico border, and (E-W) Colorado to Pacific Ocean;	Collected airborne instrument imagery from 2006-2010	yearly During fire season
WSN Sentinel-2 Val	Demmin	1 km^2	2016	one-time

Data handling

Table 7: Information about data handling

Campaign name	Data availability	Data access	Publications
AMT	freely available (up to 2005)	upon request https://www.amt-uk.org/Data	
ASTER/HISUI vicarious calibration	freely available	upon request	Tsuchida et al. 2020
Australian continental surface reflectance validation	available	We have had to change to a different data portal because of closure of the old one. We can provide you with the new portal details when the data are all transferred.	Ong et al. 2018 Thankappan et al. 2019
AWI-Lake_Constance	available (after publication)	PANGAEA	Tilstone et al. 2020
AWI-Polarstern	available (after publication)	PANGAEA	Liu et al. 2018 Tilstone et al. 2020
CHIME-SBG	available	upon request https://avirisng.jpl.nasa.gov/dataportal/	Meiler et al. 2020 Hueni et al. 2020
DLR-DESIS	project-internal	https://www.dlr.de/opairs	
DLR-Sentinel2	freely available	upon request HySpex: https://www.dlr.de/opairs Ground-based: upon request	
DLR-Shipborne field campaigns	freely available (after publication)	upon request	
UTARTU-EMI	agreement with PI	https://water.to.ee	
FlexSense	available	upon request	Cogliati et al. 2019

		http://olc.czechglobe.cz/en/flis-2/	Siegmann et al. 2019
ForDroughtDet	by agreement	case dependent	
INPE-Validation of Satellite Detected Vegetation Fires	freely available	upon request	Schroeder et al. 2019
JECAM	project restriction during project life cycle	https://www.agrisens-demmin.de http://jecam.org https://www.tereno.net	
MRI KU	available	upon request https://eomores.eu/	Vaičiūtė et al. 2021 Dabuleviciene et al. 2020
MONOCLE	freely available (soon)	https://monocle.eofrom.space	De Keukelaere et al. 2019 Burggraaf et al. 2019
MOSES-REEBUS Eddy Hunt	partly freely available	PANGAEA	
NASVF	freely available	upon request	
PRIMEWATER	freely available (in-situ) available (airborne data)	upon request	
Priscav	available	upon request http://olc.czechglobe.cz/en/flis-2/	
PRISCAV-water	freely available	upon request	
PRISCAV-water Trasimeno	freely available	upon request	
Sen3Exp	available (for R+D projects)	following the rules defined in the ESA campaigns site https://earth.esa.int/web/guest/pi-community/apply-for-data/campaigns	

SU	available (MERMAID + additional data)	upon request [MERMAID - Meris Matchup In-Situ Database (acri.fr)]()	Lavigne. et al. 2021 Kratzer et al. 2021
SurfSense	available	upon request http://olc.czechglobe.cz/en/flis-2/	
SYKE	not freely available		
UTARTU-TO	agreement with PI	https://water.to.ee	
Western States UAS Fire Imaging Missions	Available	upon request	Ambrosia et al. 2011 Marlin 2009 Peterson and Wang 2013
WSN Sentinel-2 Val	available	upon request	

Further developments

Table 8: Further developments

Campaign name	Instrumentation	Methodology
Australian continental surface reflectance validation	Permanent automated radiometric instrumentations will be available at Pinnacles soon	
AWI-Polarstern AWI-Lake_Constance		work on an above water radiometry system together with DLR-IFM
DLR-Shipborne field campaigns	Unmanned surface vehicle (LakeRover)	for improved measurements of remote sensing reflectance which are less disturbed than measurements from a ship (keeping position, shadows, structures affecting irradiance, foam, bubbles). The USV simplifies logistics and increases flexibility compared to vessels and boats, and it improves studying the spatial heterogeneity with much more data points. It will be equipped with new spectrometers, an echo

		sounder for accurate depth measurements, cameras above and under water, a temperature profiler, and an underwater spectrometer with active light source for measuring bottom reflectance.
UTARTU-EMI	Automated buoy measurements for optical data	
ForDroughtDet	Cranebasket mountable Goniometer system UltraLight low-cost system for multiseasonal imageing	
MONOCLE	Collect new datasets, including with MicaSense Dual camera (10 spectral bands) and DLS-2 (Downwelling Light Sensor). The DLS-2 distinguished direct from indirect irradiance.	Optimize MAPEO-Water processing workflow for improved product quality.
PRISCAV-water	Installation of a fixed position autonomous radiometer within the context of the H2020 HYPERNETS project	
SU		algorithm development, development of climate change indicators, eutrophication indices, further research on Inherent Optical Properties of the Baltic Sea is required to secure the retrieval of reliable level 2 products in highly absorbing waters coupled with only moderate concentrations of suspended sediments.
Western States UAS Fire Imaging Missions	Instrument has been updated with new optics components and S/W by USFS / NIFC NIROPS	AMS sensor instrument transferred to US Forest Service / NIFC - National Infrared Operations Program (NIROPS) in 2013 for operational use on USFS manned aircraft to support fire imaging for wildland fire management objectives, and other fire research support.

Conclusion

- 29 campaigns are presented dealing with optical missions. They are related to multispectral, hyperspectral and thermal satellite missions.
- The campaign type varies from large-scale campaigns (e.g., AWI Polarstern) to single one-time measurements.
- Campaigns were/will be conducted during all satellite mission phases, but most of them were organized during the operational phase. One example is the aerial survey of active wildfires. Pre-launch activities are mainly carried out for future hyperspectral missions. One example are the CHIME-SBG campaigns, whereby these also include the data of the already launched PRISMA sensor.
- The data that is validated during the campaigns is mainly BOA reflectance (surface reflectance or water leaving reflectance) or radiance. On this basis, often further products are derived and compared. Higher level products do concern land, water and fire specific objectives.
- PIs of the campaigns are related to the academic environment, research centres or space agencies.
- The funding of the campaigns is often a mixture of national funding, ESA or EU funding and internal funding.
- The presented campaigns make use of all kinds of different platforms. Since approximately half of the activities are over water surfaces, 12 campaigns involve research vessels and boats.
- For almost all campaigns, imaging and/or field spectrometers are used to measure radiance. Many different instruments are in use to perform specific water measurements or vegetation related analysis. Most instruments are “off-the-shelf”. One exceptional example of an instrument specifically designed for the validation of a mission is the HyPlant system (used for FLEX).
- Almost all utilised instruments are calibrated/characterized on a yearly basis.
- The campaigns considered do cover survey areas all over the world. Only a few identified Cal/Val sites (e.g., Demmin (D), Railroad Valley (US)) are used as study area. Within Australia, there are well defined sites which are used for their nationwide continental surface reflectance validation.
- About half of the campaigns are conducted on a regular basis (e.g., yearly).
- Most of the data is (freely) available upon request, and for some campaigns, data can be accessed via a data portal.
- The installation of permanent measurement units is foreseen for some of the surveyed sites.
- In the future, the increase use of drones shall complement the acquisition of data.

Highlight

Concerning the campaign-based data acquisition to validate optical mission products, the concept of the "Australian continental surface reflectance validation" could serve as reference for a coordinated validation effort. Within this collaborative national field data collection campaign standardized measurement protocols comprising field instrument calibration, sampling strategy and data management have been developed.

2.3.2 Altimetry missions

General Information

Table 9: General information about campaign

Campaign name	Satellite mission	Mission phase	Cal/Val data	PI affiliation	Funding
CRYOVeX	CRYOSAT-2	Operational phase	L1B/waveforms, L1B/altitude	ESA + Scientific Institutions (not always the same)	ESA
SUMOS	CFOSAT (could also benefit to S-3, S6 and S-1)	Operational phase	L1/radar waveforms L2/wave spectrum L2/wind fields	LATMOS (CNRS)	CNES, IFREMER
VorteX.io	S-3, S6, Jason-3 (and even optical missions for 3D reconstruction)	Operational and commissioning phases	L2/water surface height (proved since 2019) L2/surface velocities L2/sea level height (experimental in 2021)	Depending on the contracts	Depending on the contracts (recently, CNES and ESA for Jason-3 and Sentinel-3 activities)
Corner reflector	S-3	Operational phase	L1/radar waveforms, L2/height	CNES	CNES

Used platform

Table 10: Information about used platform

Campaign name	Platform	Operator	Related network / infrastructure
CRYOVeX	Twin-Otter	Norlandair for DTU Space/BAS/AWI	

SUMOS	ATR42 (plane)	SAFIRE	
SUMOS	Atalante (research vessel)	IFREMER	
VorteX.io	Flying drone	VorteX.io	
Corner reflector	Ground device	CNES	

Used instrumentation

Table 11: Information about employed instrumentation

Campaign name	Instrument type	Specification	Measured quantity	Quality information / uncertainty evaluation	Operator
CRYOVeX	Ku-band radar (ASIRAS)	Radar altimeter SARIn in Ku-band	Radar waveforms	Calibrated over Corner Reflectors at each campaign	ESA
CRYOVeX	Ka-band radar (KAREN)	Radar altimeter SARIn in Ka-band	Radar waveforms	Calibrated over Corner Reflectors at each campaign	MetaSensing
CRYOVeX	ALS (near infrared laser)	NIR Laser scanner Riegl Q240i	Range	Flights over runway for ALS	DTU Space
SUMOS	Ku-band scatterometer (KuROS)	(airborne) scatterometer with two antennas (~15° and ~30°) and dual polarization Full rotation	Wave spectrum, wind fields, Radar modulations	Calibrated at each campaign with flights over corner reflector Antennas characterized in anechoic chamber	LATMOS
SUMOS	Ka-band radar (KaRADOC)	(airborne)	Power	Calibration at each campaign	IETR

		Ka-band radar for power and Doppler measurements at small incidence angle	Doppler (for velocity measurement)		
SUMOS	X-band radar	(shipboard) Marine radar	Directional frequency-wavenumber spectra (waves of 20m to 500m)	Calibrated using the method of McCann and Bell (2018)	HZG
SUMOS	Stereo video	(shipboard) Video camera	3D reconstruction of the ocean	Calibration by placing a large checkerboard pattern in the field of view (Bouget, 2005)	IFREMER
SUMOS	Polarimetric imagery	(shipboard) Single camera mounted with the stereo system (based on FluxData FD1665 polarimetric imager)	Surface slopes statistics	Calibration by placing a large checkerboard pattern in the field of view (Bouget, 2005)	IFREMER
SUMOS	Wide FOV camera	(shipboard) Single camera	Images of breaking waves and whitecap coverage statistics		IFREMER
SUMOS	Drifting wave buoy	(Launched in water) SOFAR spotter GPS-based sensor wave buoys Small buoy (31cm height), position sending, solar panels	First five Fourier coefficients giving energy spectra, direction, and spectral spreading., surface current	Calibrated (see Herbers et al. 2012)	IFREMER
SUMOS	FLAME buoy	(Launched in water) Flux Air-Mer spar buoy	Long-period wave frequency spectra, wind speed and direction		IFREMER

SUMOS	Trefle	(Launched in water) Surface drifting buoy with downward-looking ADCP	Surface current		IFREMER
VorteX.io	LiDAR	8 beams VTX-1 light weight altimeter	Water surface height	Calibrated at each deployment Comparison with in-situ measurements performed by GNSS on a specific point.	VorteX.io
VorteX.io	MPx	8 MPx (PIR, G, B)	Images of the context		VorteX.io
VorteX.io	Micro-station	Automatic, connected and remote controlled in-situ static station	Water surface height (at the time of a satellite pass), water surface speed and pictures of the river	Calibrated at each deployment	Vortex.io
Corner reflector	Trihedral	Mechanical device with fixed dimension	Range	Accurate GPS positioning when deployed	CNES

Cal/Val site

Table 12: Information about Cal/Val sites

Campaign name	Location	Spatial extent	Acquisition date	Measurement frequency
CRYOVeX	Arctic or Antarctic	~10 000 km	From 2004 to 2018	Quasi annual since 2012
SUMOS	Gascogne Golfe	223 000 km2	Feb 2021	One time but the radar instruments KARADOC and

				KuROS have been used in other campaigns
VorteX.io	Deployment on contracts over rivers	Several km (e.g. 60 km along the Rhine river)	From 2019	On-demand
Corner reflector	Deployment near Toulouse (France) under altimetric tracks	Very local	Several acquisitions in 2020 and 2021	On-demand

Data handling

Table 13: Information about data handling

Campaign name	Data availability	Data access	Publications
CRYOVeX	Freely available	Downlable at ESA campaign archives https://earth.esa.int/eogateway/search?text=&category=Campaigns	
SUMOS	Available on-demand	http://kuros.projet.latmos.ipsl.fr/fr/index.php (for KuROS data) Contact IFREMER and IETR for other measurements	
VorteX.io	Contract based	https://api.vortex-io.report/api/docs	
Corner reflector	Restricted access	N/A	

Further developments

Table 14: Further developments

Campaign name	Instrumentation	Methodology
CRYOVeX	Need for a new Ku-Ka bands radar for CRISTAL	Constant improvements of algorithms to address new scientific topics
VorteX.io	Instruments for water surface temperatures and water turbidity	Constant improvements of algorithms
Corner reflector	Tests on other locations (difficulties to determine an appropriate site free of water responses)	

Conclusion

- The campaigns for the altimetry missions have all been used for the validation phases of the spaceborne mission. The calibration of the instruments does not require any specific campaign. Thus, these are oriented to the improvement of the algorithms and the characterization of the instrument systematic bias. They are also used to validate instrument concepts before or during the developments.
- We have listed three campaigns: CRYOVeX linked with CRYOSAT, SUMOS linked with CFOSAT and also all altimetry missions in general, and VorteX.io, new means for hydrology applications.
  - The CRYOVeX campaigns happen on regular basis either in Antarctic or in Artic regions. It supports the CRYOSat-2 mission and prepares for the CRISTAL mission.
  - The VorteX.io drone solution can be deployed over rivers. An extension to ocean is under study through an R&D contract with CNES. It has a strong potential to validate L2 Water Surface Height of altimetry products (S-3, S-6).
  - The SUMOS campaign has been deployed in the Golfe of Gascogne for the CFOSAT mission. It involves two airborne radar systems, KuROS and KaRADOC.
    - KuROS has been especially designed to validate the CFOSAT instruments. It has been involved in many campaigns since 2013: the HYMEX ones in 2013 and 2015 over the Golfe of Lion (Mediterranean Sea), the PROTEUVS in 2013 over Iroise Sea and the BBWAVES in 02015 over the Iroise Sea as well.

Figure 2 : KuROS antennae on-bord the SAFIRE ATR42. © LATMOS/CNRS.

    - The KaRADOC instrument has been designed to increase our knowledge on Ka-band backscattering process at low incidence angles. Originally, it focuses only on power for SWOT and it has been extended to Doppler measurements to prepare the SKIM proposal to EE9. The in-situ KaRADOC, also named SWALIS in its SWOT shape, can fly on-board a plane or an ULM (ultra-light motorized plane). This has the great advantage to simply the filght authorization. It is regularly used on-board a ULM belonging to IETR members to acquire data over lakes.

- The KUROS4SKIM campaign, funded by ESA, was hold late 2018 to demonstrate the potential of SKIM. It has embarked KuROS and KaRADOC and was completed by in-situ deployments provided by IFREMER and SHOM.

- We also have listed attempts of range validation using passive corner reflector. For altimetry, due to the observation geometry, the corner reflector is not always observed. As soon as there is a water area in the same ranges, the corner reflector signal is not seen. One should find a local summit at the nadir track to maximize the backscattering from the corner reflector. This is not always easy but it is worth it. Such device is very cheap and relatively simple to de deploy.
- The in-situ deployments of the SUMOS campaign are the largest we had recently, compared with the HYMEX, PROTEVS and BBWAVES campaigns. For this reason, we have chosen to describe the SUMOS campaign. It provides a good overview of the IFREMER in-situ means. It can be completed with Zodiac boats. They have the great advantage to be easily available with short term notice, contrary to the Atlante research vessel. The Atlante must be booked more than 1.5 years in advance. This is a strong constraint for CAL/VAL activities. However, zodiacs, and even smaller research vessels are not well suited to working even half a CFOSAT swath-width offshore. This limitation is faced for most of the altimetry and scatterometry concepts.

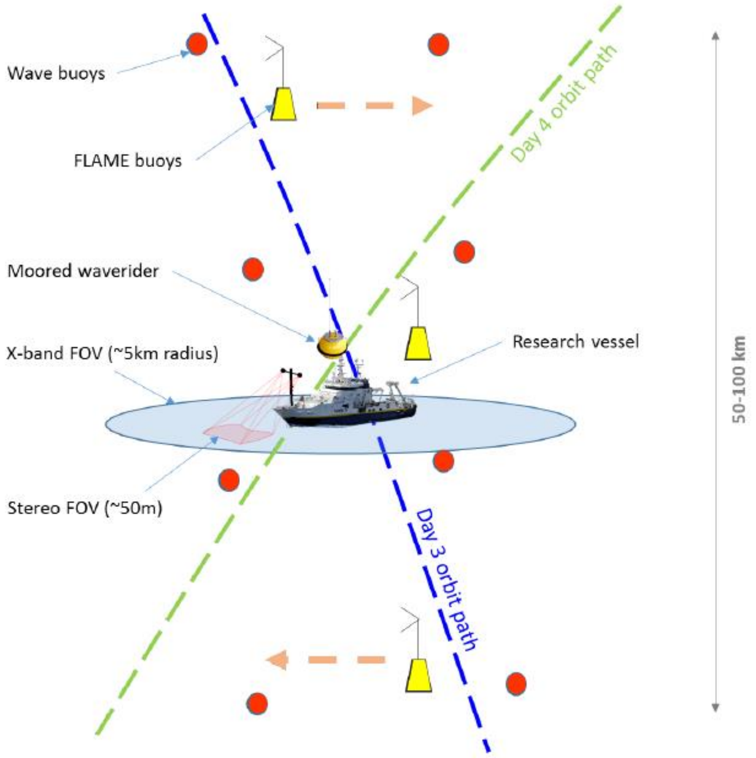

Figure 3 : IFREMER in-situ devices deployed for the SUMOS campaign around the ATLANTE shipboard.

- Note that NASA is also involved in airborne campaigns for altimetry, with the IceBridge program (https://www.nasa.gov/mission_pages/icebridge/index.html), to bridge the critical phase between IceSat and IceSat-2 but which have also applications for Sentinel-3 data validation, and with AirSWOT (https://swot.jpl.nasa.gov/mission/airswot/) to prepare the future SWOT mission. Both campaign programs can be used for altimetry understanding in the Copernicus framework.

Highlight

The airborne campaigns for altimetry (and more widely scatterometer) are used for validation or preparation of new instrument concepts. Such campaigns are not used to tune the instruments during commissioning phase. But they are key asset to validate the product, the new algorithm and to better understand interactions between the electromagnetic waves and surfaces. For the Ocean, the validation is mostly based on comparisons with models and other satellites. These campaigns provide real measurements in region where there is usually very sparse or no data.

Attempts on corner reflectors by several teams are on-going to calibrate the radar backscattering coefficients. For altimetry, the nadir geometry is not favourable for such calibration. The localization must be carefully chosen.

2.3.3 Radar and microwave missions

General Information

Table 15: General information about campaign

Campaign name	Satellite mission	Mission phase	Cal/Val data	PI affiliation	Funding
AfriSAR	BIOMASS Tandem-L	pre-launch	biomass carbon storage	DLR	ESA NASA
AgriSAR	S-1 S-2	pre-launch	SAR and optical images	DLR	ESA
ARCTIC15	TanDEM-X Tandem-L S-1	operational pre-launch	penetration depths at different wavelengths (X-C-S-L-P)	DLR	DLR
DLR-SAR-Cal	S-1A/B TerraSAR-X TanDEM-X KOMPSAT-6 future satellite missions (e.g., S-1C, BIOMASS, …)	pre-launch commissioning operational	system calibration (pointing, geometric, radiometric, polarimetry and interferometric)	DLR	DLR
JECAM	S-1 RADARSAT-2 S-2 L7 L8	operational	LAI wet biomass dry biomass (of leaves = leave, haulm, ears) leaf area leave water content	Halle Univ. (D) DLR GFZ Wuerzburg Univ. (D) Jena Univ. (D)	national funding DLR

			dry matter plant height fractional vegetation cover proportion of senescent material leaf chlorophyll content phenological stage orientation of planting rows soil moisture soil samples soil roughness aerosol optical thickness column of water vapor absolute spectral reflectance factors		
LIAISE (Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment)	SMOS SMAP	operational	soil moisture	CNRM	national funding
MACSSIMIZE	EPS-SG	operational	brightness temperatures surface emissivity and temperature	Met Office	Met Office NERC
PermASAR	TerraSAR-X TanDEM-X Tandem-L RADARSAT-2	pre-launch operational	vegetation and soil conditions in summer and winter seasons	DLR	DLR
RCM (Radar-Crop-Monitoring)	S-1 S-2	operational	vegetation properties	Jena Univ. (D)	national funding DLR

RODA	S-1	operational	soil moisture SAR images (Sigma Nought, Gamma Nought)	Jena Univ. (D)	national funding
SALDI (South African Land Degradation Monitor)	S-1 S-2	operational	soil moisture	Jena Univ. (D)	national funding DLR
SARSense	ROSE-L	pre-launch	soil and plant parameters	Forschungszentrum Jülich	ESA national funding
TropiSAR	BIOMASS	pre-launch	L and P-band PolInSAR images biomass	CESBIO	ESA ONERA

Used platform

Table 16: Information about used platform

Campaign name	Platform	Operator	Related network / infrastructure
AfriSAR	aircraft	DLR, AVDEF, NASA	Collaboration with ESA, ONERA, AGEOS, NASA
AgriSAR	aircraft	DLR	
AgriSAR	aircraft	ITRES (Canada)	
AgriSAR	aircraft	INTA (Spain)	
ARCTIC15	aircraft	DLR	
DLR-SAR-Cal	ground	DLR	DLR SAR Calibration center CEOS-WGCV SAR Subgroup
JECAM	ground	Halle Univ. (D) DLR	AgriSens - DEMMIN 4.0

		GFZ Wuerzburg Univ. (D) Jena Univ. (D)	DEMMIN (Durable Environmental Multidisciplinary Monitoring Information Network)
LIAISE	aircraft	SAFIRE	HYMEX https://www.hymex.org
MACSSIMIZE	aircraft	FAAM	NERC
PermASAR	aircraft	DLR	Canada Centre for Mapping and Earth Observation (CCMEO)
RCM	UAV	Jena Univ.	AgriSens DEMMIN 4.0 (for one test site)
RODA	ground	Jena Univ.	
SALDI	ground	Jena Univ.	
SARSense	aircraft	MetaSensing	TERENO
TropiSAR	aircraft	ONERA, AVDEF	Collaboration with ESA, ONERA, CESBIO, CIRAD, EDB, IRD

Used instrumentation

Table 17: Information about employed instrumentation

Campaign name	Instrument type	Specification	Measured quantity	Quality information / uncertainty evaluation	Operator
AfriSAR	SAR system	F-SAR	interferometric polarimetric backscattered radar signal (texture, forest height, 3D profile)	calibration report available; uncertainty evaluation available	DLR
AfriSAR	SAR system	SETHI	interferometric polarimetric backscattered radar signal (texture, forest height, 3D profile)	calibration report available; uncertainty evaluation available	ONERA

AfriSAR	SAR system	UAVSAR	interferometric polarimetric backscattered radar signal (texture, forest height, 3D profile)	calibration report available; uncertainty evaluation available	NASA
AfriSAR	LIDAR	Land, Vegetation and Ice Sensor (LVIS)	unambiguous determination of range and laser return pulse structure	calibration report available; uncertainty evaluation available	NASA
AgriSAR	SAR system	E-SAR	Interferometric and polarimetric SAR sensor in L and C-band	calibration report available; uncertainty evaluation available	DLR
AgriSAR	Optical imagery	CASI (ITRES) and ATES (INTA)	Optical images	calibration report available; uncertainty evaluation available	ITRES, INTA
ARCTIC15	SAR system	F-SAR	polarimetric-interferometric SAR data at different frequencies (X-, C-, S-, L- and P-band)	calibrated	DLR
DLR-SAR-Cal	3 corner reflectors, 3 transponders in C-Band, 1 transponder in X-Band	remote-controlled reference targets, leg length of corner reflector 2.8 m	backscatter signal, gain, phase and delay	constantly maintained, calibration as required Uncertainty: 0.2 dB absolute radiometric accuracy, precisely surveyed < 10 cm	DLR
JECAM	LAI measuring devices chlorophyll measuring devices soil moisture measuring device	LAI 2000 (LiCor) LAI 2200 (LiCor) LI3100 (LiCor) SPAD-502+ Chlorophyllmeter	Leaf Area Index Chlorophyll content Soil moisture Atmospheric composition reflectance	Measurement protocols Calibration by manufacturer	Halle Univ. (D) DLR GFZ Wuerzburg Univ. (D) Jena Univ. (D)

	sun photometer field spectrometer	HH2 moisture meter Microtops Sunphotometer II ASD FieldSpec 3, SVC HR1024			
LIAISE	UHF wind profiler	UHF Degreane PCL1300 mobile (on trailer).	Measurement of vertical wind profiles up to 3km to 6km depending on weather conditions, with a vertical resolution of 75m to 150m and a temporal resolution of about 10 minutes	Included in the processing chain	CNRM
LIAISE	mast	50 m high mast deployable anywhere	pressure, temperature, wind, humidity, radiation... and turbulent flow measurements	Calibration before each campaign	CNRM
LIAISE	Captive balloons	Captive balloons from 7m3 to 20m3 that can carry a payload of a few kg up to altitudes of about 500m - 700m	Meteorological measurements, turbulence measurements, but also, through collaborations with other laboratories, gas concentration sensors	Calibration before each campaign	CNRM
MACSSIMIZE	microwave radiometer	MARSS, ISMAR	brightness temperatures (89-325GHz)	calibrated (internal blackbodies) nominal uncertainties available	Met Office
PermASAR	SAR system	F-SAR	polarimetric-interferometric SAR data at different frequencies (X-, C-, S- and L-band)	calibrated	DLR

RCM	multispectral camera (optical)	P4 Multispectral imaging system	Radiance	General calibration	Jena Univ.
RODA	soil moisture measurement unit	SMT-100	Soil Moisture Temperature	General calibration Specified uncertainties (±3 % soil moisture; ±0,2 °C)	Jena Univ.
SALDI	soil moisture measurement unit	SMT-100	Soil Moisture Temperature	General calibration Specified uncertainties (±3 % soil moisture; ±0,2 °C)	Jena Univ.
SARSense	SAR system	STARSAR (C-band quadpol, L-band)	Polarimetric SAR images	calibrated	MetaSensing
TropiSAR	SAR system	SETHI	interferometric polarimetric backscattered radar signal (texture, forest height, 3D profile)	calibration report available; uncertainty evaluation available	ONERA
TropiSAR	Soil moisture probe	DeltaT Theta probe	Soil moisture	calibrated	CIRAD
TropiSAR	Weather stations	WS-STD1 Guyaflux tower	Meteorological parameters	calibrated	CIRAD

Cal/Val site

Table 18: Information about Cal/Val sites

Campaign name	Location	Spatial extent	Acquisition date	Measuerment frequency
AfriSAR	Central Africa (Gabon)	individual tropical forest test sites	2015 & 2016	one-time
AgriSAR	Demmin (Germany)	Individual test site	2006	one-time
ARCTIC15	Greenland	individual test sites	2015	one-time

DLR-SAR-Cal	Germany	one area of 120 km x 40 km in Southern Germany, one area of about 1 km x 1 km in the North of Germany	Sentinel-1 since 2014	with every satellite overpass
JECAM	Demmin, Germany	Variable (multiple agricult. Fields)	Since 2018	yearly 4-5 time per vegetation period
LIAISE	Lérida, Espagne	N/A	Mid-July 2021	one-time
MACSSIMIZE	Trail Valley Creek, Canada	Arctic sea ice	March 2018	one-time
PermASAR	Canada	Individual test sites located in the North-West Territories and Saskatchewan	2018, 2019	one-time
RCM	Germany: Demmin, Frienstedt, Marktneunkirchen	100 km2 20 km2 160 km2	Spring, summer, fall 2019, 2020	one-time
RODA	Roda catchment (Germany)	35 ha	Since 2015	every 15 minutes
SALDI	Multiple sites in South Africa	1 measurement per test site	Since March 2019	every 30 minutes
SARSense	Selhausen (Germany)	Individual test site	2019	one-time
TropiSAR	Nouragues, Paracou (French Guiana)	Individual tropical forest test sites	2009	one-time

Data handling

Table 19: Information about data handling

Campaign name	Data availability	Data access	Publications

AfriSAR	available	upon request https://earth.esa.int/eogateway/ https://uavsar.jpl.nasa.gov/cgi-bin/data.pl https://lvis.gsfc.nasa.gov/Data/GE.html	Banda et al. 2020
AgriSAR	available	upon request https://earth.esa.int/eogateway/campaigns/agrisar-2006	Hajnsek et al. 2009
ARCTIC15	available	upon request www.eoweb.dlr.de	Pardini et al. 2016 Parrella et al. 2019
DLR-SAR-Cal	data delivery directly to contractor		Schwerdt et al. 2019 Reimann et al. 2019 Reimann et al. 2018
JECAM	project restriction during project life cycle	https://www.agrisens-demmin.de http://jecam.org https://www.tereno.net	
LIAISE	freely available	Aeris portal https://en.aeris-data.fr/catalogue-en/	
MACSSIMIZE	freely available	CEDA data archive https://data.ceda.ac.uk/badc/faam/data/2018	
PermASAR	available	upon request www.eoweb.dlr.de	
RCM	project restriction during project life cycle	upon request (via PI)	
RODA	project internal		

SALDI	project restriction during project life cycle	upon request https://www.saldi.uni-jena.de/	
SARSense	upon request	upon request https://earth.esa.int/eogateway/campaigns/sarsense-technical-assistance-for-airborne-measurements-during-the-sar-sentinel-experiment	Mengen et al. 2021
TropiSAR	available upon request	upon request https://earth.esa.int/eogateway/campaigns/tropisar	

Further developments

Table 20: Further developments

Campaign name	Instrumentation	Methodology
DLR-SAR-Cal	two frequency bands in one transponder device (X- and L-band) for future SAR missions	

Conclusion

- Within this survey 13 campaigns in total deal with the Cal/Val of radar and microwave mission products.
- The campaigns are conducted during the pre-launch and operational phase of the different missions. Pre-launch campaigns also include data acquisition during the study and design phases of future satellite missions (e.g., Sentinel-1C, BIOMASS). These campaigns support the preparation of new data products and help for defining the spaceborne sensor requirements.
- DLR is heavily involved in the campaigns (also due to the heritage of TerraSAR-X and TanDEM-X) either with their airborne system or their ground-based calibration site.
- The ground-based campaigns DLR-SAR-Cal are realized during satellite overpasses and are conducted for the system calibration of the SAR system (pointing, geometric, radiometric, polarimetry and interferometric calibration).
- The campaigns which are related to L3 products deal with biomass and soil moisture retrieval. In this context, radar as well as optical mission data is considered (e.g., JECAM campaign).
- The SARSense campaign was conducted to prepare ROSE-L, also involving acquisitions of Sentinel-1 and ALOS data, allowing for the comparison of in-flight missions.
- The airborne F-SAR (formerly E-SAR) system is used with different frequency band combinations and the use of fully polarimetric measurement modes dependent on the campaign objective. The different possibilities of data recording support a correspondingly extensive use in the field of Cal/Val of radar and microwave missions.

Figure 4 : F-SAR installed on board the DLR Do 228-212 research aircraft. © DLR.

Figure 5 : Calibration devises of DLR's SAR Calibration Center. © DLR.

Highlight

The radar campaigns are used to investigate the potential of future and current satellite missions, and also to contribute to the mission design and missions' requirements definition. The ground-based DLR-SAR-Calibration site is a worldwide established calibration facility, which is intensively used for the purpose of system calibration of radar missions.

2.3.4 Atmospheric composition missions

General Information

Table 21: General information about campaign

Campaign name	Satellite mission	Mission phase	Cal/Val data	PI affiliation	Funding
AROMAPEX	OMI S-5P	pre-launch	tropospheric NO_2 columns	BIRA-IASB	ESA EUFAR
AROMAT	OMI S-5P	pre-launch	trace gas columns	BIRA-IASB	ESA
GMAP	GEMS S-5P	operational	trace gas columns	NIER	Ministry of Environment, Korea
LISTOS	TEMPO S-5P	operational pre-launch	trace gas columns	NASA Langley Research Center	NASA
S5PVAL-BE	S-5P	operational	tropospheric NO_2 columns	BIRA-IASB	ESA BELSPO
S5PVAL-DE-BERLIN	S-5P	operational	tropospheric NO_2 columns	BIRA-IASB	ESA
S5PVAL-DE-RUHR	S-5P	operational	trace gas columns	IUP Bremen	ESA

S5PVAL-RO + RAMOS	S-5P	operational	trace gas columns greenhouse gas columns ALH	INOE	ESA
APODRONE - AUSEA	MERLIN ,MicroCarb, IASI-NG, OCO-2, GOSAT-2, S-5P, IASI	pre-launch cal/val operational	Spatio-temporal mapping of greenhouse gases (CO_2, CH_4, H_2O) concentrations at different flight altitudes of a UAV (up to 5 km)	GSMA-URCA (Université de Reims Champagne-Ardenne)-CNRS	TOTAL, URCA, CNRS
Arrival Heights	S-5P	operational	CO_2, CH_4, CO, H_2O columns	Antarctica NZ	New Zealand Ministry of Business, Innovation and Employment (MBIE)
COMET – Ground-based activities	S-5P	operational	CO_2, CH_4, CO, H_2O columns	UHEI	German Federal Ministry for Education and Research, internal resources of the operators
CoMet	S-5P MERLIN	operational pre-launch	Greenhouse gas columns	DLR	DLR BMBF HALO
FOAM	S-5P	pre-launch	quantify the methane emission rates from urban and biogenic sources	AGH-University Krakow	EUFAR
FRM4GHG	S-5P	operational	CO_2, CH_4, CO, H_2O, HCHO columns	IUP Bremen	ESA
MAGIC	OCO-2/3, GOSAT-1/2, Sentinel-5P, IASI, MERLIN (Methane Remote Sensing Lidar	pre-launch cal/val operational	greenhouse gases (CO_2, CH_4) and CO profiles (with temperature and humidity profiles) between the	LMD - CNRS Crevoisier et al. 2019	CNES, CNRS, Ecole polytechnique, URCA, Sorbonne University, University of Lille, ONERA,

	Mission), MicroCarb, IASI-NG, Sentinel-5, CO2M		ground and flight level (aircraft), greenhouse gases profiles between the ground and balloon burst altitude (~35 km), Greenhouse gases weighted columns.		DLR, ESA, EUMETSAT, EUMETSAT, CEA, UVSQ, H2020-RINGO
MAGURELE	S-5P	operational	CO_2, CH_4, CO, H_2O columns	INOE	European Commission
MEGEI-IZO	S-5P	operational	CO_2, CH_4, CO, H_2O columns	AEMet	AEMet and KIT
MEGEI-MAD	S-5P	operational	CO_2, CH_4, CO, H_2O columns	AEMet	AEMet, KIT, UH
METHANE-To-Go	S-5P	operational	methane and sulfur dioxide	DLR	DLR, UNEP
MORE-2 – RV SONNE – Pacific transect	S-5P	operational	CO_2, CH_4, CO, H_2O columns	UHEI	UHEI, research vessel funded through German Federal Ministry for Education and Research
MOROCCO AMV station	S-5P	operational	CO_2, CH_4, CO, H_2O columns	CEA-LSCE	CEA / CNRS
MOYA	S-5P	operational	CO_2, CH_4, CO, H_2O columns	RHUL U. of Leicester	UK NERC
MUCCnet	S-5P	operational	CO_2, CH_4, CO, H_2O columns	TUM	German Research Foundation
RINGO	S-5P, MERLIN, MicroCarb, IASI-NG, OCO-2, GOSAT-2, IASI	operational	Greenhouse gas profiles between the ground and the burst altitude (balloons)	RUG	EU H2020
S5PVAL-KOLKATA	S-5P	operational	greenhouse gas columns	BIRA-IASB	ESA

S5PVAL-PORTOVELHO	S-5P	operational	greenhouse gas columns	BIRA-IASB	ESA
Seoul	S-5P	operational	CO_2, CH_4, CO, H_2O columns	SNU	National Research Foundation of Korea
ASKOS/DACCIWA (Dynamics-aerosol-chemistry-cloud interactions in West Africa)	Aeolus	operational	optical properties of aerosols, winds, cloud reflectivity @ 95GHz (W band)	LATMOS-CNES	CNES, ESA
Stratéole-2	Aeolus, EarthCare	Cal/Val during full satellite life cycle	L2B Winds	LMD-CNRS	CNES, ESA, ANR

Used platform

Table 22: Information about used platform

Campaign name	Platform	Operator	Related network / infrastructure
AROMAPEX	Aircraft	DLR (DO-228 D-CFFU) FUB (Cessna 207T DEAFU)	AROMAT EUFAR
AROMAT	Aircraft	FUB (Cessna 207T DEAFU)	
AROMAT	Car-mobile DOAS	BIRA-IASB MPIC Uni. Galati	
AROMAT	NO_2 balloon sonde	KNMI	
AROMAT	Fixed wing UAV	Reev River Aerospace	

GMAP	Aircraft	Sunny Air (Cessna 208 Caravan)	Korus-AQ
LISTOS	Aircraft	NASA (LaRC HU-25 Falcon) NASA (LaRC B200)	NESCAUM
S5PVAL-BE	Aircraft	SFS (Cessna 208B Grand Caravan EX HB-TEN)	S-5p validation campaigns BUMBA
S5PVAL-BE	Car-mobile DOAS	BIRA-IASB	S-5p validation campaigns BUMBA
S5PVAL-DE-BERLIN	Aircraft	FUB (Cessna 207T DEAFU)	S-5p validation campaigns
S5PVAL-DE-RUHR	Aircraft	FUB (Cessna 207T DEAFU)	S-5p validation campaigns
S5PVAL-DE-RUHR	Car-mobile DOAS	BIRA-IASB IUP Bremen MPIC	S-5p validation campaigns BUMBA
S5PVAL-RO + RAMOS	Aircraft	INCAS (YR-BNR BN-2)	S-5p validation campaigns
APODRONE - AUSEA	UAV: M300 and VTOL	GSMA-CNRS	
Arrival Heights	Ground-based	NIWA & Antarctica NZ	COCCON
COMET – Ground-based activities	Ground-based	UHEI, DLR, KIT, AGH, TUM	COCCON
CoMet	Aircraft	DLR FUB	HALO EUFAR TCCON
FOAM	Aircraft	FUB	EUFAR

			Related to the CoMet campaign
FRM4GHG	Ground-based Balloons	IUP Bremen BIRA-IASB FMI KIT U. of Wollongong RAL U. of Groningen	COCCON TCCON
MAGIC	Meteorological balloon	CNES Balloon division; LMD (Laboratoire de Météorologie Dynamique); LSCE (Laboratoire des Sciences du Climat et de l'Environnement); GSMA (Groupe de Spectrométrie Moléculaire et Atmosphérique), OPGC (Observatoire de Physique du Globe de Clermont-Ferrand)	AirCore Amulse ICOS-France COCCON TCCON
MAGIC	Aircraft (Falcon 20 and ATR42)	SAFIRE	EUFAR
MAGIC	Ground based	LERMA-CNRS LSCE-CNRS GSMA-CNRS CNES LOA-CNRS	COCCON TCCON
MAGURELE	Ground-based	INOE	COCCON
MEGEI-IZO	Ground-based	AEMet KIT	COCCON
MEGEI-MAD	Ground-based	AEMet KIT	COCCON

		UHEI	
METHANE-To-Go	Aircraft	DLR	EUFAR
MORE-2 – RV SONNE – Pacific transect	Ship-borne	UHEI	COCCON
MOROCCO AMV station	Ground-based	CNRS-LPC2E / CEA-CNRS-LSCE	COCCON
MOYA	Ground-based	U. of Leicester, NaFIRRI, TUM	COCCON
MUCCnet	Ground-based	TUM	COCCON
RINGO	Balloon	RUG, FMI, LSCE-LMD, GUF, UBERN	AirCore
S5PVAL-KOLKATA	Ground-based	BIRA-IASB IISER-KOLKATA IUP Bremen	S-5p validation campaigns COCCON TCCON
S5PVAL-PORTOVELHO	Ground-based	BIRA-IASB IFRO KIT	S-5p validation campaigns COCCON TCCON
Seoul	Ground-based	SNU	COCCON
ASKOS/DACCIWA	Aircraft (F20)	SAFIRE	ASKOS (https://askos.space.noa.gr/)
Stratéole-2	Long-duration stratospheric balloons	CNES	

Used instrumentation

Table 23: Information about employed instrumentation

Campaign name	Instrument type	Specification	Measured quantity	Quality information / uncertainty evaluation	Operator
AROMAPEX	Imaging spectrometer	APEX	NO_2	regular health checks + product uncertainty budget	VITO
AROMAPEX	Imaging spectrometer	SWING	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB
AROMAPEX	Imaging spectrometer	AirMAP	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	FUB Bremen
AROMAPEX	Imaging spectrometer	Spectrolite	NO_2	regular health checks + product uncertainty budget	KNMI TNO
AROMAPEX	spectrometer	Car-mobile DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB
AROMAPEX	sunphotometer	FUBISS-ASA2	Aerosol extinction profiles	regular health checks + product uncertainty budget	FUB
AROMAT	Imaging spectrometer	AirMAP	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	IUP Bremen

AROMAT	Imaging spectrometer	SWING (On FUB Cessna and on UAV)	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB
AROMAT	chemiluminescence detector	NO_2 sonde (on balloon and on UAV)	NO_2	regular health checks	KNMI
AROMAT	spectrometer	Car-mobile DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB MPIC Uni. Galati
GMAP	spectrometer	GCAS	O_3, NO_2, and HCHO	regular health checks + product uncertainty budget	NASA
GMAP	spectrometer	Ground-based PANDORAMAX-DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	NASA IUP Bremen BIRA-IASB
LISTOS	Imaging spectrometer	GeoTASO	O_3, NO_2, and HCHO	regular health checks + product uncertainty budget	NASA
LISTOS	Imaging spectrometer	GCAS	O_3, NO_2, and HCHO	regular health checks + product uncertainty budget	NASA
LISTOS	spectrometer	Ground-based PANDORA	O_3, NO_2, and HCHO	regular health checks + product uncertainty budget	NASA
S5PVAL-BE	Imaging spectrometer	APEX	NO_2	regular health checks +	VITO

				product uncertainty budget	
S5PVAL-BE	spectrometer	Car-mobile DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB
S5PVAL-DE-BERLIN	Imaging spectrometer	SWING	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB
S5PVAL-DE-RUHR	imaging spectrometer	AirMAP	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	IUP Bremen
S5PVAL-DE-RUHR	spectrometer	Airborne zenith-sky DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	IUP Bremen
S5PVAL-DE-RUHR	spectrometer	Ground-based PANDORA MAX-DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	NASA IUP Bremen BIRA-IASB
S5PVAL-DE-RUHR	spectrometer	Car-mobile DOAS	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	BIRA-IASB MPIC IUP Bremen
S5PVAL-RO + RAMOS	imaging spectrometer	SWING	NO_2, SO_2, HCHO	regular health checks + product uncertainty budget	INCAS BIRA-IASB
S5PVAL-RO + RAMOS	in-situ	AS32M CAPS	NO_2	regular health checks	INCAS BIRA-IASB

S5PVAL-RO + RAMOS	in-situ	PICARRO G2401	CO, CO_2, CH_4	regular health checks	INCAS
S5PVAL-RO + RAMOS	in-situ	TSI particle sizer 3321	Aerosols, ALH	regular health checks	INCAS
S5PVAL-RO + RAMOS	in-situ	TSI Nephelometer	Aerosols, ALH	regular health checks	INCAS
APODRONE - AUSEA	tunable diode laser absorption spectroscopy	AMULSE UAV	In-situ concentration of CO_2, CH_4 and H_2O	pre and post flight ground calibration	GSMA-CNRS
Arrival Heights	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	NIWA & Antarctica NZ
COMET – Ground-based activities	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	UHEI, DLR, KIT, AGH, TUM
CoMet	IPDA lidar	CHARM-F	CH_4, CO_2	regular health checks	DLR
CoMet	spectrometer	miniDOAS	NO_2		University of Heidelberg
CoMet	spectrometer	JIG	CH_4, CO_2, CO, and H_2O	on-board calibration	Max Planck Institute for Biogeochemistry
CoMet	spectrometer	MAMAP2D	CH_4, CO_2		University of Bremen
CoMet	in-situ instruments	Chemical ionization-ion trap mass spectrometer QCLs	CO_2, CH_4, CO, C_2H_6, N_2O	calibration for every flight available	DLR
FOAM	Imaging spectrometer	HySpex	radiance	calibration unregular, on demand 1-10% uncertainty	FUB
FOAM	in-situ cavity ring down spectroscopy	Picarro Fast Greenhouse Gas Analyzer G2311-f	CO_2 CH_4 H_2O	calibration unregular, on demand uncertainty: $CO_2 \leq 200$ ppb $CH_4 \leq 3$ ppb	FUB

				$H_2O \le 6$ ppm + 0.3% of reading	
FRM4GHG	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	KIT
FRM4GHG	Portable spectrometer	Bruker IRcube	CO_2, CH_4	Follow TCCON protocols	U. of Wollongong
FRM4GHG	Portable spectrometer	Bruker Vertex70	CO_2, CH_4, CO, H_2O, HCHO	Follow TCCON protocols	IUP Bremen BIRA-IASB
FRM4GHG	Portable spectrometer	Laser Heterodyne Spectroradiometer	CO_2, CH_4, H_2O	Follow own quality control protocols	RAL
FRM4GHG	Stationary spectrometer	Bruker IFS 125HR	CO_2, CH_4, CO, H_2O, N_2O, HDO, HF	Follow TCCON protocols	FMI
FRM4GHG	Stationary spectrometer	Bruker IFS 125HR (low-resolution)	CO_2, CH_4, CO, H_2O	Follow TCCON protocols	FMI & KIT
FRM4GHG	In-situ	AirCore	CO_2, CH_4, CO	Calibration pre and post flight	RUG & FMI
MAGIC	Cavity Ring-Down-Spectroscopy (CRDS)	Picarro G2401-m	In-situ concentration of CO_2, CH_4, CO and H_2O	on-board calibration	SAFIRE, LSCE-CNRS
MAGIC	In-situ absorption infrared laser spectroscopy	SPIRIT (Infrared ultra-high- resolution spectroscopy) Catoire et al. 2017	In-situ concentration of CO, NO_2, CH_4	on-board calibration	LPC2E-CNRS (Laboratoire de Physique et de Chimie de l'Environnement et de l'Espace)
MAGIC	Atmospheric sampler flying under souding balloon	AirCore	CO_2, CH_4, CO, H_2O and T profiles (from ground to burst altitude)	Calibration pre and post flight	LMD – CNRS; LSCE-CNRS; GSMA-CNRS; OPGC-CNRS

MAGIC	in-situ spectroscopy under souding balloon	AMULSE (Atmospheric Measurements by Ultra-Light Spectrometer) Joly et al. 2020	CO_2, CH_4, H_2O and T profiles (in-situ measurements from ground to burst altitude)	regular health checks	GSMA-CNRS
MAGIC	Mobile ground based FTIR spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, and H_2O total columns	Follow COCCON protocols	LERMA-CNRS, GSMA-CNRS, LSCE-CNRS and CNES
MAGIC	Mobile ground based FTIR spectrometer	CHRIS (Compact High-spectral Resolution Infrared Spectrometer) El Kattar et al. 2019	CO_2, CH_4, CO, and H_2O total columns	regular health checks	LOA-CNRS
MAGURELE	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	INOE
MEGEI-IZO	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	AEMet & KIT
MEGEI-MAD	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	AEMet, KIT, U. of Heidelberg
METHANE-To-Go	in-situ instruments for measuring trace gases	Chemical ionization-ion trap mass spectrometer for SO2 QCLs (quantum cascade lasers) for CH4	methane (CH_4), sulfur dioxide (SO_2)	Calibration for every flight available Uncertainty evaluation available SO_2 accuracy ±20% CH_4 1 s–1σ uncertainty of 1.85 ppb	DLR
MORE-2 – RV SONNE – Pacific transect	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	UHEI

MOROCCO AMV station	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	CNRS-LPC2E / CEA-CNRS-LSCE
MOYA	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	U. of Leicester, NaFIRRI, TU Munich
MUCCnet	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	TUM
RINGO	In-situ	AirCore	CO_2, CH_4, CO, H_2O, N_2O, COS and T profiles	Calibration pre and post flight	RUG, FMI, LSCE/LMD, GUF, UBERN
S5PVAL-KOLKATA	Portable spectrometer	VERTEX70 FTIR	CO_2, CH_4, CO, H_2O, HCHO	Follow TCCON protocols	BIRA-IASB IISER-KOLKATA IUP Bremen
S5PVAL-PORTOVELHO	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	BIRA-IASB IFRO KIT
Seoul	Portable spectrometer	Bruker EM27/SUN FTIR	CO_2, CH_4, CO, H_2O	Follow COCCON protocols	SNU
ASKOS/DACCIWA	HSR Lidar	Airborne HSRL LNG Lidar	wind, backscatter and aerosol extinction	Autocalibration on molecular backscatter.	LATMOS, SAFIRE
ASKOS/DACCIWA	radar	95GHz RASTA airborne radar	speed of detected hydrometeors	N/A	LATMOS, SAFIRE
Stratéole-2	GPS, thermistor, thermocouple, UV photometer, GPS Radio-occultation		Pressure, Temperature	no	CNRS, LASP/University of Colorado, Scripps Institution of Oceanography
Stratéole-2	IR spectrometer	pico-SDLA	water vapor, CO_2, CH_4	N/A	CNRS/GSMA and CNRS/DT-INSU

Stratéole-2	hygrometers	frost-point/Lyman-alpha hygrometers	H_2O	N/A	LMD-CNRS LATMOS-CNRS
Stratéole-2	backscatter lidar	BeCOOL	800 nm, attenuated backscatter from the balloon to the ground	N/A	LATMOS-CNRS

Cal/Val site

Table 24: Information about Cal/Val sites

Campaign name	Location	Spatial extent	Acquisition date	Measuerment frequency
AROMAPEX	Berlin, Germany	~800 km²	April 2016	one-time
AROMAT	Bucharest, Romania Jiu Valley, Romania	~2000 km²	September 2014 August 2015	two-times
GMAP	Seoul Ansan Pyeongtaek Youngin Yeoju	~11000 km²	end of 2020 end of 2021 main campaign from October 2022 to June 2023	
LISTOS	Long Island Sound, USA	~10000km²	June-September 2018	potential follow-up campaign
S5PVAL-BE	Brussels, Belgium Antwerp, Belgium	~1000 km²	summer 2019 summer 2021	potential follow-up campaign
S5PVAL-DE-BERLIN	Berlin, Germany	~800 km²	April 2021 - December 2022	Recurrent flights (~once/month) when weather conditions allow (total of 12-18 flights)

S5PVAL-DE-RUHR	Duisburg (51.44°N, 6.76°E) Cologne (50.94°N, 6.97°E) Rhenish lignite mining district	~2000 km²	September 2020	potential follow-up campaign
S5PVAL-RO + RAMOS	Bucharest, Romania	~700 km²	May 2021 - December 2022	Recurrent flights (~once/month) when weather conditions allow (total of 12-18 flights)
APODRONE - AUSEA	France	0-5 km2 - the spatial resolution is a few meters	2019-2020	Several campaigns
Arrival Heights	Arrival Heights, Antarctica	Total column measurements from ground-based spectrometer	Nov 2019 – Feb 2020	one-time
COMET – Ground-based activities	USCB, Poland	Total column measurements from ground-based spectrometers	May – June 2018	one-time
CoMet	pan-European (CoMet 1.0) Arctic region (CoMet 2.0)	e.g. coal fields in Poland	2018 (CoMet 1.0) 2022 (CoMet 2.0)	one-time
FOAM	Katowice Pyrzowice, Poland	variable areas	28 September - 4 October 2017	one-time
FRM4GHG	Sodankylä, Finland	Total column measurements from ground-based spectrometers, Profile measurements from AirCore	2017 - 2019	one-time
MAGIC	France (Magic 2018, 2019, 2020), Northen Sweden planned for Magic 2021	Selected areas depending on the campaign: part of France and ocean or a particular place in the South East of France	May 2018 June 2019 September 2020	Around 10 days of measurements for each campaign

			August 2021	
MAGURELE	Magurele, Romania	Total column measurements from ground-based spectrometer	2018 – 2021	one-time
MEGEI-IZO	Tenerife, Spain	Total column measurements from ground-based spectrometer	May 2018 - present	one-time
MEGEI-MAD	Madrid, Spain	Total column measurements from ground-based spectrometers	17/09/2018 – 10/10/2018, 16/09/2019 – 27/09/2019	two-times
METHANE-To-Go	pan-European (METHANE-To-Go Europe), West Africa (METHANE-To-Go Africa)	METHANE-To-Go Europe: The 14 science flights were mainly conducted in Italy and in the Balkan states of Croatia, Serbia and Bosnia-Herzegovina. Selected areas above natural gas extraction platforms in the Adriatic Sea and coal-fired power plants on the Balkans. METHANE-To-Go Africa: methane emissions from oil and gas exploration facilities along the West African coast	2020 (METHANE-To-Go Europe), 2021 (METHANE-To-Go Africa)	two-times
MORE-2 – RV SONNE – Pacific transect	Vancouver to Singapore, roughly aligned with 30°N through the Pacific Ocean	Total column measurements from ground-based spectrometer	June 2019	one-time
MOROCCO AMV station	AMV station, Morocco	Total column measurements from ground-based spectrometer	17/09/2019 - 14/10/2019	one-time

MOYA	Jinja, Uganda	Total column measurements from ground-based spectrometer	Jan – April 2020	one-time
MUCCnet	Munich area, Grmany	Total column measurements from ground-based spectrometers	Sep – Oct 2017 Aug 2018 Sep 2019 - present	three-times
RINGO	Sodankylä, Finland Trainou, France	Profile measurements from ground to burst altitude (balloon)	June 2018 June 2019	two-times
S5PVAL-KOLKATA	Kolkata, India	Total column measurements from ground based FTIR spectrometer	October 2021 – November 2022	Extension of the campaign if funding is available
S5PVAL-PORTOVELHO	Porto Velho, Brazil	Total column measurements from ground based FTIR spectrometer	February 2021 – June 2022	Extension of the campaign if funding is available
Seoul	Seoul, South Korea	Total column measurements from ground-based spectrometers	2020 – present	one-time
ASKOS/DACCIWA	Cape Verde	Max radius of 2500km from Cape Verde	Planed July 2020, postponed to July 2021	N/A
Stratéole-2	Whole tropical belt	150 10^6 km^2	between 2019 and 2024	dependent on measurements, from 1 Hz to 4 times per day

Data handling

Table 25: Information about data handling

Campaign name	Data availability	Data access	Publications
AROMAPEX	freely available upon request	http://uv-vis.aeronomie.be/airborne/aromapex.php	Tack et al. 2019
AROMAT	freely available upon request	http://uv-vis.aeronomie.be/aromat	Merlaud et al. 2018, Merlaud et al. 2020
GMAP	Freely available	will be available on https://nesc.nier.go.kr/	Hong et al. 2017
LISTOS	Freely available	https://www-air.larc.nasa.gov/cgi-bin/ArcView/listos	Judd et al. 2020
S5PVAL-BE	freely available upon request	will be available on https://evdc.esa.int/	Tack et al. 2017, Tack et al. 2021
S5PVAL-DE-BERLIN	freely available upon request	will be available on https://evdc.esa.int/	
S5PVAL-DE-RUHR	freely available upon request	will be available on https://evdc.esa.int/	Meier et al. 2017
S5PVAL-RO + RAMOS	freely available upon request	will be available on https://evdc.esa.int/	
APODRONE - AUSEA	free of charge in the context of a collaboration		
Arrival Heights	Freely available	will be available on https://evdc.esa.int/	
COMET – Ground-based activities	Freely available	Request for data to the campaign PI	Luther et al. 2019
CoMet	freely available upon request	https://halo-db.pa.op.dlr.de/	
FOAM	Freely available	EUFAR database https://www.geo.fu-berlin.de/wew/index.html	
FRM4GHG	Freely available	will be available on https://evdc.esa.int/	Sha et al. 2020, Tu et al. 2020
MAGIC	freely available soon	AERIS portal https://magic.aeris-data.fr/	
MAGURELE	Freely available	will be available on https://evdc.esa.int/	

MEGEI-IZO	Freely available	will be available on https://evdc.esa.int/	Sepúlveda et al. 2012
MEGEI-MAD	Freely available	will be available on https://evdc.esa.int/	García et al. 2019a, García et al. 2019b
METHANE-To-Go	Freely available upon request	HALO database: https://halo-db.pa.op.dlr.de/	
MORE-2 – RV SONNE – Pacific transect	Freely available	PANGAEA at https://doi.org/10.1594/PANGAEA.917240	Knapp et al. 2021
MOROCCO AMV station	Freely available	will be available on https://evdc.esa.int/	
MOYA	Available upon request	will be available on UK CEDA archive	Humpage et al. 2020
MUCCnet	Freely available	will be available on https://evdc.esa.int/	
RINGO	Available upon request	Request for data to the campaign PI	
S5PVAL-KOLKATA	freely available upon request	will be available on https://evdc.esa.int/	
S5PVAL-PORTOVELHO	freely available upon request	will be available on https://evdc.esa.int/	
Seoul	Freely available	will be available on https://evdc.esa.int/	
ASKOS/DACCIWA	Will be Freely available	Aeris portal	
Stratéole-2	Freely available 1 year after each campaign	https://thredds-x.ipsl.fr/thredds/strateole2.html (also on Aeris portal soon)	

Further developments

Table 26: Further developments

Campaign name	Instrumentation	Methodology	Goal
AROMAPEX	The four imaging systems operated simultaneously over Berlin and retrievals were intercompared in order to better understand their differences/errors and	The four imaging systems operated simultaneously over Berlin and retrievals were intercompared in order to better understand their differences/errors and	Improve intercomparability of instruments and harmonization of data retrievals. The four imaging systems are

	uncertainties and improve/harmonize the instrument retrievals.	uncertainties and improve/harmonize the instrument retrievals.	deployed now in several locations in Europe for S-5p validation.
S5PVAL-DE-BERLIN	Instrument will be further developed to operate autonomous from a wingpod instead as from a window in the bottom plate of the aircraft.		
S5PVAL-RO + RAMOS			The RAMOS project aims at the development of an atmospheric observation system in Romania, consisting of ground-based and airborne instruments
APRODRONE-AUSEA			Fluxes measurement from UAV
Arrival Heights	Future campaigns to Arrival Heights and elsewhere in NZ using multiple EM27/SUN instruments are planned		
COMET – Ground-based activities			Mobile EM27/SUN for multiple platforms, subject to funding opportunities.
CoMet	Lidar system with higher repetition rate		better resolve plumes from localized emission sources
FRM4GHG			Improvements based on lessons learned during the project.
MAGIC	On-going collaborations with ONERA (LIVE wind lidar), DLR (CHARM-F CH4 lidar), FMI (Sodankylä site), KIT (COCOON), U. of Leicester (EM27/SUN from UK).	Validation measurements using intercomparisons of all the instruments involved in the campaign.	Next campaigns: MAGIC 2021 in Northern Sweden, MAGIC 2022 in France around a medium-sized city, tropics.
MAGURELE			Improvements based on lessons learned during the project.

MEGEI-IZO			Improvements based on lessons learned during the project.
MEGEI-MAD			Improvements based on lessons learned during the project.
METHANE-To-Go	Since 2021 new SO2 instrument in construction at DLR based on laser-induced-fluorescence (as described here: https://amt.copernicus.org/articles/9/4601/2016/amt-9-4601-2016.pdf		
MORE-2 – RV SONNE – Pacific transect			Routine ship-borne operations, subject to funding opportunities.
MOYA	Longer term deployment with more stable/robust power supply to begin in 2021 following re-calibration and replacement of solar tracker mirrors in January 2021, still using the TU Munich automated enclosure.		
MUCCnet			Improvements based on lessons learned during the project.
RINGO			Further developments needed before it is ready to be integrated into ICOS, hopefully in RINGO2.
Seoul			Improvements based on lessons learned during the project.
ASKOS/DACCIWA			Planed July 2021
Stratéole-2			Planned Strateole-2 campaigns: October 2021-March 2022, October 2024-March 2025

Conclusion

- 29 campaign activities are presented dealing with atmospheric missions. PIs are related to the academic environment, research centres or space agencies. Funding is a mixture of ESA/EU funding, national funding and internal funding. Often European/national funding is mainly foreseen for data acquisition and is limited for proper data exploitation and analysis.
- The campaign type varies from large-scale campaigns bringing together a large number of instruments and teams (e.g. AROMAT) to decentralised activities that are organized with a small group of teams and instruments but which are part of a larger framework (e.g. Sentinel-5p campaigns / S5PVAL). The large-scale campaigns allow in-depth analysis based on a broad range of instruments and expertise. The decentralised approach allows more flexibility and reduction of cost and also allows to cover a broader range of geophysical parameters (pollution levels, albedo type, weather conditions, etc.).
- Most of the atmospheric campaigns are organized and occur during the pre-launch and operational phase of the satellite missions. Pre-launch campaigns are organized mainly (i) to define and prepare satellite data validation strategies, e.g. for new satellite data products (new geophysical quantity, alternative retrieval approach) or for new satellite instruments with unprecedented specifications, and (ii) to simulate potential future satellite missions. Pre-launch campaigns are also useful to develop/test instruments, to prepare methods and tools, and to train the scientific and support teams in order to be prepared for the campaigns in the operational phase which are very time constraint. Campaigns organized during the operational phase are mainly set up (i) to validate compliance of the products with defined requirements, e.g. vertical sensitivity, target uncertainties due to systematic and random effects, different geophysical conditions (polluted vs background scenes), (ii) to get observational data on a wider list of influence quantities and ancillary parameters than usually available to routine validation, and possibly to perform the satellite retrieval with the parameters measured during the campaign instead of using for example climatologies, (iii) to get access both to sub-pixel inhomogeneities and features of the atmosphere and surface properties, and to the surrounding environment of the air masses probed by the satellite, and (iv) to assess the effect of influence quantities and atmospheric state on the data product quality, e.g., as polluted vs background conditions, high vs low surface albedo, dry vs humid conditions, different seasons, etc.
- For UV-VIS trace gases, most of the campaigns focus on the tropospheric NO_2 column product and to a lesser extent on HCHO and SO_2. For greenhouse gases, most of the activities focus on CO and CH_4 total column observations along with CO_2 total columns. Most campaigns focus on either the vertical distribution or the horizontal distribution of an atmospheric constituent. More efforts should be done to combine both.
- Cal/Val activities are performed with 1) airborne instruments, 2) mobile instruments, e.g. mounted on cars, ships, balloons and 3) stationary instruments. Airborne instruments mostly consist of hyperspectral imagers that allow to map the horizontal distribution of atmospheric constituents at high spatial resolution. Such data sets are well-suited to

compare with and average within the larger satellite pixels. Airborne instruments are often a first version, or use the same technology of the satellite. Some activities deploy airborne in-situ instruments to measure for example the vertical distribution of atmospheric constituents and/or aerosols. Mobile instruments, e.g. multi-axis DOAS spectrometers, allow to sample a fair amount of satellite pixels from the ground during the overpass and to capture spatial variability along the route. The deployment of COCCON spectrometer onboard a ship allows to measure the greenhouse gas total column concentration along the trajectory of the ship. The deployment of AirCore and Amulse (two atmospheric samplers) on meteorological balloons allows to measure the vertical profile of the target greenhouse gases. The stationary instruments are usually set up in a certain area for a short time interval (1-3 months) to support an airborne campaign activity. Sometimes they are set up for a longer time (1-2 years) to complement the existing ground-based monitoring networks, e.g. COCCON instruments are deployed in high/low albedo locations, polluted locations or regions with high humidity to complement the TCCON network.

- The campaigns have a strong emphasis on (sub-)urbanized/industrialised areas in Europe. These are densely populated areas with high exposure to air pollution. Thus, it is very relevant to perform measurements in these areas. Another reason is that strongly polluted sites are characterized by higher concentrations that allow to perform measurements well above the instrument detection limits. Such areas are also characterised by a strong spatiotemporal variability. Activities including COCCON instruments are on the other hand often set up in remote locations in order to cover strong high albedo (ice, desert) and low albedo (forest) sites.
- Most of the data is freely available upon request, and for most campaigns, data can be accessed via a data portal.

Highlight

The atmospheric campaigns are used for the preparation of future satellite instrument concepts and future Cal/Val phases, or for the Cal/Val of existing satellite instruments. The campaigns are performed during the operational phase of the satellite missions to validate if the satellite products meet the mission requirements and to provide an in-depth analysis of the data quality and associated retrieval process. The instruments are operated either on airborne (aircraft or balloon based), mobile, or stationary platforms. The campaign duration can vary between a few days and several weeks, sometimes even years depending on the scientific goals. The campaigns provide (i) high quality reference measurements from regions or areas not covered by operational monitoring networks or (ii) local high-resolution measurements around some network sites. This allows an in-depth analysis of the mission requirements under different geophysical conditions.

3 Networks/Infrastructures

3.1 Compilation of available networks/infrastructures

Overall Goal: Compilation of several networks/infrastructures supporting the implementation of campaigns.

Remark: Networks here are different from the ones listed in WP 2.4. These networks imply measurements with human intervention or they are depending on an external condition as a clear sky (e.g., balloon based atmospheric sampler AirCore and Amulse). This is why we also to refer to as network/infrastructure instead of purely network.

Our basis of this compilation of networks/infrastructures are the corresponding notes within the campaign survey forms. We did contact the managers of the infrastructures and project PIs (it should be noted, that projects like HEMERA can also be considered as networks) in order to complete a questionnaire, which is a combination of the campaign survey form and the questionnaire of WP 2.4, but more general and with a focus on sustainability aspects.

The five sections covered within the questionnaire are 1) general information, 2) financing and legal status, 3) data acquisition, 4) data handling and 5) future developments. This breakdown is reflected in the following chapter.

3.2 Available networks/infrastructures

3.2.1 General Information

Table 27: General information

Infrastructure	Website	Objective	Participating Copernicus Cal/Val	Financer	Status
AEROSTATS - French balloons	https://ballons.cnes.fr/fr	carry out balloon-born scientific experiments	No Copernicus Cal/Val	CNES CNRS	Permanent infrastructure (50 years of existence)
AirCore-Fr	https://aircore.aeris-data.fr	Measuring 0-30 km vertical profiles of CO_2, CH_4, CO, temperature and H_2O at 4 sites in France: Aire-sur-l'Adour, RMH (Reims-Moulin de la Housse), Trainou, Puy-de-Dôme.	No and no. Validation has been punctually performed for OCO-2, GOSAT-1/2, S5P and IASI. It is used for the preparation of the validation of MicroCarb, Merlin and IASI-NG.	CNES, CNRS, CEA, Ecole polytechnique, Université de Reims-Champagne Ardennes	Consortium
ARES	https://ares-observatory.ch	Measure terrestrial processes of the Earth system at regional scale	CHIME	Financing is currently covering the development and integration of the imaging spectrometer (ARES-IS), expected to be finalized in 2022.	Consortium of different research organizations, Lead: University of Zurich

DLR SAR Calibration Center	https://www.dlr.de/hr/desktopdefault.aspx/tabid-2459/3715_read-53570	SAR System Calibration	S-1A/1B, S-1C/1D, S-1 Next Generation, ROSE-L	DLR	Permanent infrastructure
EUFAR	https://eufar.org/	Linking the airborne environmental research community in Europe	Partly involved through the activities of its member organizations	membership fees and in-kind contributions	AISBL (Association internationale sans but lucratif)
EUROFLEETS+	www.eurofleets.eu	Alliance of European marine research infrastructure to meet the evolving needs of the research and industrial communities	No Copernicus Cal/Val	H2020 European Program	project
FLIS	http://olc.czechglobe.cz/en/flis-2/	Access to airborne hyperspectral or laser scanner data	FLEX PRISMA LSTM	Project-funded	Infrastructure of Global Change Research Institute of the Czech Academy of Sciences
HALO	https://www.halo.dlr.de/ or: http://www.halo-spp.de/	Atmospheric research and earth observation	Yes (S-5P)	initially funded by the Federal Ministry of Education and Research, the Helmholtz-Gemeinschaft and the Max-Planck-Gesellschaft. The operational standby costs are shared by six German research centers and the DFG (Deutsche	consortium

				Forschungsgemeinschaft), the HALO consortium	
HEMERA	https://www.hemera-h2020.eu/	HEMERA is a Research Infrastructure funded by the Horizon 2020 framework Programme of the EU which integrates a large starting community in the field of tropospheric and stratospheric balloon-borne research, to make existing balloon facilities available to all scientific teams in the European Union, Canada and associated countries. A wide range of scientific and technical themes are addressed, in particular atmospheric physics and chemistry, climate research.	No Copernicus Cal/Val	H2020 European Program	project
IFREMER	https://www.flotteoceanographique.fr/	Oceanographic measurements		IFREMER	Permanent infrastructure (deployment on-demand)
INTA-ARS	www.inta.es	Providing airborne remote sensing data for R+D projects (including Cal/Val activities)	No - the only obstacle is the lack of specific projects/contracts	Basic costs covered by INTA own funds; but marginal costs (i.e. campaign costs) have to be funded externally	Facility of INTA
INTA-PAZ	www.inta.es www.inta.es/paz-ciencia/en/	Calibration and validation of space systems, mainly focused on SAR.	No. No obstacles known.	INTA	Facility of INTA
MDH Reims site	https://www.univ-reims.fr/gsma/	This site is integrated on several networks for GHG, O3 and aerosols measurements	It is not yet integrated into Cal/Val's activities	CNES, URCA	it was created in 2019 and will be fully

					operational in 2022
ONERA-TERRISCOPE	http://onera.fr ; https://www.onera.fr/en/node/3292	TERRISCOPE is a shared research platform in airborne optical remote sensing for the characterization of the environment and continental surfaces from aircraft and drones	Most of our airborne experiment are devoted for cal/val activities in national program (defence) ou space mission like TRISHNA and Biodiversity/HYPXIM.	The TERRISCOPE platform was co-financed by the European Union (European Regional Development Fund), the Occitanie Region and ONERA	facility of ONERA
OpAiRS	http://www.dlr.de/opairs	Operating airborne sensors for optical remote sensing	Yes (S-2, DESIS)	DLR internal (HySpex is a DLR research facility), Calibration Home Base (CHB) is partly ESA funded	DLR user service
SAFIRE	https://www.safire.fr/en	Implement three research aircraft under the authority of CNRS, Météo-France and CNES for the benefit of scientific research during experimental campaigns. Member of EUFAR.	Yes	Météo-France, CNRS and CNES share the operating costs of the unit	research facility of Météo-France, CNRS and CNES
SIOS	www.sios-svalbard.org	Regional observing system for long-term measurements in and around Svalbard		Research Council of Norway	Cooperating RI
TERENO	www.tereno.net	investigate the impacts of global change on terrestrial ecosystems and their socio-economic effects.	several unofficial contributions	mainly through own funds from the participating Helmholtz centers	consortium
TERN-Tumbarumba	https://www.tern.org.au/	Refer to 2.4, TERN	Refer to 2.4, TERN	National Collaborative Research Infrastructure Strategy (NCRIS)	National research infrastructure

3.2.2 Data Acquisition

Table 28: Data acquisition

Infrastructure	Platform	Instrumentation	Measurement Target	Example of Campaigns
AEROSTATS - French balloons	stratospheric balloons (Zero Pressure Balloons ZPB and sounding balloons		Atmosphere	Stratéole-2
AirCore-Fr	Meteorological balloon	AirCore-light (atmospheric sampler <3kg)	atmosphere	MAGIC, RINGO
ARES	aircraft	imaging spectrometers (AVIRIS-NG, APEX, ARES-IS)	land, marine, atmosphere	UZH_CHIME
DLR SAR Calibration Center	Ground-based	one calibration site in Southern Germany with 29 target positions and permanently installed: 23 corner reflectors (1.5 m leg length), 3 remote controlled corner reflectors and 3 remote controlled transponders and an additional site in the North of Germany with 4 permanently installed corner reflectors (1.5 m leg length). Furthermore, several software tools for analyzing and evaluating the measurement data and deriving the calibration parameters	Spaceborne SAR system	DLR-SAR-CAL
EUFAR	aircraft	Variety of instrumentation to study Atmospheric composition and dynamics / Cloud and aerosol properties / Land and water surface properties / Vegetation identification and characterization /…	land, atmosphere, marine	FOAM
EUROFLEETS+	27 research vessels, 7 ROV's and 5 AUVs	requested/provided by the scientific users	marine	https://www.eurofleets.eu/access/scheduled-transnational-access-cruises/

FLIS	aircraft	Hyperspectral scanners (CASI-1500, SASI-600, TASI-600); Laser scanner (Riegl LMS Q780); Ionicon PTR-TOF6000 X2	land, atmosphere	Priscav SurfSense FLEX
HALO	aircraft High Altitude and Long-Range Research Aircraft (HALO)	wide variety of instruments (earth observation, particle measurements, trace gas measurements, geophysics) https://www.halo.dlr.de/instrumentation/instrumentation.pdf	land, marine, atmosphere	CoMet
HEMERA	stratospheric balloons (Zero Pressure Balloons ZPB and sounding balloons	provided by the scientific users	Atmosphere	Around 15 atmo experiements (DUSTER, Vortex-dust…)
IFREMER	18 shipboards with different capacities	Sonar, radar, weather stations, nautilus, specific buyos, sismology instrument, quality water analysis, GNSS, etc. + partner instruments depending on the campaigns	Ocean	SUMOS
INTA-ARS	Manned aircrafts (C-212, Stemme)	> hyperspectral sensors AHS, CASI, Headwall-CFL > thermal multispectral sensor (AHS) > field instrumentation: 2 ASD-FS3 spectro-radiometers	Land and coastal areas	Sentinel-3 pre-launch campaign (Sen3Exp)
INTA-PAZ	Satellite and calibration field	PAZ instrument (X-band SAR, 300MHz Bw) SAR calibration field: 32 passive corner reflectors (1m / 1.5m leg size) deployed over 30 calibration sites. 1 dual frequency RTK GPS.	Earth observation	PAZ mission commissioning phase and routine calibration. PAZ / TerraSAR-X cross verification campaign.
MDH Reims site	Tower, meteorological balloon	AMULSE, AirCore, LOAC, O3 probe	atmosphere	MAGIC, RINGO, APODRONE –AUSEA Networks: AirCore, ICOS, COCCON
ONERA-TERRISCOPE	we currently are using Safire national facilities (3 aircrafts), DLR	3 hyperspectral cameras covering 0.4-2.5 µm Fenix, Hyspex, Mjolnir 1 hyperspectral system covering 0.4 – 12 µm: Sysiphe	Land: forest (species, health, bio-chemical-	NAOMI 2018-2019: pollution AI4GEO 2021: urban area Foldout 2021-2023: H2020

	aircraft, but also our own aircraft (autoglider), and 5 drones (payload up to 7-8 kg)	One multispectral camera (up to 6 bands) in 0.4 -0.9 µm, very high spatial resolution: MUSCA 6 broadband and multispectral cameras in the MWIR and LWIR domains 2 x 3D lidar Riegel	physical properties, EBV), urban, bare soil, short vegetation, soil pollution, water pollution, plastic detection, soil moisture content Atmosphere: industrial pollution Marine: coastal zones	
OpAiRS	aircraft	imaging spectrometer (HySpex); high-resolution aerial camera system (3K camera)	land, marine, atmosphere	DLR_DESIS; DLR_Sentinel-2
SAFIRE	aircraft	Variety of instruments (for radiometry, microphysics, thermodynamics, dynamics and chemistry) https://www.safire.fr/en/our-facilities/aircraft-a-instruments/instruments-list.html	Land, marine, atmosphere	MAGIC, SUMOS, LIAISE, ASKOS/DACCIWA https://www.safire.fr/en/scientific-missions/scientific-projects.html
SIOS	aircraft drone	Imaging spectrometer; RGB camera	land, ice	https://sios-svalbard.org/AirborneRS_Call2020
TERENO	ground-based drone aircraft	4 different observatories in Germany acquisition of geophysical and spectral parameters hyperspectral systems and infrared cameras, microwave radiometer, SAR, LIDAR, air-chemistry instruments	land, atmosphere	JECAM

TERN-Tumbarumba	ground-based aircraft	Airborne and on-ground LiDAR and hyperspectral imagery calibrated using SLATS star transects, leaf sampling, tree structure and LAI measurements	land	Australian continental surface reflectance validation

3.2.3 Data Handling

Table 29: Data handling

Infrastructure	Data Quality Management	Quality Control	Metadata standard	Data Policy	Data Archive	Archive depth
AEROSTATS - French balloons	Depending on instrument	Depending on instrument	Depending on instrument	Depending on instrument	Depending on campaigns. Available on Aeris portal. https://www.aeris-data.fr/catalogue/	Many years
AirCore-Fr	Yes	yes	NASA AMES protocol	FAIR	https://aircore.aeris-data.fr	Several years
ARES	yes	yes	EUFAR HYQUAPRO	open access	https://apex-esa.org/en/campaigns https://avirisng.jpl.nasa.gov/dataportal/	The archive includes all data flown to date and will continue to do so in the future.
DLR SAR Calibration Center	yes	yes	CEOS: http://calvalportal.ceos.org/sar_subgroup/	data availability only for contractor	n/a	n/a
EUFAR	depending on instrument / operator	depending on	Good practices exist within EUFAR, implementation is operator specific	Data acquired within former EUFAR TNA (transnational access) is free and open	EUFAR data portal https://www.eufar.net/data-archives	The archive includes all data flown to

		instrument / operator	EUFAR standard metadata creators exist (ASMM, EMC)			date and will continue to do so in the future.
EUROFLEETS+	yes	yes	EUROFLEETS+ data management guidelines SeaDataNet Cruise Summary Report (CSR) and Common Data Index (CDI) files	https://www.eurofleets.eu/access/sea-call-oceans/eurofleetsplus-data-policy/	EVIOR portal https://evior.eurofleets.eu/ SeaDataNet CDI portal https://cdi.seadatanet.org	intermediate
FLIS	yes	yes	no	open to share data for scientific purposes	http://mapserver.czechglobe.cz/en/map	Project dependent
HALO	There is a data protocol	this is done individually by the instrument PIs	no	Agreed on in the HALO data protocol	HALO data bas	At least 10 years, depending where the data are stored
HEMERA	Depending on instrument Plateform data have no QM.	Depending on instrument	N/A	Users are asked to upload their scientific data after instrument correction on the HEMERA Data Portal.	https://data.hemera-h2020.eu/	Will depend on future funding
IFREMER	yes	yes		Open access (at least for most of them)	https://www.flotteoceanographique.fr/La-Flotte-en-action/Donnees-des-campagnes/Donnees-des-campagnes	Data available since 1901
INTA-ARS	no	yes	no	Data policy specified in each campaign agreement	Offline	

INTA-PAZ	No	yes	Same product definition and formats than TerraSAR-X mission.	https://www.inta.es/export/sites/default/.galleries/Paz-Ciencia-Descarga/EULA_PAZ_SCIE_EN_v1.0.pdf	Offline. Data portal in development	PAZ mission end of life + 15 years
MDH Reims site	Yes	yes	Depend on the instrument	Some free access through Aeris portal, some requested in the framework of a collaboration		
ONERA-TERRISCOPE	YES, following EUFAR Hyquapro standard	partially	Yes, owner metadata format	most of the time, ask ONERA		data availability since 2008
OpAiRS	Yes (ISO 9001 certification since 2007)	yes	CF convention, INSPIRE conform	tbd	DLR DSDA	Permanent
SAFIRE	There is a data protocol for SAFIRE's instruments.	Performed individually by the instrument PIs	No	Depend on the campaign	SAFIRE+ web portal (belongs to Aeris) https://safireplus.aeris-data.fr	
SIOS			WIGOS metadata standard		https://sios-svalbard.org/metadata_search	
TERENO	yes	yes	TEODOOR metadata	https://ddp.tereno.net/ddp/docs/TERENO-Data%20Policy%20V2.0.pdf	TERENO data discovery portal https://ddp.tereno.net/ddp/	
TERN-Tumbarumba	Refer to 2.4, TERN	Refer to 2.4, TERN	Refer to 2.4, TERN	Refer to 2.4, TERN	Refer to 2.4, TERN	Refer to 2.4, TERN

3.2.4 Further Developments

Table 30: Further developments

Infrastructure	Instrumentation	Method	Status
AEROSTATS - French balloons	Depending on scientific project, fully flexible		
AirCore-Fr		Possibility to launch balloon-borne AirCore at the overpassing time of a satellite.	
ARES	Additional instrumentation (LiDAR, photogrammetric camera system) planned		
DLR SAR Calibration center	two frequency bands in one transponder device (X- and L-band) as well as extension and adaption of analysis tools for future spaceborne SAR missions		
EUFAR	Fostering of coordination for the harmonized development of future airborne observing systems including aircraft, UAVs and instrumentation		
EUROFLEETS+			Project work package specifically aimed at developing a Roadmap for the future of the Eurofleets network to transition to a legal entity.
FLIS		test utilization of infrastructure for atmospheric measurements	

HEMERA			Possible future phase HEMERA 2 within Horizon Europe, starting after 2023. Possible extension towards an ERIC after this phase.
IFREMER	Many research fields to offer new opportunities to scientists to explore the Oceans https://www.flotteoceanographique.fr/Nos-technologies/Projets-de-R-D		
MDH Reims site	New measurements planed: - measurements under captive balloons (0-600 m) - measurements of N_2O and CO_2 with a Picarro labelled by ICOS - measurements of NO, NO_2, N_2O, NH_3 (MIRO)		
ONERA-TERRISCOPE	Use our recent instruments acquisitions onboard our drone flotte		
SAFIRE	The renewal of the Falcon 20 of the SAFIRE fleet by another jet is currently under study.		

3.3 Conclusions

- The collection of networks/infrastructures includes research aircraft, research vessels, balloons and calibration sites
- Several of the aforementioned networks/infrastructures offer a fully equipped research aircraft including the service of campaign management and data processing (e.g., ARES, OpAiRS, FLIS)
- Some of the mentioned infrastructures provide platforms for instruments (e.g., HALO, AEROSTATS) which can be involved in Cal/Val activities. The access for the scientific community to these infrastructures is highly variable: based on call for proposals or based on a partnership.
- DLR and INTA invested in infrastructure to calibrate SAR systems
- Mentioned project-like networks such as EUFAR, HEMERA or IFREMER support and govern the use of research infrastructures.
- TERN and TERENO offer well defined and instrumented survey sites as infrastructure.
- Overall, there is a different status of sustainability throughout the listed networks/infrastructures (from project-based facilities to established national research infrastructures)
- Supersites tend to appear, concentrating several measurements of several species, belonging to several networks and sometimes, moreover able to give access to platforms.

4 Possibilities and limitations

4.1 Campaigns for Cal/Val purposes

- Do the campaigns meet the FRM requirements:
    - documented SI traceability: a large proportion of the instruments are calibrated on a regular basis, so traceability to a standard is given.
    - uncertainty budget for all FRM instruments: this is so far only true for a smaller number of the instruments. Instrumentation, which is mainly used to validate satellite-based products (e.g., instruments of DLR's SAR Calibration Center) offer information on the uncertainty budget
    - defined measurement protocols and procedures: the use of protocols is common in most cases. Some of them are used only within the specific campaign, some are commonly used and developed for a larger community (e.g., EUFAR protocols, COCCON or TCCON protocols)
    - accessible to other researchers: data availability upon request with an underlying data portal to access the data is true for the majority of the campaigns
- During the pre-launch phase campaigns help
    - to define spaceborne sensor requirements
    - to prepare satellite product validation strategies
    - to test new measurement processes and new instruments
    - to support data product developments
    - to simulate potential future satellite missions
- During the commissioning phase, campaigns are necessary to validate the system calibration and to estimate the performance of the mission against the mission requirements. However due to administrative, financial, technical and other reasons campaigns are often delayed too deep into the operational phase, which is for example the case for S-5P.
- Campaign activities during the operational phase of a mission are conducted
    - to validate the product against the requirements, e.g., in terms of systematic and random errors and thus the product uncertainty
    - to assess the impact of different geophysical parameters on the product retrievals
- Airborne and ship-borne campaigns allow to record validation data at remote locations
- Airborne campaigns
    - cover a larger footprint than in-situ measurements on ground and therefore increases the spatial extent of the Cal/Val site

  - are often restricted to a certain aspect of the product, for example only the vertical distribution or horizontal distribution in the case of atmospheric constituents. More efforts are needed to combine both for in-depth analyses.
  - are very expensive: necessity of gathering several missions to mutualize.
- Drones as affordable and flexible solution to provide additional opportunities for "small" campaigns. However, from a legislation point of view it is not straightforward to operate drones over urbanised/industrialised areas.
- Calibration of airborne instruments may be as tricky as the spaceborne ones (esp. for altimetry):
  - common practice is often missing. Each institute (and maybe each instrument development event in the same institute) has its own habits and requirements.
  - nevertheless, joint standards for instrument calibration and operation are in development (e.g., for imaging spectrometers by IEEE P4001 and EUFAR)
- For active microwave (altimeter, scatterometer at low incidence angles): the airborne geometry is very different => large resolution gates, small swath (so very few gates per swath compared with the spaceborne instruments)
  - Due to the big geometry difference, the campaign data cannot be used for direct validation of ground segments
    - Nonetheless, very useful to SAR images because at medium incidence angles, the geometry is less different. It can be very representative of future images with respect to the SNR and resolution. Spatial swath will be very different.
  - Yet very useful for physics and preparing new missions
    - Especially, backscattering coefficient phenomenology (mostly when this is a new band or incidence to validate electromagnetic models),
    - first demonstration of concepts even if the geometry is very different (can prove that the signals contain the geophysical information)
  - Great benefits from the in-situ deployment specific to airborne campaigns: added-value to in-situ networks on very specific areas (e.g., Arctic campaigns) which may not be well covered usually
- Financing of campaigns are often an issue:
  - funding mostly only involves the data acquisition but not the further data analysis
  - there is mostly no secured long-time funding for the infrastructures (platforms, instrumentation)
- Survey site used for Cal/Val purposes within the campaign need to be very well characterized: best would be to make use of supersites /develop supersites
- Knowledge about the accuracy of the measurements / error traceability mandatory for Cal/Val campaigns

4.2 Infrastructures to support campaigns

- Well established infrastructures to assure good quality data acquisition
- Infrastructures to support/promote standards and protocols
  - Example: TERENO elaborates on good practices documents for terrestrial remote sensing validation
- Infrastructures to identify/define supersites
- Availability and exchange of instruments
  - Provision of an appropriate platform for the exchange of information
- Networks to provide validation frameworks and automatic independent validation tools
  - Link to CEOS WGCV Cal/Val group activities

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