2nd ESA EarthCARE Cal/Val Workshop Report

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Workshop introduction by Anthony Illingworth

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The launch of the EarthCARE mission is foreseen for March 2023, as all of its four advanced instruments have now been mounted on the satellite and are undergoing system tests. Two of these instruments use an active measurement technique, namely high-spectral-resolution LIDAR at 355 nm in case of the ATmospheric LIDar (ATLID), and Dopplerised RADAR operating at 94GHz for the Cloud Profiling Radar (CPR). This active sensing payload is complemented with passive remote sensing instrumentation, namely the Multi-Spectral Imager (MSI) and the Broad Band Radiometer (BBR). This specific combination of instruments is aimed at providing unprecedented insight into the vertical structure of clouds, precipitation, aerosols, and radiative properties in the atmosphere. The validation of the complex and numerous synergistic geophysical retrievals involved is in turn a daunting task, which requires preparation. As part of this preparation, thus far 2 workshops have been organised and the present report addresses the recent second ESA EarthCARE Validation Workshop.

The objectives of this 2nd ESA EarthCARE Validation Workshop were as follows:

- Fostering interactions between the algorithm developers and the validation team.
- Discuss and optimize validation approaches and methods
- Broaden international collaboration beyond the ESA and JAXA validation teams.

All presentations are available at the workshop website:

https://earthcare-val.esa.int/display/EEVP/2nd+ESA+EarthCARE+Validation+Workshop

These extensive presentations and the conclusions drawn from them provide a well-defined road map for the activities that are needed before the EarthCARE launch.

As the ongoing pandemic required that the workshop was organised as an online event, the decision was taken to collect inputs from validation teams and from algorithm developers in advance, and exchange this information prior to the workshop. This information was also used by the co-chairs to foster exchanges during the interactive sessions of the workshop. The workshop was attended by 248 participants.

Executive Summary

The (chronologically) last session of the workshop consisted of summaries of earlier sessions and a final interactive discussion, followed by closing thoughts by Anthony Illingworth. For the readers' convenience, these summaries are moved forward in this report in the form of the present executive summary, prior to detailed reporting on each of the domain-specific sessions in the full report.

Validation of the EarthCARE mission is an unprecedented challenge, as it has many data products (44 products produced by ESA and various others provided by JAXA) which cover a broad range of geophysical domains. A further complicating factor is the synergistic manner in which some of these products are generated. In addition the narrow swath of both active instruments presents challenges of its own, as does the dependence of the measured signals on microphysical properties of the particles along the beam, that cannot be characterised by remote sensing alone.

A few examples of focal areas for validation effort are aerosol type and size distributions, mixtures of aerosols, hydrometeor phase and size, ice-crystal characteristics at the cloud top, snowfall in high-latitutes, persistent deep layer of super-cooled water at cloud top, and many many more.

As for resources, by now there is a dense coverage by the various networks and stations, with most operating 24/7 with well-established quality control. Airborne measurements are of pivotal importance especially for EarthCARE, but very expensive.

Focussing on the first stage of validation, namely the commissioning phase, it is important to take into account the lessons learned from Cloudsat and CALIPSO on the importance of airborne validation measurements early on. The optimal flight configuration for such campaigns involves tandem flights along the ground track where one high-level aircraft with the same instruments as the satellite is flying above an aircraft equipped with in-situ sensors for cloud and aerosol particle characterisation. During the workshop the significant overlap was highlighted between the needs of EarthCARE in-orbit validation and the AtmOS (ACCP) sub-orbital component activities that are needed prior to the launch of the AtmOS orbital component.

Of the many lessons learned of, among others, the Aeolus mission, the importance of earliest possible release of preliminary data to the validation teams stands out. It cannot be stressed enough how much benefit has been derived from many independent 'eyes' looking at these not-yet-consolidated products. Also the benefits of monitoring of biases and variability in the deviations between lidar and radar observations and corresponding background values from the ECMWF IFS (and hopefully soon CAMS) models has been a lesson learned that should be taken to heart and if possible expanded to include even Doppler and MSI/BBR.

Discussions were numerous but highlighted the general need to coordinate the approaches and common practices, and to foster collaboration and build bridges to related missions and projects in the field of aerosol, cloud, precipitation, and radiation observations studies. Another common thread in all sessions was the difficulty of many teams to obtain funding, with prospects for improvement now that launch date confidence has markedly improved, which in turn should facilitate interactions of Principal Investigators and ESA with national funding agencies. There was a general request for access to Algorithm Theoretical Baselines of level 1 and level 2 products, and a general need for a process to identify priority areas and regions for further validation activities.

The following is a compilation of session-specific highlights, recommendations, and open issues as presented during the closing session. The order is identical to the detailed session reports in the next part of this report, which in turn matches the chronology of the actual workshop sessions.

ATLID Level 1 product validation

Highlights:

- Ground and Space-based ATBs (attenuated backscatter coefficient profiles) can not be directly compared. In order to validate the L1 ATBs, it will be necessary to use terrestrial based L2 products as a basis for "simulating" the corresponding ATLID ATB profiles (the Ground/Aircraft-L1-L2-Space-L1 approach).
- Monitoring of ATLID L1 signals by the Met centers (e.g. ECMWF) will be useful. This will build on efforts now coming on-line for Aeolus.
- Fast feedback from and to the Developer, Cal/Val, and Instrument teams will be necessary especially in the early stages of the mission. For Aeolus, the Cal/Val Wiki was found to be essential for facilitating rapid communication/feedback.

Recommendations:

- L1 ATBD as well as L1 (and L2) test data should be provided to the Cal/Val community as soon as this year.
- Simulated L1 ATLID ATBs from ground-based measurements should be reported in the Cal/Val data base together with the terrestrial based signals and their inversion products.
- The Simulation of L1 ATLID signals using terrestrial (ground/air) lidar data should be done in a coordinated manner. It should be up to the large networks to deal with that issue (e.g. setting up protocols) as well as setting sensible quality-control standards which can even be adopted by operators not in the networks. It is strongly recommended that ESA support the networks in this aspect. At the very least, a "How-to/best-practices" document including all required ATLID info should be formulated !
- Measurements at 355 nm will be prioritized. However, data at other wavelengths can be useful as well. Data from visible + IR wavelengths can be very useful for validating ATLID sensitivities as they are good for detecting thin cloud and aerosol boundaries (less Rayleigh Scattering than at 355n m). Using multi-wavelength systems (+photometers) for aerosol typing is considered very useful as well as using data bases, as e.g., LIVAS, to transform measurements at no-EarthCARE wavelengths to 355 nm..

Further Improvements and needs:

- Coordination between the networks and ESA including the Cal/Val data center likely needs to be made more concrete.
- The recommendations specified in the previous section should be followed. In particular the Simulation of L1 ATLID signals should be done in a coordinated manner, for example by the

networks, and it is recommended that ESA supports the networks, with at least supplying a “How-to/best-practices” to the Cal/Val community. Networks should also harmonise setting sensible quality-control standards which can even be adopted by operators not in the networks.

Aerosol product validation

Highlights:

Seven different parameters which need to be validated were discussed (Cloud-discrimination, layering, extinction/backscatter/AOD (355, 670, 865), depolarization, lidar ratio, Angstrom, aerosol typing)

Recommendations:

- If possible, Lidar systems should be upgraded to include a 355 nm channel (incl. depolarization capabilities) for validation of EarthCARE & Aeolus.
- Other wavelengths (532, 1064nm) can be used for many comparisons, however take care and describe how the wavelength conversion is performed.
- Having early information on the orbit will advise on network design, e.g. in setting up of specific stations dedicated for EarthCARE
- Campaign data sets can already be used for validation exercises (i.e. HSRL-2, 2021 Tropical Campaign, NARVAL/NARPEX, STRATEOL, A-LIFE, LOAC).

Further Improvements and needs:

- HETEAC is the aerosol model used by the L2 algorithms and needs validation (before and after launch; especially with airborne in-situ). There is need for information on HETEAC, a description will be provided soon by the developers.
- Common practice has to be documented and shared as well as how the retrievals/profiles were compared; i.e. For stations that do not belong to any network, quality control procedures can be based on ACTRIS practice if not yet defined.
- The publications of the EarthCARE Level 2 algorithms will be ready by mid 2022 and are eagerly awaited by the validation teams.

Observational Networks

Highlights:

Continental and global networks have well-established QA/QC procedures, well-defined products and central processing chains with NRT capabilities (ACTRIS/EARLINET, AERONET, ACTRIS/Cloudnet, MPLNET, AD-Net, SKYNET, LALINET…).

Recommendations:

- Intercomparisons between the networks should be made using the approach which is most feasible (field campaigns, collocated sites, aircraft overflights).
- Harmonization of the approaches for EC Cal/Val (collocation criteria, L3 products, statistical approaches, targets, -conversion…) need to be fostered.
- QA/QC support to single stations needs to be provided (access to calibration centres, provision of QA and processing tools)
- It was strongly recommended to include the ARM sites in the EarthCARE Cal/Val.

Therefore it was supposed to collect opportunities for EarthCARE Cal/Val after the workshop and make this information available.

Further improvements and needs:

- Possible improvements of the network strategies and Cal/Val products with respect to make use of additional observations for homogeneity and representativity checks (e.g. E-PROFILE, scanning systems…). Furthermore, it was recommended for the networks to use long observation periods around overpasses together with trajectory analysis to improve comparability. Finally, it was highlighted that priority geolocations need to be defined and observational gaps need to be closed by establishing additional sites or deploying mobile facilities
- Need of fast access to meteorological data for NRT processing, possibility to use X-MET product
- Need of interaction between the network data centres and EVDC to agree on data flows and harvesting of (meta)data

A meeting between ESA atmospheric Validation Data Centre and PIs was announced to be planned in the near future and was seen as essential by the network PI's.

Clouds & Precipitation (& CPR L2a) Validation

Highlights:

The community has a wealth of experience from CloudSat/CALIPSO/MODIS and their validation. The ground networks are mature, advanced and have stable funding. There is strong overlap between the EarthCARE and AtmOS pre-launch sub-orbital activities.

Recommendations:

- Validation of cloud-base estimated from EarthCARE synergy (AC-TC) using networks of ground-based ceilometers and lidars.
- Validation of EarthCARE detection (AC-TC) and retrieved microphysics (C-CLD, ACM-CAP) of liquid, supercooled and mixed-phase cloud using ground-based radar-lidar retrievals, and complemented by microwave radiometers and/or dual-frequency radar techniques to constrain estimates of liquid water content.

- Insights from multiple-frequency Doppler radars in ground-based and airborne configurations should be used for ongoing development, evaluation and inter-comparison of cloud and precipitation retrieval algorithms.
- Multiple-frequency radar techniques for constraining the vertical distribution of liquid cloud water should be developed and evaluated, for use in validating EarthCARE's synergistic blind zones.
- Provide to ESA recommendations and requirements for a commissioning phase aircraft campaign, including: (a) when to fly within the constraints of the commissioning of EarthCARE instruments and the possibility of short launch delays; (b) required aircraft instrumentation and flight strategy; and (c) locations and regimes to target.
- Coordination on standard procedures for accounting for gaseous, water vapour and liquid water attenuation from ground-based radars.
- Development of tools for transforming between downward- and upward-looking remote sensors for statistical validation against ground-based networks.
- Use ground-based and ship-based microphysical measurements to inform spatio-seasonal changes in cloud and precipitation microphysical assumptions.
- Aircraft remote-sensing with hyperspectral and microwave radiometers in addition to EarthCARE-like payloads will be essential to validating the consistent representation of ice microphysics across the spectrum, as well as to assessing the MSI smile effect. Ground-based stations with complementary radiation measurements should also be used for validating surface fluxes and heating rates.

Further improvements and needs:

- The target classification from active ATLID/CPR synergy suffers from blind zones (e.g. cloud base, liquid & mixed-phase cloud), with impacts on downstream retrievals including radiation.
- There are uncertainties in ice and snow microphysical properties & scattering across regions/regimes, and across wavelengths. There is a need for ongoing (perennial) in-situ measurements.
- Cloud & precipitation over the ocean is both of critical importance and difficult to validate (especially rain retrievals leveraging CPR ocean surface return).

Validation Campaigns

Highlights:

Many well characterized airborne (remote sensing and in-situ) and ground-based (incl. mobile platforms) facilities with well established QA/QC procedures exist. The capability of these facilities for EC Cal/Val has been proven in pre-launch campaigns for very different aspects and strategies for intercomparison of the different measurements have been developed. Quite a few planned campaigns (in different stages of maturity) have been identified which can serve for EC Cal/Val: E.g., two integrated campaigns with airborne/ground-based and additional activities with balloons, UVAs and ground-stations.

Recommendations:

- The potential of combining multiple aircrafts with remote sensing and in-situ instrumentation should be addressed.
- The combination of measurements with lidars and radars at complementary wavelengths is seen as very useful and should be supported. While clearly the EC wavelengths/frequencies are favored.
- Ground-based (campaign and network/permanent sites) and airborne measurements should be synchronized or combined to use the full synergy of these instruments for EC Cal/Val. In this way, the products from the different platforms can be intercompared and representativeness of the platform products can be investigated.
- Combining remote sensing and in-situ measurements should be done because it is very powerful. In-situ measurements alone are not favored as the context to the EC products is missing.
- Mobile facilities (some of them are available on demand) should be used to close the gap in the global observations. Especially, shipborne platforms (there are quite a few RV which can board remote sensing) should not be forgotten which might be exploited for EC cal/val to close the observational gaps over the oceans.
- L2 algorithms should be brought together with real measurements (previous and scheduled). This also means to foster the exchange between the different teams.
- Teaming up with the ATMOS initiative is seen as very beneficial for both sides.

Further improvements and needs:

- Bringing “everything” together is seen as key. The communication between the different PIs need to be established to combine efforts, e.g. in defining best measurement strategies and also best locations.
- It is still unclear how to deal with funding issues. Some proposed campaign activities are lacking secured funding and thus are yet very uncertain to take place.
- Regarding the cal/val schedule of airborne activities, a gap at the beginning of the post-launch mission was identified. If this is seen as crucial, the question arises how it could be filled. E.g., by ground-based measurements or if some opportunities for other airborne measurements can be identified.

Radiation Product Validation

Highlights:

- Established calibration procedures for MSI and BBR have been proposed
- Importance of good communication with instrument providers is an important lesson learned
- Importance of continuous monitoring of instrument performances and calibration, and to be ready to adapt processing
- The design of the BBR looks excellent, and implements solutions to the many problems encountered on GERB.

Recommendations:

- Make more use of Invariant Calibration Targets: Rayleigh Calibration, Deep Convective Clouds, Sun Glint, SST, (Pseudo) Invariant Calibration Sites (PICS) – and continue to do so during the entire mission lifetime
- Agree on protocols/procedures/common approaches for comparisons with other Satellite L1 products
- Use the moon as calibration target (if at all possible)

Further improvements and needs:

- Possible improvements of Radiation Cal/Val activities
- Establish/develop procedures for continuous monitoring of MSI and BBR L1 products
- Develop a procedure for spectral characterisation of MSI bands after launch
- Publish data about ground calibration sources (e.g. ground calibration source that should be close to "science" scenes).
- There is a need of access to housekeeping data data for instrument health analysis
- Funding has not (yet) been secured for several proposals or partners

-->**need for discussion between ESA and PIs on instrumental data availability and applied procedures**

Modelling

Highlights:

- There are a number of models being used within the cal/val effort (instrument, radiative transfer, dynamical models).
- Data can be used to evaluate models in clever manners, e.g., forward simulators, sampling, statistics.
- Methods, and models, could play a role in overall EarthCARE evaluation.
- Data can also be used for operational models, e.g., assimilation of lidar, radar.

Suggestions/recommendations:

- Consider of use of cal/val data to augment EarthCARE observations for models
- Coordinated modelling with campaigns, surface networks: reach out to modellers, AtmOS Modelling Group as needed?
- EarthCARE signal/product simulators to facilitate apple-to-apple model evaluation: appropriate complexity needs to be considered.

Remaining main issues and further needs:

- Is EarthCARE cal/val data of interest to those evaluating and developing models. Reach out as needed to groups.

Validation Workshop - Session Reports

In the following reports sections the individual sessions are reported in chronological order

Introduction Session

	Title	Presenter
Chairs: A. Illingworth (U.Reading), U. Wandinger (TROPOS) , N. Clerbaux(RMIB)		
Introduction	Welcome	R. Koopman (ESA)
	Workshop opening	D. Gillieron (ESA)
Mission & System	EarthCARE Status	D. Bernaerts (ESA)
	In-Orbit Characterization, Calibration and Verification of BBR and MSI	K. Wallace (ESA)
	In-Orbit Characterization, Calibration and Verification of ATLID	G. Tzeremes (ESA)
Chairs: Pavlos Kollias (Stony Brook U.), Luca Baldini (ISAC-CNR)		
Algorithms	EarthCARE L2 Validation Needs of the ESA Products and Algorithms	S. Mason (ECMWF)
Tools	ESA Atmospheric Validation Data Centre	A.M. Fjæraa (NILU)
	Atmospheric Virtual Lab	S. Niemeijer (S&T)
	E3SIM - EarthCARE Simulator	D. Donovan (KNMI)
	ICAROHS - Inter-Comparison of Aerosol Retrievals and Observational Requirements for Multi-Wavelength HSRL Systems	G.J. van Zadelhoff (KNMI)

Chairs: J. Fischer (FU Berlin), A. Battaglia (U.Leicester)		
QA/QC	Quality Assurance for Earth Observation (QA4EO) concept and example	J.C. Lambert (BIRA/IASB)
	The power of monitoring EarthCARE observations at ECMWF and preparing towards their assimilation.	M. Fielding (ECMWF)
	Fiducial Reference Measurement concept and FRM4Radar Cloud Profiling for Satellite Validation	J. Von Bismarck(ESA) L. Pfitzenmaier (IGMK)
ECVT	Validation preparations timeline	R. Koopman (ESA)
New principal investigators	EVID33 / AOID 51515 Validation of Atlid lidar data with ground-based lidars in Northern Sweden	P. Völger (IRF)
	EVID34 / AOID 51949 WEGN4CARE - Validation of EarthCARE cloud and precipitation products by the WegenerNet 3D Weather Research Facility in Southeastern Austria	G. Kirchengast and J. Fuchsberger (WegCenter)
	EVID35/AOID 60799 Validate Cloud Profiling Radar on EarthCARE against Aircraft Observations of Cirriform Cloud	V. Philips (INES)

Rob Koopman opened the introduction session by a brief overview of changes with respect to the previous workshop, and thanking ESA colleagues Alain Lefebvre (former EarthCARE project manager) and Damien Maeusli (former EarthCARE mission and system manager) and introduced their respective successors, Dirk Bernaerts (PM) and Kotska Wallace (Optical payload and mission manager).

Dominique Gillieron explained the context in which EarthCARE is developed, in particular the ESA Earth Observation programme in collaboration with European and global partners, and in particular the Earth Explorer programme implementing new missions for scientific research. His presentation also gave examples of Earth Explorer missions already in orbit, including Aeolus with its major impact on numerical weather prediction.

Dirk Bernaerts addressed the status of the EarthCARE mission, payload, and ground segment in detail, and stressed that EarthCARE is the most complex Earth Explorer developed thus far both in terms of payload instrumentation and in terms of data processing complexity. On the payload, the Atmospheric LIDAR (ATLID) is integrated onto the satellite and has completed all its performance tests and integration tests. The lifetime tests on a space copy of the laser are ongoing. The Multi-Spectral Imager (MSI) is also integrated onto the satellite and has completed its performance tests and integration tests. A modification of the baffle is underway to reduce thermal straylight into the thermal infra-red module. The intervention and subsequent tests can be done with the instrument mounted on the spacecraft.The Broad Band Radiometer (BBR) is also fully integrated and tested, and is awaiting the start of the system-level test campaign. The JAXA Cloud Profiling Radar (CPR) is mechanically and electrically integrated on the spacecraft. At present one of its two high-power transmitters (only one is needed for the functioning of the instrument, the other is backup) is integrated into the instrument, the second unit is presently being manufactured. The present configuration will allow some system-level tests to proceed, and once the spare power transmitter is available, it will be integrated and the remaining system-level tests can be completed. Having all four instruments mounted and their performance tested has allowed to further consolidate the EarthCARE schedule with a launch date of March 2023 with a detailed schedule for staggered release of the data products to the validation team, well before the public release.

Kotska Wallace addressed the in-orbit characterisation, calibration, and verification in general, and also specifically for the BBR and the MSI instrument. The instruments each have a different timeline of checkout and decontamination and characterisation, with ATLID expected to be the last instrument to enter the phase of nominal observations after approximately 50 days. For BBR, the Long Wave and Short Wave calibration steps were addressed, and also the use of black-body swap for detector linearity characterisation. For MSI the approaches for the VNS (Visible, NIR, and SWIR-1) camera and TIR (Thermal Infra-Red) camera calibration approaches (involving diffusers and black body respectively) and verification approaches were presented.

Georgios Tzeremes presented the ATLID calibration and verification, in particular the calibrations performed during routine operations, namely radiometric calibration assessment through background signal monitoring, spectral cross talk calibration by seeking out “Mie-” and “Rayleigh”-only situations, absolute Rayleigh and Mie co-polar and cross polar calibration again by using nominal measurements with for each of these calibrations a specific combination of scene selection/filtering (e.g. high ice clouds), and the application of extra information (e.g. the already characterised known cross talk of a pure Rayleigh spectrum into the co-polar channel, or the use of already characterised ground sites).

David Donovan summarized the validation needs for the ATLID products. For that, he gave a brief summary about ATLID, highlighting its HSR capabilities and detection sensibility. He emphasized that ATLID L1 products are not directly measured, but are a product of applying instrument response function and cross-talk correction to the measured signals. He explained the different cross talks (spectral and polarization related) and presented the applied correction scheme and identified that the main challenge of validation of L1 products is the validation of expected sensitivity limits and the spectral-polarization cross-talk correction. Following that he stressed the need to validate the value of the effective Rayleigh Depolarization ratio for ATLID! As spaceborne and ground-based attenuated backscatter coefficients cannot be directly compared, Dave Donovan recommended to use high quality terrestrial (inc. airborne) lidar observation of extinction, backscatter and linear depolarization ratio profiles at 355 nm to “simulate” the EarthCARE attenuated backscatter coefficient profiles. Finally, he stressed that even though the presentation has focused on the cross-talk problem there will also be several other less-complex but still important issues to deal with and which should not be forgotten about: E.g. the altitude assignment and the correct pointing of the instrument.

Rene Preusker presented the validation needs for the MSI. The MSI instrument was briefly introduced, and he highlighted that the radiometric accuracy required should be better than 10% or 1K, interchannel accuracy better than 1% or 0.25K and a radiometric stability of 1% or 0.3K/year. A short review of the calibration of the MSI - VNS was also presented, daily calibrations will be done over the South Polar Region and Dark calibration will be performed at the night side of the orbit. The MSI - TIR calibration will be performed once per day. A comprehensive list of in-flight needs to be validated was presented, including, absolute and relative radiometric, linearity, straylight (spectral and spatial), spectral position, and their dependencies with respect to the FoV and the orbit. René provided examples of invariant calibration targets, i.e, Rayleigh Calibration, Deep Convective Clouds (DCC), Liquid Water Clouds (LWC), Sun Glint, the Moon, Sea Surface Temperature (SST) and pseudo invariant calibration sites. The Simultaneous Nadir Observations (SNO) for intersatellite comparisons using Geos and HR sensors was also proposed for the Calibration / Validation. Closure between the BBR and MSI measurements in the same platform was recommended. Eventually, Rene underlined some lessons learned from previous missions, such as: the importance of effort and budget to be allocated to instrument pre-launch characterisation and knowledge transfer; multi-sensor radiometric inter-comparisons; orbital maneuvers to provide view on the moon for stability monitoring, diffusor BRDF investigations and finally calibration as a never-ending process to be performed throughout the full mission lifetime and beyond.

Shannon Mason presented a breakdown of the EarthCARE L2 algorithms and summarized the validation needs raised by their developers (Table 1). Two kinds of uncertainties were most common: challenges in identifying cloud and aerosol layers and constraining their properties in complex or layered scenes; and of how the applicability of the physical assumptions underpinning our retrievals may vary across regions, seasons, and regimes. Finally, a range of validation paradigms were discussed with examples from EarthCARE's synergistic cloud-aerosol-precipitation retrieval algorithm (ACM-CAP), from direct validation of microphysical assumptions using airborne and ground-based in-situ and remotely-sensed measurements, to developing statistical datasets characterising key processes and regimes, and using numerical models and instrument simulators to quantify retrieval uncertainties.

Table 1. Summary of the EarthCARE L2 algorithm development and validation needs

	Uncertainty	Locations/scenes/regimes	Measurements needed	Products
Macrophysics	Aerosol layer detection	•Multiple aerosol layers •Aerosol layers with strong internal structure •Attributing aerosol plumes at nadir to features in the across-track imagery	•Ground-based (& scanning?) and airborne lidars	A-ALD, AM-ACD, A-TC
	Aerosol/cloud discrimination	•Cloud embedded in aerosol layers	•Ground-based lidars	A-ALD, AM-ACD, A-TC
	Cloud layer detection and structure	•Multiple cloud layers •Cirrus over liquid cloud •Non-precipitating liquid clouds	•Ground-based (& scanning?) lidars & radiometers	M-CLD, AM-CTH, A-TC, C-TC, AC-TC
	Liquid clouds not fully resolved by radar/lidar synergy	•Physical depth of liquid clouds (i.e. cloud base height) •Mixed-phase layers embedded in ice •Liquid (& liquid-topped mixed-phase) clouds below optically thick ice clouds •Warm liquid clouds within cold rain	•Ground-based ceilometers/lidars •Multiple-frequency radars to constrain W-band attenuation •Microwave radiometers for LWP •Aircraft profiles of LWC	A-TC, C-TC, AC-TC

	CPR surface clutter removal	•Range of surface types	•Ground-based radars	C-TC, C-FMR
Ice cloud & snow	Snow microphysics (e.g. PSDs, microwave scattering, density & fallspeed)	•Stratiform vs convective •Rimed snow	•Bulk precipitation and particle imaging measurements at surface •Profiles of in-situ particle properties in ice clouds	C-CLD, ACM-CAP
	Ice microphysics (e.g. PSDs, ice optics, mass-size rel'n)	•Cloud-tops across range of temperatures, locations & cloud types	•In situ aircraft measurements •Visible & IR radiances	A-ICE, ACM-CAP
	Surface snow rate	•Range of meteorological conditions	•Ground-based radars and in-situ at surface	C-CLD, ACM-CAP
Liquid cloud	How to account for radiatively-important liquid clouds not detected by ATLID	•Deep ice clouds: embedded mixed-phase layers •Layered cloud scenes •Warm liquid clouds within cold rain	•Microwave radiometer for LWP •Profiles of liquid water content	ACM-CAP
Rain	Relation between rain rate and drop size distribution	•Warm rain (maritime) •Convective/stratiform rain	•Ground-based multiple-frequency radars •Dual-pol weather radars over ocean	C-CLD, ACM-CAP
	Melting layer structure & radar attenuation	•Dependence on snow properties aloft •Continuity of mass flux & size distributions across melting layer	•Ground-based & airborne multiple-frequency radar	C-CLD, ACM-CAP
Aerosol	Large AOT uncertainties over land; sensitivity to aerosol classification	•Range of different land classes (biomes) & ocean •Range of different aerosol classes	•Ground-based, e.g. AERONET(-OC) •Ship-based sun photometers, e.g. MAN •Satellite imagers, e.g. MODIS, VIIRS, 3MI	M-AOT
Radiation	Detection of and/or representation of fluxes over snow-covered surfaces	•Range of snow-covered surfaces	•High-latitude ground stations	BM-RAD, BMA-FLX

The recent updates to the functionality of the ESA atmospheric Validation Data Centre (EVDC) were presented by A.M. Fjæraa (NILU). She mentioned that the data centre served several ESA missions but also hosted data from networks such as NDACC, EARLINET, PGN, TCCON, COCCON and ACTRIS and is providing input data for the COPERNICUS Atmosphere Monitoring Service (CAMS). The EVDC hosts validation data ("correlative data") and for some missions it also provides access to satellite data with subsetting and filtering. The full functionality for correlative data handling is available when data are uploaded in GEOMS format, and support tools for conversion of files to this metadata standard are available on the EVDC portal. Also analysis and forecast data files of global gridded meteorological parameters from ECMWF are available via the EVDC. The OPOT tool on the EVDC portal provides overpass information for many missions, including already a hypothetical scenario for EarthCARE. It should be noted that the actual overpass pattern may shift as the exact position of the EarthCARE orbit has not been decided yet.

Sander Niemeijer from S[&]T presented the ESA Atmospheric Virtual Lab and in particular the HARP toolbox that supports intercomparison between EarthCARE data and correlative data, for example those in the ESA Atmospheric Validation Data Centre (EVDC). He mentioned the upcoming adaptations for EarthCARE, including ingestion of correlative data and dedicated HARP operations for the cloud and aerosol domains. HARP is already used operationally for Sentinel 5P systematic validation, at the EVDC, and in the CAMS service.

David Donovan from KNMI presented after the coffee break the potential role of E3SIM in the Cal/Val activities. He used the example made in the first talk, to highlight that measured signals from ground and space cannot be directly compared. In that case, E3SIM may help especially when the simple simulation by high performance ground based data as explained in his first talk is not sufficient to traceback potential problems of ATLID. Nevertheless, using E3SIM is for sure not a simple approach, which can be easily applied by someone. Expert knowledge and practically speaking significant resources and commitment is needed to run this model. So E3SIM is very powerful but will be used for a few selected cases and cannot be offered by KNMI as a ``general service'' to the community.

Following Dave Donnovan's presentation, Gerd-Jan van Zadelhoff , also from KNMI gave an overview over ICAROHS for the creation of realistic scenes using E3SIM. He showed various examples and presented some of the input dtaa. He concluded that simulations will play an important role in ATLID L1 validations and, like Dave Donovan stated, that the simple approaches should be used first. But if these simple simulations are not applicable, E3SIM is a powerful but complex toolbox to be used - even though it should be always clear that it is not direct validation.

Jean.-Christopher Lambert (BIRA) introduced the framework for Quality Assurance for Earth Observation (QA4EO) and addressed implementation methods, tools, and examples. The framework formulates guidelines for establishment of requirements, interoperability, definition of quality indicators and for quality reporting, and is already applied structurally in many CEOS missions. To support the workshop objective of common validation approaches, he highlighted a study of validation practices across domains. As example of QA4EO implementation, Quality Assurance system for EO Essential Climate Variables was described, namely for NO2

Mark Fielding (ECMWF) presented the developments for monitoring and potential assimilation of EarthCARE data at ECMWF. Using Aeolus monitoring as an example he explained the power of monitoring using assimilation models as it is very sensitive to detection of biases (e.g. the data quality turned out to have a dependence on primary telescope mirror temperature, which has been corrected by a bespoke correction algorithm). In preparation for EarthCARE data availability, tests have been run with simulated EarthCARE data and with Cloudsat and CALIPSO data, demonstrating the ability to detect even small biases rapidly. In turn, simulations also suggest a significant impact of the ingestion of EarthCARE lidar backscatter and radar reflectance on the ECMWF cloud model analysis and forecasts.

Jonas von Bismarck (ESA) introduced the concept of Fiducial Reference Measurements (FRM) namely a suite of independent, fully characterized, and traceable ground measurements that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO). The traceability to SI standards should be documented and follow metrology standards and/or community standards with a well-specified uncertainty budget and community wide practices for measurements, processing, archiving, accessing, and documentation. He itemised several ongoing initiatives to work towards such community standards, the “FRM4 ….” projects, as introduction to the following talk on the FRM4Radar project.

Lukas Pfitzenmeier presented the FRM4Radar project (https://geomet.uni-koeln.de/forschung/frm4radar), a Cloud Profiling Radar Network for Satellite Validation, which targets to pave the way towards Fiducial Reference Measurements for the EarthCARE Cloud Profiling Radar (CPR) L2 ESA products. The standards and approaches that will be followed consist of complementary 94-GHz radar network measurements as part of Cloudnet, in the same wavelength as the EarthCARE CPR radar, the fill of geographical gaps in the ground-based network with long term observations, the coverage of different cloud climate regimes, the development of new cal/val products, the near real time data processing and visualization with GEOMS data format files, data quality checks (concerning the received power calibration and the antenna pointing characterization) and data retrievals with the Cloudnet algorithm. Within the project a simple radar forward model will be developed (to account for different sampling, sensitivity and surface clutter between the ground-based and space based observations) in order to enable a more objective comparison between the CPR and the FRM4Radar measurements. The same framework was suggested to be applied to model-CPR comparisons.

The organisation of the upcoming activities of the ECVT was addressed by Rob Koopman (ESA). He addressed the upcoming workshops and planned and possible dedicated/topical online events in between, and introduced the organisational subgroups for the validation team, which were already reflected in the workshop agenda. The interactive portal was already intensely used as preparation tool and confirmation was obtained that also co-investigators of the ECVT principal investigators will be provided with access to the portal. In closing the EarthCARE validation effort was placed into the broader context of multi-mission aerosol, cloud&precipitation, and radiation product validation. Scientific effort on EarthCARE validation builds heavily on experience with earlier missions and will be highly relevant to already planned upcoming missions beyond EarthCARE. This was also reflected in the workshop agenda with lessons-learned and forward looking presentations.

Peter Völger (IRF) opened the brief introductions of those projects that joined the ECVT after the Bonn workshop, by presenting the plans for the IRF lidar system at Kiruna and the in-situ samping of cloud particles with a balloon-borne particle imager. The project is aimed at validation of cirrus and Polar Stratospheric Clouds

Gottfried Kirchengast and Jürgen Fuchsberger (WEGC of the University of Graz) introduced the dense network of 156 climate stations on almost a regular grid covering 22km x 16km including at selected stations precipitation radars, microwave and infra-red radiometers, and GNSS water vapour measurements. The project seeks to validate cloud base height, convective classification and melting layer base and top heights with the cloud radar and liquid water content and path with the radiometers. The combination of Xband weather radar and ground-based precipitation data will validate the rain rate, rain water content, raindrop number concentration and diameter, the rain classification and the convective classification

As preview of his later presentation in the model session Vaughan Philips (INES) introduced the plans to validate the microphysical assumptions of the algorithms by inferring ascent from EarthCARE, by using aircraft data flying through cirriform clouds during EarthCARE overpasses.

Session 1: ATLID Level 1 and Aerosol product validation

Chairs: U. Wandinger, H. Baars, D. Donovan, G.-J. Zadelhoff, M. Haarig , N. Docter, M. Eisinger

This session opened the sequence of sessions discussing the validation approaches applicable to a specific domain. This particular session was dedicated to validation of the ATLID Level 1 product, and the second part of this session focused on the ESA aerosol products (single and multi-sensor products.

Presentation summary

Title	Presenter
Lessons learned from Aeolus Cal/Val and the DISC	**Oliver Reitebuch - DLR**
Lessons learned from CALIPSO	**Dave Winker - NASA**
The ACCP orbital component	**Dave Winker - NASA**
ACCP suborbital component - Aerosol	**Jens Redemann - Univ. of Oklahoma**

O. Reitebuch (DLR) presented the Aeolus mission and its highlights. He stressed the great importance of DISC for a successful mission especially due to the close cooperation between scientists, ESA and industry. DISC includes the algorithm and processor development, instrument monitoring and product quality assessment. He reported on how the processor chain is updated every 6 months according to the actual findings of the Cal/Val teams and the DISC. He also stresses that Aeolus and EarthCARE (EC) benefit from each other. EC feature mask has been implemented in Aeolus, Dave Donovan's OEM will be implemented in the September 2021 Aeolus data processing chain release.

Concerning validation, he states that ground based measurements are key and there is a need for routine observations by active teams which need national fundings. **Funding of expert Cal/Val teams** is crucial for the Cal/Val and should be well prepared. The VIRES tool proved to be very powerful. A modern communication strategy including the cal/val wiki page and confluence is key. The main lessons learnt from Aeolus are:

- Monitoring tools for instrument parameters and products are essential after launch
- Many unexpected behaviours --> continuous commissioning phase
- DISC is crucial
- Strong support from Cal/Val teams is essential for mission success. He proposes a joint Aeolus validation in preparation of EC
- Benefit between EC and Aeolus and in support of an operational follow-on mission of Aeolus

Recommendation: EC Cal/Val teams should join Aeolus Cal/Val! It was further discussed that the already existing synthesis reports of Aeolus could be used as input, i.e. , as template for EC.

Dave Winker (NASA) talked about the lessons learned from CALIPSO and especially stated that calibration is a never ending process. After each data release, validation efforts are ongoing. He also stated that the first targeted **validation campaign was one month post launch**. Here, **a gap for EC was seen** as currently no dedicated airborne campaign in the commissioning phase is foreseen. He also considered the continuous HSRL underflight as useful to check the Calipso calibration over time. Direct L2 validation is considered to be difficult. He considered as validation resources ground-based networks (Aeronet, Earlinet, ADnet), satellite comparisons (MODIS, MLS, AIRS, CALIOP vs IIR), targeted and continuing airborne campaigns, and large field campaigns. He also emphasized that a global data set needs global validation: There are "empty areas" in terms of validation capabilities like the southern oceans. On the other hand, validation tends to be only one of many objectives in a scientific campaign (airborne or ground or both). Therefore satellite2satellite validation is considered to be as always useful. It also was discussed that retrieval consistency checks are very useful as well as the inter-comparison of the algorithms from multiple retrievals based on independent assumptions. During the discussion, Ulla Wandinger recommended that one should make the best possible use of **other scientific campaigns** not yet targeted for EC Cal/Val but **could make a valuable contribution.**

In his **second talk David Winkler** presented the ACCP orbital component which is now called ATMOS. He presented that the dual-orbit concept was recommended to NASA headquarters and that they are now entering Pre-phase A. ATMOS or fromer ACCP has 3 main elements, the orbital one, the sub-orbital one and modelling. This holistic view on a mission is considered to be a main achievement already. They aim to determine the size and number of aerosols due to the HSR and polarimeter capabilities. Lifetime is officially to be 3 to 5 years.

Jens Redemann (Univ. of Oklahoma) later presented the suborbital (in ESA language: the Cal/Val) of ATMOS. He highlighted that **suborbital activities are an integral part of ACCP missio**n as already Dave Winker has done and that a process mission like ATMOS can be done only when suborbital science is done. He also stressed the spectrum of implementation strategies from ground-based to multi-aircrafts with **emphasis on strong intra-agency, inter-agency, and international partnerships** with m**aking use of existing networks, regional supersites, and targeted campaigns.** Thus, use of existing data sets and foster relationships with partners is key. The real sub-orbital work, e.g. first pre-studies for ATMOS will start not earlier than Spring 2022.

ATLID Level 1 Product Validation

Highlights:

Ground and Space based attenuated backscatter profiles (ATBs) cannot be directly compared. In order to validate the L1 ATBs of EC,it will be necessary to use terrestrial based L2 products as a basis for "simulating" the corresponding ATLID ATB profiles (the Ground/Aircraft-L1 L2Space-L1 approach).

Monitoring of ATLID L1 signals by the Met centers (e.g. ECMWF) will be useful. This will build on efforts now coming on-line for Aeolus. Might be particular useful to identify "rogue" profiles.

Fast feedback will be necessary especially in the early stages of the mission. Therefore also preliminary data from the Cal/Val teams is beneficial and should be fostered to be delivered as soon as possible. Not only data delivering but also own investigations are very welcome and should be communicated to ESA. For Aeolus, the Cal/Val Wiki was found to be essential for facilitating rapid communication/feedback.

Recommendations:

- The Level 1 ATBD as well as the L1 (and L2) simulated data should be provided to the Cal/Val community (ECVT) as soon as this year.
- Real L1 data should be made available to Cal/Val teams as soon as possible after launch
- Predicted L1 ATLID ATBs should be reported in the Cal/Val database as well as the terrestrial based signals and inversion products.
- The simulation of L1 ATLID signals using terrestrial (ground/air) lidar data should be done in a coordinated manner. One option would be to have the networks deal with (as well as setting sensible quality-control standards which can even be adopted by operators not in the networks). It is recommended that ESA support the networks in this aspect. At the very least, a “How-to/best-practices” document including all required ATLID info should be formulated !
- Cal/Val (correlaive) lidar measurements at 355 nm will be prioritized. However, data at other wavelengths can be useful. Green + IR data can be very useful for validating ATLID sensitivities as they are good for detecting thin cloud and aerosol boundaries (less Rayleigh Scattering than at 355 nm). Green + UV mapping using multi-wavelength systems (+photometers), aerosol typing and, e.g., LIVAS database info may be useful.
- Dave Winker is recommending that calibration should be done between 35 and 40 km (as done now for Calipso) and by using Merra-2

Further Improvements and needs:

- Coordination between the networks and ESA including Cal/Val data center likely needs to be made more concrete.
- The recommendations specified in the previous section should be followed. In particular: The Simulation of L1 ATLID signals should be done in a coordinated manner.

For the L1 validation, measurements at the wavelength of 355 nm are needed. Whereas L2 validation could make use of input at other wavelengths, especially 532 nm, as well, although 355 nm are prefered. L1 validation also needs measurement covering the stratosphere. Coordinated underflights are seen as key, while from ground-based remote-sensing measurements the long-term observations are considered especially useful.

The L1 ATBD is on the way to be available to Cal/Val teams. The L1&L2 test data should follow to help the Cal/Val teams in getting familiar with the data structure. A Wiki/Confluence is a crucial tool for fast feedback from Cal/Val teams during the whole mission.

Aerosol Product Validation

Highlights:

The algorithm developers defined the following validation needs for the aerosol L2 products:

1. **Aerosol-cloud discrimination**
   Here lidar measurements at any wavelength are welcome. Longer wavelengths are more powerful in the separation of aerosol and cloud layers as they are less affected by Rayleigh scattering. Model data such as from ECMWF could be used to check for cloud probability. The cloud forecast is included in X-MET and can be used.
2. **Layering / layer heights**
   Hlidar measurements at any wavelength are welcome. Longer wavelengths are more powerful in the detection of aerosol layers as they are less affected by Rayleigh scattering. For validation layer height a different (stricter) colocation criteria might be used as for e.g. the lidar ratio.
3. **Aerosol Extinction/backsatter & AOD**
   The aerosol optical depth is not just needed at 355 nm, but as well at 670 and 865 nm to validate the MSI retrieval. The extinction coefficient could be transferred from other wavelengths using the Ångström exponent provided by AERONET.
4. **Lidar ratio**
   A Raman or HSR lidar is necessary to measure independently the extinction coefficient and to provide the lidar ratio. Measurements at 355 nm are prefered as the spectral behavior of the lidar ratio depends on aerosol type and age.
5. **Depolarization ratio**
   For the particle linear depolarization ratio, measurements at 355 nm are prefered as the spectral slope in the 355 - 532 nm range depends on aerosol type. A good aerosol typing is needed to use the correct relationship. Note that Aeolus measures the circular depolarization ratio.
6. **Ångström exponent (AE)**
   The AE should be considered as a diagnostic quantity as it is estimated from retrieved AOTs at 355, 670 and 865 nm.
7. **Aerosol typing**
   Various aerosol typing schemes are available in literature. The definition of the aerosol types should be clearly communicated, as there might be significant differences (typing based on origin, emission source, physical properties etc.). For EarthCARE, the HETEAC scheme is used. Nevertheless, a typing for validation can originate from a combination of lidar ratio and depolarization ratio at 355, 532 and/or 1064 nm (HSRL or Raman lidar) or airborne (this includes UAV) in-situ data inside the aerosol layer (e.g., effective diameter, refractive index) combined with lidar profiles for layer information if available.

Recommendations:

If possible, upgrade your Lidar systems to 355 nm including a depolarization channel for validation of EarthCARE & Aeolus.

Other wavelengths (532, 1064nm) can be used for many comparisons, however take care and describe how the wavelength conversion is performed.

Having **early info on the orbit** will advise on network design and enable the setup of specific stations.

Campaign data sets can already be used for validation exercises (i.e., HSRL-2, 2021 Tropical Campaign (now called A-TAC), NARVAL/NARPEX, STRATEOL, A-LIFE, LOAC).

Trajectory analysis in combination with ground-based observation shall be used for analysing the representativeness. Co-location is only one criteria. For different products (e.g. layering, cloud detection) stricter co-location criterion might be applied than to others (lidar ratio).

Heritage from the ESA project to validate sentinel-3 AOD can be used for the validation of the EC AOD.

Further Improvements and needs:

HETEAC is the aerosol model used by the L2 algorithms. It is worth to remind that HETEAC is made for radiative closure of EC and thus estimates aerosol microphysical properties. Thus, HEATEC needs validation. This should already be done before launch, especially with collocated airborne in-situ and lidar observations (ground-based or airborne). This effort should be continued after launch as well by **adding** airborne in-situ observations of the **aerosol effective diameter and refractive index to the validation strategies** by ground-based lidar stations and airborne lidar systems. For underflights with an EarthCARE-like payload, a second aircraft should be considered to measure inside the aerosol (and cloud) layers.

There is need for information on HETEAC, a describing publication will be provided soon (an conference proceedings paper is already available here: doi.org/10.1051/epjconf/201611901004). HETEAC information should be made available on confluence. The L2 algorithm publications will be ready by mid 2022.

For own Cal/Val investigations, the common practice has to be documented and shared as well as how the retrievals/profiles were compared; i.e. QC can be linked to ACTRIS practice if not defined yet. The QA/QC should follow the network guidelines, e.g., the ACTRIS/EARLINET calibration procedures. These standards are open to everybody.

Session 2: Observational networks

Chairs: Jonas v. Bismarck, Luca Baldini, Ulla Wandinger

“In this session, validation considerations for networks were discussed, including application of network standards to non/not-yet networked stations.”

The session was dedicated to the well-established continental and global lidar, radar and photometer networks. These **networks have** long-term experience in supporting satellite Cal/Val activities and **their own dedicated quality-assurance measures and processing chains**. Lessons learned from previous activities were introduced, and the networks presented their efforts in preparing EarthCARE Cal/Val activities.

Title	Presenter

Lessons learned from the validation of Aeolus L2A product with EARLINET	**Nikos Siomos - NOA**
Perspectives on ground validation from the NASA/JAXA Global Precipitation Measurement Mission	**S. Joseph Munchak - NASA**
ACTRIS Aerosol Remote Sensing in support of EarthCARE Cal/Val	**Doina Nicolae - INOE**
ACTRIS Cloud Remote Sensing in support of EarthCARE Cal/Val	**Ewan O'Connor - FMI**
MPLNET observations in support of EarthCARE Cal/Val	**Judd Welton - NASA**
Approaches to intercalibration/QA/QC and other network aspects of AD-Net and SKYNET systems	**Tomoaki Nishizawa - NIES**
LALINET network approaches for QA/QC, validation and data handling	**Eduardo Landulfo - IPEN**

Presentation summary

Ulla Wandinger introduced the scope of the session, consisting of short (10-min) presentations followed by a discussion.

Nikos Siomos (NOA) introduced the EARLINET Cal/Val activities. EARLINET is part of ACTRIS and involved in the validation of Aeolus L2A products. Data collection is conducted for orbits within 100 km and ±3hours. Own threshold-based criteria have been developed for data quality checks of Aeolus, but more sophisticated approaches are under development. Data flags developed for Aeolus have increased the correlation between EARLINET and Aeolus estimates, especially for estimates collected at 2 km above the ground. Specific strategies are under development for identification of Saharan dust. EARLINET data are converted to Aeolus-like profiles (as Aeolus is measuring only the co-polar component of the backscatter). **Cloud flagging is considered to be key**.

S. Joseph Munchak (NASA) summarized the lesson learned from the GPM ground validation programme. GPM Ground Validation (GV) is based on three main components, namely Direct GV (involving operational network for statistical comparisons), Physical GV (based on field campaigns to investigate physical assumptions of algorithms), Integrated GV (to assess the impact of products). Fields campaigns were conducted in both pre- and post-launch phases. GV includes two supersites (Wallops and Marquette) and relies heavily on ground-based weather radar belonging to operational networks, both in the US and outside the US. Conclusions stress the importance of a **link between GV outcomes and product release**. Phasing of campaigns is important for this purpose. Interaction between the algorithm developers and the Cal/Val teams is seen as very important. **Data collection and analysis need to balance**, thus dedicated resources need to be available.

Doina Nicolae (INOE) illustrated the structure of Aerosol Remote Sensing (ARS) in ACTRIS, based on three components, namely ARES (the ARS Data Centre Unit, in charge of data processing and product release), CARS (Centre for ARS, for establishing the technical procedures and quality assurance for acquisition and instrument managements) and the ARS national facilities. Today ACTRIS ARS comprises 30 Aerosol stations, for 2025 51 Aerosol stations are foreseen. It mainly includes aerosol lidars (EARLINET) and sun photometer (AERONET-EUROPE). The measurements collected in several nodes of the network are processed with a central processing chain, from data collection to quality assurance of geophysical products. Especially important is the traceability of data. The network has experience in supporting Cal/Val campaigns (Aeolus, CATS, and CALIPSO, the latter from 2006) and has coordinated 19 campaigns. A specific effort is being devoted to developing a specific workflow for EC. For this purpose, **access to NWP data in near real time is necessary** as well as a direct transfer of the overpass information from ESA/EVDC to ACTRIS.

Ewan O'Connor (FMI) illustrated the capability of ACTRIS Cloud Remote Sensing (CRS) in the perspective of supporting EC Cal/Val. The network has developed common practice for calibration procedures and for geophysical product retrieval. Shown are 16 sites of the network. From the point of instrumentation, the network is not homogenous, using instruments of the same class, but from different manufacturers, and also in terms of wavelengths used. Coordination is assured by two structures, CCRES (Centre for CRS) focused on procedures for running sites (including calibration and monitoring of calibration, carried out also using properties of natural targets, such as for Doppler velocities used to verify the vertical pointing of radars, but also external measurements, such as disdrometers) and CLU (the CRS Data Centre Unit) focused on products and their evaluation. Recently, graphical tools to facilitate the display of key functioning parameters have been made available. Other procedures have been developed to mitigate attenuation effects due to both propagation and radome wetting. ACTRIS CRS has strong expertise in validation of clouds in numerical weather prediction and global circulation models.

Judd Welton (NASA) introduced MPLNET, a worldwide lidar network for global backscatter measurements designed following the AERONET model, running since 2000. It is composed of 75 sites (7 more in the future) co-located with AERONET. The procedures (QA/QC) adopted for the network are well established and described in papers published since 2002-2003. An upgrade to polarization was defined in 2007 and completed in 2016. New procedures and products are illustrated in conference papers and a journal article is in preparation. An overview of version 3 products was provided which can be tailored for EC. For EarthCARE validation they will target only wavelength independent products: cloud height, cloud phase, aerosol height, surface attached mixed layer top and top of atmosphere cloud radiative effect (TOA CRE). L1 and L1.5 products are provided in near real time. Some locations are in common with EARLINET and LALINET. Inter-network validation is foreseen (also with AD-Net). **MPL-NET offered to set up new sites dedicated for EC Cal/Val -waiting for input** concerning priority regions from the EC community (i.e., EURO-MAG?).

Tomoaki Nishizawa (NIES) described two networks, AD-Net (lidar) and SKYNET (sun photometer), the latter present in both Asian countries and Europe. Ad-Net consists of Raman lidars and HSRL lidars, partly equipped with 355 nm depol capabilities. For both networks, procedures for calibration of instruments have been established and applied. Products suitable for EC validation were presented. A data centre for SKYNET is under construction and includes products for EC validation.

Eduardo Landulfo (IPEN) introduced the Latin America Lidar Network (LALINET) and the specific aspects that are of interest for monitoring in South America, namely forest fires, biomass burning and volcanic ashes. A specific example involving ground-based measurements and satellite measurements was shown. 14 stations in Latin America are existent (5 more than originally proposed for EC validation), many co-located with AERONET.. Many of these lidars have 355 nm capabilities, but depol is available at 532 nm only. Coincidence criteria are based on 3 hours and 120 km distance to the overpass. Passive satellite data is used to analysis representativeness. QA/QC procedures are similar to those used by EARLINET as both networks collaborate. Umbrella projects to create join frameworks would be highly desirable.

Discussion summary

The *Discussion* was introduced by Ulla Wandinger who summarized in a couple of slides items for discussion in the session or for future discussion. The necessity to harmonize and intercalibrate the different network approaches was discussed. Doina Nicolae pointed out that **ACTRIS can support other programs, including campaigns** and internetwork calibration with, e.g., with mobile platforms via ATMO ACCESS. Specific field campaigns can benefit from this experience, for a better usage of mobile instruments, through guidance on sites and installation. Silke Groß highlighted that **aircraft can be used for network intercomparison.** In principle, it was emphasized that networks and campaigns should be connected in both directions. S. Joseph Munchak was asked to clarify the role of operation weather radar network for EC. In spite of the difference in wavelength, there are rooms for employment especially for estimating and mitigating effects of W-band attenuation.

Recommendations:

- Collect opportunities for funding and support schemes but also for common measurements and common sites.
- Efforts should be undertaken to check representativeness of a ground-based site.
- Define gaps observation gaps in the view of EC Cal/Val and beyond.
- Provide all networks with ECMWF meteorological fields (mainly p and T) for their Cal/Val stations to assure the same input for the retrievals.

Session 3: Cloud and Precipitation product validation

Chairs: Pavlos Kollias, Alessandro Battaglia, Shannon Mason, Eleni Marinou

This session focused on validation of the CPR-only (L2a) and synergistic (L2b) cloud and precipitation products.

Title	Presenter

CloudSat Cal/Val lessons learned & intro to ACCP and its Suborbital program with emphasis to Cal/Val	Jay Mace, Univ. of Utah, USA
Summary of inputs from Principal Investigators	Eleni Marinou, National Observatory of Athens, Greece
Summary of the algorithm needs with respect to clouds and CPR for Level 2	Shannon Mason, ECMWF, UK

Presentation summary

J. Mace (University of Utah) provided a survey of cloud and precipitation validation campaigns from the A-Train, followed by an update on the AtmOS mission and plans for its suborbital component. E. Marinou (National Observatory of Athens) consolidated input from Cal/Val PIs and gave an overview of the capacity and distribution of Cal/Val facilities and activities planned for EarthCARE. S. Mason (ECMWF) summarized validation needs from the perspective of the developers of level-2 cloud and precipitation retrieval algorithms (Table 2).

Table 2 Summary of L2 algorithm development needs for the cloud products

	Uncertainty	**Locations/scenes/regimes**	**Measurements needed**	**Products**
CPR L2a	Antenna pointing correction	•Ice clouds at all latitudes	•CFADs of reflectivity and Doppler velocity from ground-based radars	C-APC, C-CD
	Doppler decomposition: sedimentation + air motion	•Unrimed/rimed snow •Drizzle/rain •Convective/stratiform; other sources of vertical motion	•Multiple-frequency Doppler radars •In-situ measurements	C-CD
Macrophysics	Aerosol/cloud discrimination	•Cloud embedded in aerosol layers	•Ground-based lidars •Collocated in-situ aerosol sampling	A-ALD, AM-ACD, A-TC
	Cloud layer detection and structure	•Multiple cloud layers •Cirrus over liquid cloud •Non-precipitating liquid clouds	•Ground-based (& scanning?) lidars & radiometers	M-CLD, AM-CTH, A-TC, C-TC, AC-TC
	Cloud spatial scales	•Cumulus & stratocumulus clouds •Land/sea, day/night, boundary layer conditions, etc.	•High-resolution satellite imagery	M-CM
	Liquid clouds not fully resolved by radar/lidar synergy	•Physical depth of liquid clouds (i.e. cloud base height) •Mixed-phase layers embedded in ice •Liquid (& liquid-topped mixed-phase) clouds below optically thick ice clouds •Warm liquid clouds within cold rain	•Ground-based ceilometers/lidars •Multiple-frequency radars to constrain W-band attenuation •Microwave radiometers for LWP •Aircraft profiles of LWC	A-TC, C-TC, AC-TC
	CPR surface clutter removal	•Range of surface types	•Ground-based radars	C-TC, C-FMR

Ice cloud & snow	Snow microphysics (e.g. PSDs, microwave scattering, density & fallspeed)	•Stratiform vs convective •Rimed snow	•Bulk precipitation and particle imaging measurements at surface •Profiles of in-situ particle properties in ice clouds	C-CLD, ACM-CAP
	Ice microphysics (e.g. PSDs, ice optics, mass-size rel'n)	•Cloud-tops across range of temperatures, locations & cloud types	•In situ aircraft measurements •Visible & IR radiances	A-ICE, ACM-CAP
	Surface snow rate	•Range of meteorological conditions	•Ground-based radars and in-situ at surface	C-CLD, ACM-CAP
Liquid cloud	How to account for radiatively-important liquid clouds not detected by ATLID	•Deep ice clouds: embedded mixed-phase layers •Layered cloud scenes •Warm liquid clouds within cold rain	•Microwave radiometer for LWP •Profiles of liquid water content •Can models help train assumptions?	ACM-CAP
Rain	Relation between rain rate and drop size distribution	•Warm rain (maritime) •Convective/stratiform rain	•Ground-based multiple-frequency radars •Dual-pol weather radars over ocean	C-CLD, ACM-CAP
	Melting layer structure & radar attenuation	•Dependence on snow properties aloft •Continuity of mass flux & size distributions across melting layer	•Ground-based & airborne multiple-frequency radar	C-CLD, ACM-CAP

TARGET CLASSIFICATION

J. Mace reminded us that a novel result of CloudSat and CALIPSO flying in formation—and a foundational concept of EarthCARE—is the near-complete view of the atmospheric profile provided by the synergy of radar and lidar. The target classification and associated hydrometeor layer boundaries are an important "zeroth order" cloud and precipitation product, as well as forming the essential basis for microphysical retrievals. An early objective of the CloudSat/CALIPSO Cal/Val activities was to confirm the performance of the synergistic radar/lidar observations using airborne observations. Such comparisons are great for evaluating the performance of the target classification in complex, layered and precipitating cloud scenes, where the extinction of the lidar signal at the top-most layer of cloud very frequently means that the distribution of liquid and mixed-phase clouds, and especially cloud-base height, are unknown. These synergistic blind zones make it difficult to exploit passive and integrated measurements in synergistic retrievals and contribute to uncertainties in EarthCARE radiative transfer products.

Today, surface-based networks such as the US ARM and EU ACTRIS observatories provide well established networks with routine synergistic observations from radars, lidars, radiometers and surface sensors and used for statistical validation of EarthCARE target classification and microphysical products. For example, ceilometer and lidar networks will enable widespread statistical validation of cloud-base height; surface-based observations of rainfall rate and precipitation type can be used to validate our precipitation target classification. Complementary information from microwave radiometers will allow for more robust identification of liquid and mixed-phase cloud that cannot be identified with active remote-sensing.

Recommendations:

- Validation of cloud-base estimated from EarthCARE synergy (AC-TC) using networks of ground-based ceilometers and lidars.

- Validation of EarthCARE detection (AC-TC) and retrieved microphysics (C-CLD, ACM-CAP) of liquid, supercooled and mixed-phase cloud using ground-based radar-lidar retrievals, and complemented by microwave radiometers and/or dual-frequency radar techniques to constrain estimates of liquid water content.

MULTIPLE-FREQUENCY RADARS

Additional insights into cloud and precipitation are facilitated by the addition of lower-frequency Doppler radars that are less attenuated than the W-band radars of CloudSat and EarthCARE and provide complementary scattering and sizing information in snow and rain. Some existing multiple-frequency radar campaigns datasets provide valuable resources for evaluating EarthCARE cloud and precipitation retrievals. J. Mace highlighted the TC4 campaign (Costa Rica, 2007), which employed dual-frequency Doppler radars, lidar, and multispectral, microwave, and broadband radiometers aboard the high-altitude ER-2 aircraft, creating a high-quality dataset that includes EarthCARE-like instrumentation and, with its multiple-frequency Doppler radars, prefigures plans for the AtmOS satellites. The BAECC campaign at Hyytiälä, Finland (2014) combined triple-frequency Doppler radars alongside microwave radiometers and ground-based in situ measurements; this field campaign and ongoing measurements from the Hyytiälä supersite have provided the basis for many process studies and radar retrievals of mixed-phase cloud and melting, rimed, and aggregate snowfall. S. Mason showed examples of the ACM-CAP retrieval algorithm applied to both datasets, using multiple-frequency radars to improve and evaluate retrievals of rain drop size distribution, and rimed snow.

Recommendations:

- Insights from multiple-frequency Doppler radars in ground-based and airborne configurations should be used for ongoing development, evaluation and inter-comparison of cloud and precipitation retrieval algorithms.
- Multiple-frequency radar techniques for constraining the vertical distribution of liquid cloud water should be developed and evaluated, for use in validating EarthCARE's synergistic blind zones.

AIRCRAFT CAMPAIGNS

J. Mace was unequivocal that the greatest contribution to CloudSat/CALIPSO retrieval algorithms from field campaigns was from systematic and collocated in-situ cloud microphysical measurements, which are essential for developing and evaluating priors and covariance matrices. The AtmOS operational ground segment will include systematic measurements along key "corridors", similar to the SPartICus campaign which included 21 CloudSat/CALIPSO under flights and a total of 200 flight hours over the continental US. One of the innovations for CloudSat/CALIPSO Cal/Val field campaigns was the capacity to coordinate multiple aircraft for remote-sensing and in-situ measurements along the satellite track. Direct CloudSat/CALIPSO underflights from the CCVEx campaign were achieved within months of launch and were critical to validating radar-lidar synergy for hydrometeor detection, and for diagnosing and quantifying the effects of multiple scattering on the CloudSat radar. Proposals for aircraft campaigns for EarthCARE Cal/Val included remote-sensing and in-situ measurements from the LATMOS, DLR and FAAM aircraft, with 4 campaigns proposed between October 2023 and 2025. This highlighted an apparent gap in Cal/Val aircraft campaigns planned for the EarthCARE commissioning phase (March to October 2023). While the pre-launch AtmOS suborbital program will overlap with EarthCARE, plans for specific field campaigns are not yet finalised.

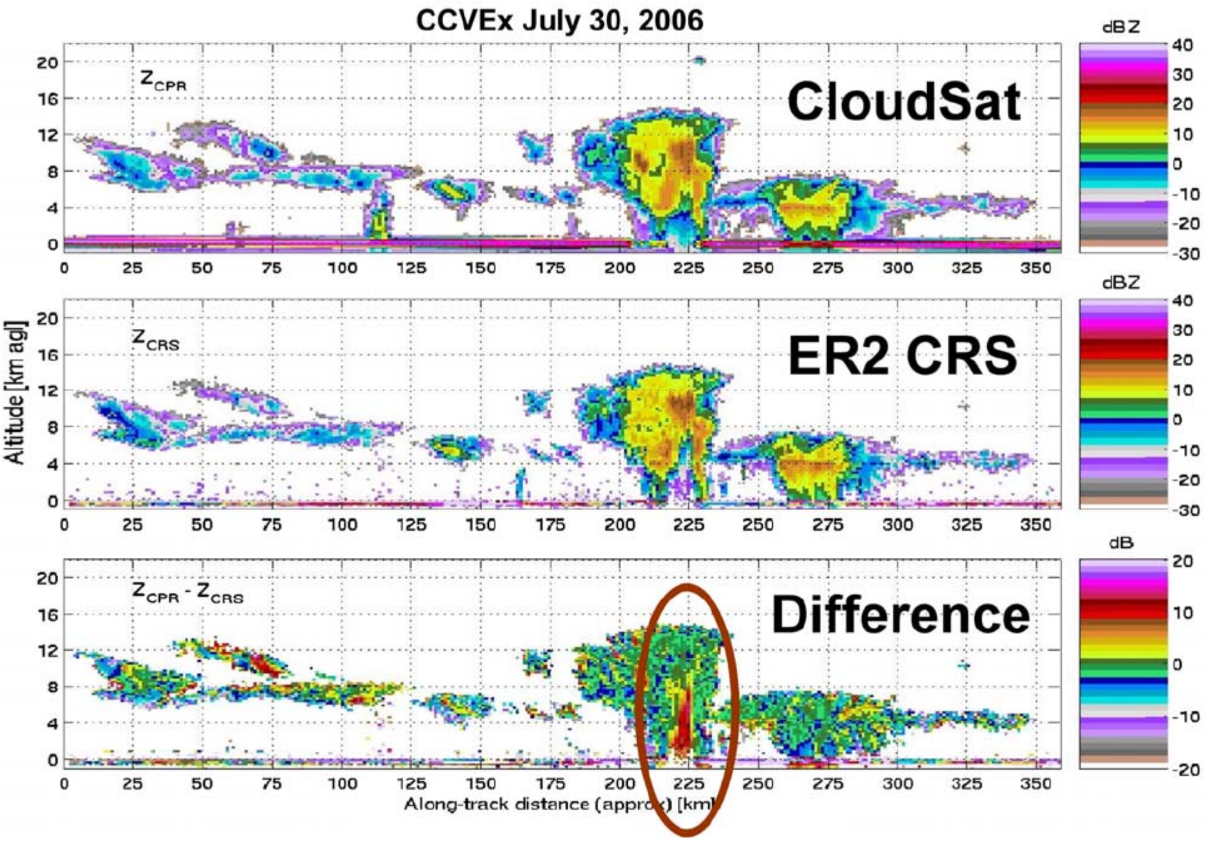

Figure 1 Direct validation of CloudSat radar reflectivity factor using airborne cloud radar aboard ER-2 during CCVEx. This comparison helped quantify the effects of multiple scattering on CloudSat CPR. Figure reproduced from Battaglia et al, 2008, JGR-Atmospheres.

Recommendations:

- Provide to ESA recommendations and requirements for a commissioning phase aircraft campaign, including: (a) when to fly within the constraints of the commissioning of EarthCARE instruments and the possibility of short launch delays; (b) required aircraft instrumentation and flight strategy; and (c) locations and regimes to target.

GROUND-BASED STATIONS AND NETWORKS

E. Marinou provided a quick overview of the existing ground-based in-situ and remote-sensing stations for EarthCARE cloud and precipitation Cal/Val activities. The surface-based facilities include around 50 radars, more than 100 lidars, and over 400 ceilometers, as well as weather radar networks in the USA and Finland. These mature and stable networks provide standardized instrumentation, calibration and data processing. These supersites and networks constitute a resource for statistical validation of hydrometeor detection and microphysical retrievals that was not available at the launch of CloudSat/CALIPSO, but have since been used for robust validation of cloud and precipitation detection, retrievals, and radiative transfer modelling from those satellites (e.g. Protat, A. et al, 2014, *JAMC*). While a paucity of stations throughout Australasia was noted, especially given the importance of Cape Grim, Tasmania for long-term Southern Ocean aerosol measurements, the density of high-quality network sites over Europe presents obvious opportunities for statistical validation across large spatial scales.

The systematic use of ground-based remote-sensors to validate spaceborne measurements requires the development of a standard way of accounting for the different viewing geometries, and the effects of attenuation of cloud radars and extinction of lidars. The uncertain vertical distribution of liquid cloud is a problem to which multiple-frequency ground-based radars stand to make a significant contribution, but in many circumstances a relatively forward-model could be used to transform between upward- and downward-looking remote-sensors in order to better exploit ground-based networks for validation of EarthCARE.

Figure 2 Global map of ground-based lidar and radar stations (not including NEXRAD and FMI weather radars).

Recommendations:

- Coordination on standard procedures for accounting for gaseous, water vapour and liquid water attenuation from ground-based radars.
- Development of tools for transforming between downward- and upward-looking remote sensors for statistical validation against ground-based networks.

VALIDATION OVER OCEANS

While large ground-based measurement networks provide widespread, if not evenly distributed, capacity for systematic validation of cloud and precipitation retrievals over land, the large part of global cloud and precipitation occurring over the oceans are much harder to validate. CPR path-integrated attenuation (PIA)—critical to constraining rain retrievals—is estimated from the ocean surface return, making EarthCARE rain retrievals especially difficult to validate. Snow is more readily validated over land at ground-based sites with both in-situ and remote-sensing measurements, but the microphysics of snow and mixed-phase precipitation over ocean are also poorly constrained by observations. This reinforces the importance of widespread in-situ aircraft measurements for validating cloud microphysics over a range of locations and cloud regimes. For precipitation microphysics, the systematic collection of ship-based measurements may be a critical product for statistical validation (Klepp et al., 2018), and especially for informing priors and covariances in retrieval algorithms. Experience of in-situ and remote-sensed measurements of clouds and aerosols over the Southern Ocean reinforce the need for resolving regional and even seasonal microphysical differences in these priors. Evaluation against other retrievals may include statistical evaluation against polarimetric weather radars in coastal locations (e.g., NEXRAD) or GPM satellite retrievals.

Recommendations:

- Use ground-based and ship-based microphysical measurements to inform spatio-seasonal changes in cloud and precipitation microphysical assumptions.

CLOUD AND RADIATION

EarthCARE’s cloud detection and microphysical retrievals will be represented in the radiative transfer (ACM-RT) product, and their quality will be evaluated in the top-of-atmosphere radiative closure assessment (ACMB-DF). The passive cloud retrievals (M-CLD), active (A-ICE and C-CLD) and synergistic cloud and precipitation retrievals (ACM-CAP) may each made different assumptions about the radiative properties of ice clouds. Aircraft remote-sensing with hyperspectral and microwave radiometers in addition to EarthCARE-like payloads will be essential to validating the consistent representation of ice microphysics across the spectrum, as well as to assessing the MSI smile effect. Ground-based stations with complementary radiation measurements should also be used for validating surface fluxes and heating rates.

Discussion summary

The discussion period covered a breadth of topics related to the EarthCARE Cal/Val activities.

The participants discussed the need to coordinate and harmonized data records from surface-based observatories and the need for funding to do this. In addition, funding is needed for analyzing past field campaign datasets such as those collected by NASA’s airborne platforms. Regarding data standardization and requirements for L2 Cal/Val activities, the new EarthCARE L2 activity called CARDINAL contains an early task led by P. Kollias that aims to outline data needs for L2 Cal/Val activities.

The participants expressed the need to coordinate with the AtmOS suborbital program for Cal/Val activities post-launch.

The participants discussed the role of numerical weather prediction models in EarthCARE Cal/Val activities in a way similar to how ECMWF helped the Aeolus mission.

Session 4: Validation Campaigns

Chairs: Silke Groß, Julien Delanoë, Dirk Schüttemeyer

This session was dedicated to campaign activities in preparation of the EarthCARE mission and to campaigns as opportunities for future EarthCARE validation. Four presentations were given:

Title	Presenter
Introduction to ESA campaigns and Pre-launch lessons learned	Silke Groß - DLR Julien Delanoë - LATMOS
CCREST, *an example for a science/validation campaign on validation of several missions combined with general science*	Stuart Fox - UKMO
Latest status and future plans for in-situ	Wolde Mengistu - NRC
Opportunities for dedicated or piggy back campaigns	Silke Groß - DLR Dirk Schuettemeyer - ESA

Presentation summary

Silke Groß and Julien Delanoë presented the lessons learned from ESA Pre-Launch campaign activities. Four main points were addressed with those campaigns:

(1) Airborne measurements were used to compare lidar and radar measurements form aircraft and from satellite (A-Train). Macro-physical properties were compared to evaluate effects due to sensitivity and resolution. Cirrus clouds and shallow marine convection were in the focus. Small scale structures are unlikely to be fully resolved from the satellite measurements leading to a potential shift in the overall analysis and should thus be treated with care. Direct comparisons of satellite and airborne lidar measurements of height and location of the observed structures showed a good collocation agreement of +/- 600 seconds. In addition to the lidar alone studies, the synergistic radar-lidar algorithm was implemented and tested on HALO lidar-radar measurements. The results were compared to the same scenes from satellite measurements to study wavelength and resolution effects.

(2) Tandem flight with radar-lidar measurements at different wavelengths were performed on two different aircrafts; the German HALO and the French Falcon20. The synergistic algorithm was further developed and tested with respect to its multi-wavelength capability of the synergistic algorithm. It is now possible to use different combinations and different resolutions, which is crucial to directly compare measurements from different platforms. Directly measured variables (L1) of the different platforms as well as derived properties (L2) were compared to characterize the impact of different wavelengths/resolution/sensitivity. Experience could be gained for coordinated multi-aircraft satellite underpasses, and first strategies for future EarthCARE validation could be developed and tested.

(3) Closure analysis including hyper spectral imager and in-situ measurements were performed. Radiative closure with Hyperspectral Imager measurements show the capability of further information

to identify situations in which the synergistic approach fails, and may help to overcome this issue. Coordinated in-situ measurements could prove the overall good performance of the algorithms and identified reasons for its failure in other situations.

(4) The pre-launch campaign activities further focused on a performance check of the aerosol classification and the link of remote sensing measurements to microphysical properties. In general measurements of the lidar ratio and the particle linear depolarization ratio can be used for aerosol typing. The linked and derived microphysical properties showed good agreement with in-situ measured microphysical properties.

The following campaign needs and gaps were identified from the pre-launch studies:

- Airborne in-situ and ground-based lidar measurements should be brought together to test L2 algorithms or to look at the sensitivity.
- There is a need for more in-situ measurements (prior information – covariance matrix/validation)
- There are some occasions where the retrieval doesn't work, but we have a very limited number of measurements. Closure studies are a valuable tool to check the performance of the algorithm. More closure studies should be performed.
- Airborne campaign data should be used for L2 retrievals (one gap: to investigate the impact of the used ice microphysical properties).

Suart Fox presented ideas for CCREST campaign and thus showed an example how science campaigns could provide opportunities for combination with cal/val activities. The main goal of the campaign is to characterize cirrus and ice cloud across the spectrum (PIs: A. Baran/S. Fox) with the focus on: diversity of ice crystal size and shape, mass-dimension/area-dimension, shape of the particle size distribution (small and large modes) to bring realistic microphysics and optical model across the spectrum, issues having consistency between measurements in mid-far IR, and to reduce the uncertainty in global average shortwave. During the campaign multiple aircrafts (FAAM/DLR F20/ATR42) shall be involved, combining in-situ and active/passive remote sensing. The campaign is planned for March 2024 with its base still to be decided. Possible locations are Iceland, UK, NE-US, Kiruna. Target of 3-4 weeks of campaign. The interest of using passive and active measurements would be ideal for EarthCare and FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring – ESA mission EE9). Possible coordinated tracks with EC could be performed, but it is unlikely to fly under clear sky conditions. Ice clouds are targeted in this campaign and flight altitude shall be, if possible, above them so the tropopause must be low. Overflights of Chilbolton depend on the selected area for the flights.

Mengistu Wolde presents their experiences from in-situ measurements. In addition to the in-situ instrumentation, NRC Convair is also equipped with remote sensing instrumentation: X, Ka, W band radars including polarisation diversity (following WIVERN), 355 nm lidar system and radiometers for aerosol and cloud measurements. The team has already performed a few campaigns: e.g. CloudSat/CALIPSO validation, for GPM/ WIVERN, RadSnow (in-situ + 3 frequencies). New instruments (optical probes) for better measurements in flights were added: AERI, HiSRAMS, SPE, HVPS-4. Their focus is on in-situ measurements with new instruments (including bulk measurements): SPEC HVPS4 (2022), NRC cIKP (2022), HISRAMS (2021), CVI inlet (2022), Artium HIS (2021) both PSD and images

In addition they have ground-based systems which could also be used for EarthCARE validation: Climate Sentinel Station in Ottawa (2021). Campaign activities are planned for 2021-2022 but nothing planned later on yet.

Silke Gross summarized the proposals related to EarthCARE calibration/validation campaigns. A number of ground-based field campaigns are planned; e.g. in the Mediterranean or in the high-latitudes, balloon-borne and UAV measurements available on selected locations. Measurements with lidar and radar (+ceilometer) available in Antarctica during the first phase of EarthCARE.

Airborne campaign activities				
AOID	**PI**	**activities**	**location**	**time**
38018	Marenco	1-2 potential ad hoc research flights compatible with other experiments with FAAM; preferentially combined with multiple aircraft	High-latitudes (CCREST) and UK	CCREST winter 2023/2024 UK in summer 2023
38188	Wandinger	Airborne campaign dedicated to EC validation (ECVAL) with EarthCARE-like payload on HALO – potential of combined ATR42 measurements (Delanoë)	Portugal (tbd)	Summer 2024
		Airborne campaign with 2-3 dedicated cal/val flights with EarthCARE-like payload on HALO (TOOC)	Barbados	Summer 2024
		Airborne lidar and in-situ measurements on HALO during ASCCI and HALO-south	High-Latitudes	2025
			NZ	2025
38810	Delanoë	Airborne EarthCARE-like + in-situ measurements (CCREST + NAWDIC) as opportunity campaign	High-latitudes	Winter 2023/2024
			Extra-tropical NA	2025
	Nicolae / Stachlewska	Airborne campaign with MULTIPLY (multi-wavelength HSRL) system (ESA project)	Romania / Mediterranean	

39821	Qu	Airborne measurements		
60799	Phillips	Airborne radar measurements in combination with satellites		
Campaign activities with balloons and UAVs				
AOID	**PI**	**activities**	**location**	**time**
38810	Delanoë	Balloon-borne radar X + W-Band radar	TBD	2023/2024
38809	Renard	Balloon-borne lidar measurements	Launch site in France	
39067	Hu	UAV measurements with dropsondes, radiometer and THz Radar and lidar for cloud observations	Chinese South Sea	Every summer
51515	Völger	Balloon-borne in-situ measurements (in combination with ground-based lidar)	Northern Sweden	On occasion
Ground-based campaigns				
AOID	PI	activities	location	time
38810	Delanoë	Mobile ground systems – BASTA (W-Band radar) and BALI (scanning BASTA + ulidar)	mobile	Already running (on demand)
		Scanning C-Band (POLDIRAD) and W-Band (BASTA) radar	Southern Germany	Starting 2022
38623	Genthon	Ceilometer measurements	Antarctica	
38909	Gausa	Radar and lidar measurements	Northern Norway	ongoing
	Voelker	Lidar measurements (in combination with balloon in-situ measurements)	Northern Sweden	On occasion

39183	Amiridis	Ground-based PANGEA station (lidar, cloud radar, MWR, Radiation)	Eastern Mediterranean	ongoing
	Sicard	Lidar deployments during different campaigns		
	Stachlewska	Lidar measurements in Poland and possibility for campaign participation in Romania	Eastern Mediterranean	ongoing
38188	Wandinger	Cloud Radar, MW-Lidar, MWR, Radiation measurements	Cape Verde	ongoing
		Balloon-borne in-situ measurements (in combination with ground-based lidar)	Melpitz	ongoing

Two airborne campaigns are proposed:

- Flying the MULTIPLY lidar on the Romanian aircraft (~2024) in connection to the ongoing network activities and the campaign activities in the Eastern Mediterranean. First ideas of a possible campaign were evolved but no fixed plans yet. The consortiums proposing a dedicated campaign in the Eastern Mediterranian comprises TROPOS, ECoE, Cyprus Institute, INOE and NOA. A focus on aerosol optical and microphysical properties and thus aerosol typing is made. Funding for the overall campaign is still needed.
- Having HALO and ATR42 flying out of Portugal (Location can still be changed); Portugal as base for the aircrafts would provide the possibility to perform validation measurements in different aerosol/cloud situations. Ground-based measurements are in the reach of the aircrafts. Overpasses should be planned for a general characterization of the situation and for inter-comparisons. HALO is available for this campaign and the schedule is already confirmed. The plans are quite advanced.

In the presentation general thoughts, that came up by reviewing the updated proposals and from the summary of the 1st Cal/Val workshop were mentioned:

- Many activities are proposed to be performed in the mid- or high latitudes
- TOOC (HALO airborne measurements in combination with ground-based and ship-borne measurements) as an opportunity campaign is one of the few campaigns in the (sub-)tropic regions.
- Multi-aircraft campaigns (with different wavelengths of the lidar and radar measurements and combined remote sensing and in-situ information) are needed.
- Connecting airborne measurements with ground-based stations is a crucial thing in the validation process. Mobile facilities should be placed at strategic locations or be used for inter-calibration
- Flights over land and over the ocean are needed to test the performance of the EarthCARE algorithms with respect to different surfaces.
- Funding of the campaign activities is often still open and the proposed activities may change depending on funding.
- There is no dedicated airborne validation campaign planned directly post launch.

- The possibility of doing campaigns from the home bases during commissioning should be explored

Needs were identified from the L2 developer related to campaign cal/val activities that was mentioned in the previous sessions:

- Lidar measurements of Mie and Rayleigh signal preferable at 355 nm
- Simultaneous lidar measurements of low depol and high depol measurements
- Depolarization measurements at 355 nm. Measurements at 532 nm would work as well but might add potentially additional uncertainties due to conversion.
- Macro-physical properties (PBL height, multi-layer aerosol scenarios, broken clouds and aerosols, multi-layer cloud scenarios) must be addressed.
- L2 algorithms should be run with airborne and ground-based measurements.
- Simulation of non-EC products should be performed, e.g. to compare with measurements at different wavelengths
- Information of extinction and IWC/LWC are needed for simulations and closure
- AOT measurements from ground (e.g. AERONET) and satellite (e.g. MODIS, VIIRS, …)
- Ground-based remote sensing measurements located along flight track
- Imager measurements
- Synoptic observations
- In-situ measurements (underflights along EC flight track)
- Airborne microwave measurements
- Polarization radar measurements and precipitation radar scans

Questions that were raised during the campaign discussion:

- How can we best combine airborne and ground-based measurements (+ satellites?)
- Which are the best locations for (ground-based) measurements?
- Which / how many mobile facilities would be available?
- How can we best combine remote sensing and in-situ measurements (airborne + ground-based)?
- Which regions are missing? And how can the gaps be filled?

Discussion summary

After the presentation an extensive discussion started. The main points of the discussion were:

- Shipborne measurements (like the POLARSTERN or the METEOR) should also be considered for EarthCARE calibration/validation. It was also discussed about the Australian RV – Alain Protat is the contact; Rob Koopman is already in touch with him. METEOR will most probably be deployed during TOOC, and there are also planes to have shipborne measurements during the ECVAL campaign.
- It was highlighted that in-situ and remote sensing is very powerful. In situ and no remote sensing makes it difficult to place the in-situ measurements in context.
- In connection of the proposed Cal/Val campaign in the Eastern mediterrainian, it was mentioned that the Cyprus Institute has strong interest to participate with its UAV fleet for in-situ observations. Furthermore it was highlighted that Limassol will become a permanent aerosol and cloud remote sensing station starting in 2022.
- Once the EarthCARE orbit pattern will be decided, ACTRIS can propose a more detailed plan; e.g. fixed observation sites in combination with mobile platforms (many with complex instrumentation for aerosols and clouds).

- Following this comment a discussion about the EarthCARE's tracks started. The main question was if it is possible to move them to be better collocated with highly import sites? How does this work for AEOLUS? And which radius (50km?) should be applied as 'direct' overpass? The latter one depends on the topic; e.g. cloud or aerosol. For aerosols it further depends on the region; in Africa it is not so crucial, over europe 100km can make a big difference. According to Michael Eisinger no ideal setting was identified so far. David Donovan suggested developing a cost function (weighting what the stations have to offer from their measurements). Oliver Reitebuch mentioned that a cost (weighting) function was used to fix the AEOLUS track as well. Aeolus L2A colocation criteria is 100 km. Usually for AEOLUS collocation is considered within a 30 km distance.
- Patric Seifert: highlighted the opportunity for deployments of mobile sites, such as LACROS, even for rather short periods (2-8 weeks) to defined locations. This can be done via trans-national access procedures, which are currently under development. For example, the LACROS site could be put directly below the swath of EarthCare, e.g., in a coastal or mountainous region which is of interest for Cal/Val. ESA could apply for the deployment of the LACROS mobile station. – Rob Koopman takes action https://www.atmo-access.eu/.

Session 5: Radiation, and BBR Level 1 and MSI level 1 product validation

Chairs: Jürgen Fischer (FUB), Tobias Wehr (ESA), Michael Eisinger (ESA), Almudena Velazquez (RMIB) and Nicolas Clerbaux (RMIB).

Title	Presenter
MMP - Monitoring MSI/EarthCARE L1 Performances using concomitant intercalibration and stand-alone approaches	Dr. Noelle Scott - Laboratoire de Météorologie Dynamique
Geostationary Earth Radiation Budget (GERB) - Lessons learned	Dr. Jacqueline E. Russell - Imperial College London
Lessons Learned from CERES	Kory Priestley - NASA Langley Research Center

Presentation summary

The Cal/Val of the MSI level 1 data (M-NOM and M-RGR) is addressed in 3 activities: Monitoring MSI/EarthCARE L1 performances using concomitant intercalibration and stand-alone approaches (MMP, lead by Noelle Scott at LMD), the German Initiative for the Validation of EarthCARE (Ulla Wandinger, Tropos, Leipzig, Germany) and the Validation of EarthCARE Product in China (Xiuqing Hu, National Satellite Meteorological Center, Beijing, China). Within GIVE, MSI Cal/val is addressed more specifically by FUB (J. Fischer, R. Preusker) and comprises: (i) inter-comparison of different satellite aerosol products and additional radiative transfer simulations are further used to interpret the MSI Level 1 radiance measurements, (ii) comparisons of validated aerosol products from OLCI and SLSTR (long operational perspective of the European Sentinel-3 series), and (iii)The EarthCARE BMA-FLX product will also be compared to fluxes that are estimated from MSG-SEVIRI radiance measurements (DLR contribution in GIVE). As regards to the Validation of EarthCARE products in China, synchronous radiometric calibration experiment will be conducted at China Dunhuang (China Radiation Calibration Site) CRCS site for the visible and near infrared bands of MSI. Finally, the MSI long-term stability can be monitored by using the Dunhuang desert site

A first invited talk was given by **Dr. Noelle Scott** (LMD, Palaiseau, France) about calibration of optical instruments. She proposed two concomitant approaches: a relative (sometimes referred to as inter-calibration or observation-to-observation) approach and a "stand alone" (observation to simulation) approach. The selected method should use: all geographical regions and seasons, as well as land/sea/day/night scenes, clear/cloudy/aerosols scenes, thus encompassing a broad range of brightness temperatures. The shown simulations were performed with the 4A/OP model fed with adequate descriptions of the atmospheric and surface state. The talk stressed the complementarity of the two approaches. In terms of “Lessons learned”, Noelle stressed the importance to pay the highest attention to permanently quality control not only the observations but also the models and auxiliary data sets. It is also important to stay in close contact and interact with PIs and all human actors/teams in charge of the observations or of the processing of the observations (L1, L2, …). Getting feedback from PIs is of paramount importance and (using) reprocessed data (L1, L2, …) is part of the game. The talk was illustrated with results from the IIR/Calipso intercomparison with MODIS-Aqua and MSG/SEVIRI.

The Cal/Val of the BBR level 1 and 2 is specifically addressed in 4 proposals. First activity is from the CERES team at NASA Langley. Second comprises GERB partners (Imperial College London, RMIB) in collaboration with the CERES instrument team and the University of Valencia (in charge of field campaigns at the Valencia Anchor station). Third proposal, from the National Satellite Meteorological Center, China, proposes the comparison of the BBR with FY-3 instruments. The fourth proposal, ACROSS (lead by Vassilis Amiridis) will implement various tools and algorithms to retrieve synergistic products and implement radiation closure studies.

A second invited talk was given by **Dr. Kory Priestley** on the lessons learned for CERES. He shared the large experience of the CERES team on ERB measurements (7 instruments since 1997, 6 of them still flying). His first recommendation was to Calibrate as much as possible since calibration is crucial to untangle instrument artifacts from climate signals. He stressed from CERES experience that it is very important to make sure that the spectral content of the calibration sources adequately represents the science targets. Experience of the darkening of the SW channels when pointing in the forward looking direction for CERES was shared. A very comprehensive list of recommendations was provided in his talk, including pre-launch, post-launch and Data Product Release Strategy. In particular: increase weighting / influence of Radiometric Performance in cost/schedule trades, maintain positive / open relationship with hardware provider, re-verify your ground targets frequently, establish collaborations with international agencies such as NIST, implement automated Data Acquisition System on Calibration Chamber, do not point optics in “forward” looking direction, provide additional SW spectral characterization capability (important for the unfiltering and LW calculation), minimize possibility of contamination and develop inspection and cleaning procedures, science team has a Lifecycle responsibility, establish a calibration team early and hold regular reviews, understand requirement traceability, be adept at responding to change (the instrument won’t work exactly as in the testing environment), keep a good communication between the engineers and scientists, develop logical and well understood approach to data release, minimize Editions / Versions of Data, use Data Quality Summaries for the community.

A third invited talk was given by **Dr Jacqueline Russell** who nicely summarized the “lessons learned” from the GERB instruments cal/val activities. The talk started with a summary of the GERB measurements and onboard calibration, showing it some strengths and some limitations of the approaches. Then, Dr Russell introduced many unexpected signals and instrument / satellite effects. Finally, the power and difficulties of inter-instrument in-orbit comparisons and checks was discussed.

In summary, it was stressed that instruments and satellites do not behave as expected. Flexibility and revisiting processing may be necessary. Inter-instrument in-orbit comparisons are extremely useful although not definitive. Differences in processing and footprint can lead to systematics, whilst temporal and angular matches are more likely to be noise. Tracking SW aging is not straightforward and, if significant, allows for adaptations in processing to correct aging. Another point of summary is the difficult ground to orbit calibration transfer (particularly in the SW). However, in orbit tests for consistency can be sufficient to indicate that ground calibration analysis needs to be revisited. As for the MSI, vicarious targets and quality checks are important throughout the mission life and are useful to evaluate processing and provide inter instrument comparison for ideal cases, identifying systematic changes and gross offsets. As Kory, Jacqui stressed that there will be things you don’t expect and that communication with the instrument team is likely to be needed to understand and solve some issues and that we can expect to update the processing and revisit the Cal/val plans. Some errors and effects only get highlighted by use or time and thus maintain communication with the instrument team and enable baseline values to be revisited. There will be changes to the instrument over time you have to deal with to maintain data quality. From the GERB mission, it is clear that some artefacts that were never expected could occur years into a mission and this stresses the importance of continuous quality monitoring.

Discussion summary

A strong interest was shown in obtaining confirmation from the Mission and Optical Payload Manager (Kotska Wallace) about the foreseen calibration procedures and the performed on-ground characterizations. This stressed the importance for the Cal/Val teams to get detailed information on the activities done and foreseen by ESA and industry. As it was already largely discussed during the talks, several interventions stressed the importance of good communication with instrument providers and the importance of continuous monitoring of instrument performances and calibration, and to be ready to adapt processing. It was also discussed how the drift of the Aqua spacecraft (currently at 13:30 ECT but that is going to drift later in the afternoon from 2022 onward) could lead to better matching with EarthCARE. This would allow good matching, not only between MODIS and the MSI, but also between the CERES FM3/FM4 and the BBR.

Recommendations: From the presentations and the discussion, the co-chairs of the session have proposed the following recommendations. First, an extensive use of invariant calibration targets should be foreseen: Rayleigh calibration, deep convective clouds, sun glint, SST, (pseudo) invariant calibration sites . A second recommendation is to agree on procedures/protocols for intercomparison of satellites L1 data. Lunar observations are also recommended, even if this looks especially difficult for EarthCARE with its long trailing solar panel (21 m²). Finally, preparations in view of a continuous calibration effort during the full mission lifetime are absolutely recommended.

Session 6: Use of models for validation

Chairs: Tobias Wehr and Jason Cole

Title	Presenter
Introduction	J. Cole (ECCC)
Vertical velocity in storms	V. Phillips (INES)
Cal/Cal campaigns and synergies for desert dust modeling studies	V. Amiridis (NOA)
Considerations for using radar observations to guide numerical model development	K. Lamer (BNL)
NWP model evaluation using ACTRIS cloud profiling	E. O'Connor (FMI)

Presentation summary

J. Cole introduced the session. The presentations include using models for calibration/validation and using sub-orbital and space-based measurements to improve and evaluate models and model simulations.

V. Phillips presented a proposal to use a convective storm model to validate statistics of vertical velocity and ice cloud properties using aircraft and space-based observations. In turn, the convective storm model will be used in combination with EarthCARE data to study the global distribution of convection and relationships with lightning and its land/sea contrast.

V. Amiridis illustrated how ATLID measurements could be used to improve desert dust products and processes through climatological dust property and dust deposition products, new dust parameterizations and radiative closure studies. The utility of ATLID for assimilation was highlighted since one could use backscatter profiles for aerosol mass and in a new approach lidar ratio to improve aerosol optical properties. A suggestion was made to consider calibration/validation efforts in the context of broader community in scientific studies.

K. Lamer presented the use of surface and space-based observations, mainly radar, to evaluate low and high resolution models. It was shown that instrument simulators, with appropriate level of detail and considering including instrument sensitivities, are important for like with like comparisons. In addition to instrument simulators, one needs to consider sampling in time and space between the instruments and model and should also consider appropriate evaluation metrics.

E. O'Connor continued the discussion about the use of observations to evaluate models, highlighting the need to consider representativeness, e.g., a 2D sample from EarthCARE instead of the 3D model field or observations of atmosphere advected over a fixed surface site. By sampling models in a similar manner as the observations, including filtering data to account for known sensitivities and issues plus using statistical, rather than case-by-case, evaluation, issues due to mismatches in sampling between observations can be reduced.

Discussion summary

The discussion was limited due to time constraints. A summary of information from the session and proposals, use of models include instrument models/simulators and multiple scattering models as well as radiative transfer models for radiative closure studies. Model systems are planning to use EarthCARE data, e.g., ECMWF, which can be used to monitor the changes in the data.

Given the significant amount of sub-orbital observations being taken, including in-situ aircraft and surface-based observations, a question is if this data can be used for model evaluation and development. This could include coordinated model studies overlapping surface sites and aircraft campaigns.