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DOCUMENT

ESA Workshop on Land Validation Strategy (30/11– 1/12/2020): Highlights and Recommendations

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Issue 1.3
Date of Issue 08/03/2021
Status
Document Type TN

European Space Agency
Agence spatiale européenne

APPROVAL

Title: ESA Workshop on Land Validation Strategy (30/11– 1/12/2020): Highlights and Recommendations	
Issue 1	**Revision** 3
Author EOP-GMQ	**Date** 08/03/2021
Approved by	**Date**
Philippe Goryl (EOP-GMQ)	08/03/2021

CHANGE LOG

Reason for change	Issue	Revision	Date
First Issue distributed to WS participants	1	2	09/02/2021
Revised version including comments from K. Ruddick (RBINS)	1	3	08/03/2021

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1 SUMMARY AND HIGHLIGHTS

1.1 Summary

The European Space Agency (ESA) organized a two days on-line Workshop on Land products Validation during: 30 November – 1 December 2020. The main objective of the WS was to discuss and define the ESA **Land Products Validation Strategy**, with main focus on Surface Reflectance and derived vegetation parameters (FAPAR, LAI in particular). European key players and stakeholders in the land validation domain were invited to present relevant initiatives; in particular, representatives from: JRC, CEOS-WGCV, Copernicus Land Monitoring Service and MPCs participated to the WS. Contributions from the following projects were specifically requested to compile the agenda: FRM4VEG, Eradiate, GBOV, MPC, RadCalNet, HYPERNETS, and IDEAS-QA4EO. Moreover, strategic contributions on: Metrological approach to Cal/Val, CEOS-LPV strategy and H2020 Copernicus Cal/Val Solution (CCVS), were presented.

The rationale of the WS was to focus on few key topics, understand the current gaps and review the planned solutions, with the goal to elaborate a way forward for addressing those gaps in coordination with the relevant stakeholders. As a matter of fact, a set of **seed questions** was sent to the participants in advance, in order to drive them in the compilation of the slides and prepare the ground for the live discussion. These questions were also distributed in the form of a questionnaire and the answers collected after the WS. As a result of this preparatory work, the discussion session was extremely animated and allowed us to retrieve an incredible amount of feedback and **recommendations** on how to address current needs in the Land domain and who should play a role in tacking the associated scientific and financial challenges.

Overall, the EU Land Validation community is extremely active and a large number of concurrent projects are running under different umbrella (ESA, EC, CEOS). On the other hand, there is a **lack** of a single EU entity, which is responsible for **coordinating** these efforts, exploiting synergies and facilitating the uptake of their output within the scientific community. Furthermore, existing EU and US networks are potentially available, despite the fact that many of them were not primarily designed for Land Cal/Val purposes (e.g., ICOS, NEON). Yet, it is clear that we **cannot just leverage on existing infrastructure**, especially for some variables (FAPAR, LAI) for which we are still largely dependent on non-EU networks and we observe a significant gap in geographical coverage, notably over Africa, South America and Asia. The clear take-home message form the WS is that we should work to **fill gaps** (with priorities) with a sustainable long-term solution.

The most urgent data gap is a ground-based network of **Surface Reflectance** measurements, ideally hyper-spectral and multi-angular, which would be the key component supporting the validation of BOA (L2) products for the full suite of ESA current and future optical sensors (S2, S3, FLEX, CHIME). The ESA-funded HYPERNET-VN project is moving in this direction, although much effort is still required to reach global representativeness and long-term sustainability remains a concern.

Currently available Land networks still do not meet the stringent requirements for satellite Cal/Val applications, notably owing to the **disparity** of used measurement **protocols** and the little attention to uncertainty estimates and traceability. The support for **metrological** entities, such as NPL, in coordination with CEOS-LPV, is essential in this respect, but Space Agencies should support the update of these networks to fully address Cal/Val needs. The ESA-funded FRM4VEG project is working to foster the usage of metrological practices for land products validation, however, effort is still required to reach the ideal condition of a sustained network of permanent **FRM** sites, providing a QA framework for enhancing satellite product interoperability and user confidence

In order to **enhance readiness** of ground-based infrastructure for supporting Cal/Val needs of current and future land-focused ESA/EC missions (S2/S3, BIOMASS, FLEX, LSTM, CHIME), the adopted strategy should enable **synergies** across missions, such as using well characterizes **super-sites**, following CEOS-LPV guidelines, allowing to measure multiple geo-physical variables (multi-mission). In general terms, the lack of an integrated EU approach for Cal/Val was mentioned as one of the limiting factors. Synergies are still largely **under-exploited**, notably for Sentinels missions, causing duplication of efforts and increase of associated costs.

In terms of sensor technology, we clearly observe a surge of **advanced technological devices**, such as using drones, automated low-cost sensors, or more sophisticated Lidar systems. These new solutions present clear advantages for Cal/Val applications, in particular by addressing the fundamental question of spatio/temporal **upscaling**, from the in-situ point measurement to the satellite pixel scale. Active Lidar systems are additionally crucial for 3D characterization of complex vegetated landscapes and for complementing passive optical remote sensing of vegetation parameters, such as LAI.

With respect to **theoretical advances**, the landscape of used RTMs for modeling radiative interaction within the canopy layer and along the atmospheric path is very diverse and the observed discrepancies are not fully understood. Furthermore, progress need to be made in understanding the contribution of different canopy elements to the retrieved total vegetation parameters. Various **inter-comparison** exercises are currently running (ACIX, BRIX, SRIX, RAMI) to fully understand weaknesses and strengths of the various algorithms with the long-term objective to converge towards a common solution.

Finally, the issue of **Cal/Val data management and uptake** was discussed. Currently Cal/Val data are stored in various archives, using different format, metadata and associated quality information. This situation clearly hampers the integrated usage of this large amount of data by the satellite EO community. There is a urgent need of providing a centralized access to Land Cal/Val data from networks and field campaigns using an harmonized approach to data quality information. Ideally, Cal/Val data should be supplied with associated on-line **validation tools**, based on community-agreed protocols, and potentially with satellite match-up, in order to allow a transparent and standardized validation procedure.

The number of insightful feedback and comments gathered during the WS will be used to compile a **Validation Strategy paper**, which is currently in preparation. The main challenge for the years to come will be to integrate all the different Cal/Val initiatives into an overall consistent solution for Land products validation, which should include all elements presented during the WS: FRM, super-sites, metrology, networks, protocols, RTMs, database and tools.

1.2 Highlights

The WS agenda consisted of 10 presentations organised into the following three sessions:

1. Land validation in a metrological context
2. Future operational validation needs and outlook
3. Land validation in an operational context

All presentations are available online at the ESA dedicated page:

https://earth.esa.int/eogateway/events/esa-workshop-on-land-validation-strategy/programme

The key highlights from the main topical sessions are summarised in the tables below.

1.2.1 Land validation in a metrological context

Nigel Fox (NPL) – Fiducial Reference Measurements (FRM): on the need of a metrological approach to Cal/Val
• Metrology allows to **build trust on EO satellite-based data**, this trust is built along three main principles: traceability, uncertainty estimation and comparison • **SI traceability**, including robust uncertainties, is now recognised as **critical for climate**, especially for risk/cost sensitive info. It is an end-to-end process, starting from L1 and continues to L2 products and it should be well documented. • Uncertainties need to be trusted, **traceable uncertainties** allow building trust on EO data • **Maturity matrices** allow to provide users with evidence on the **fit-for-purpose** for the considered EO data • Post-launch Cal/Val methods must be SI-traceable • The concept of **FRM** provides a mechanism and template for consistent satellite validation • A network of FRM quality sites (underpinned by comparisons) provide QA framework for enhancing product **interoperability** and **user confidence**
Joanne Nightingale (NPL) – Fiducial Reference Measurements (FRM): on the need of a metrological approach to Cal/Val
• **Land Cal/Val** community faces several **challenges**: multiple and independent sources of EO data generated with different algorithms and assumptions, lack of continuous monitoring Cal/Val sites, currently used Cal/Val networks not primarily designed for Cal/Val purposes, **consistency** between measurement of the same parameter cannot be guaranteed • Existing Cal/Val Land networks are keen to contribute to EO Cal/Val, the challenge is to **improve uncertainty estimate**, the adoption of rigorous metrological principles will allow to integrate in-situ measurements acquired with different sensors and techniques • The **ideal validation scenario** (FRM), to be considered as long-term objective, includes end-to-end traceability, uncertainty characterisation and propagation, plus full documentation with use case examples • It is clear that **we cannot just leverage on existing networks** due to current gaps, we **need to complement and address these gaps** • The Cal/Val **protocols are living documents** that need to be updated. It takes time to compile and agree upon them, but they are becoming out-dated and need to be maintained to account for recent technological advances.

Yves Govaerts (Rayference) – Eradiate: a new 3D RTM supporting traceability for Land Cal/Val applications
• There is currently a steady **improvement in radiometric accuracy** of spaceborne observations, approaching the 3%, and this is expected to further improve (1%) in the coming years with TRUTHS. However, **current RTMs accuracy** is not enough to support analysis of this new data. • **Challenges** to be addressed: improving surface BRF accounting for topography, improving molecular absorption (e.g. accounting for minor trace gases), accounting for coupling between surface/atmosphere, scattering/absorption, go beyond plane-parallel atmosphere for large zenith angles, include polarization, enhance traceability of used RTM input data • **Eradiate is a open-source 3D RTM** based on Monte-Carlo ray-tracing, with focus on supporting Land Cal/Val activities and with the aim of achieving an **accuracy of 1% for simulations** • **Eradiate should serve the E2E process for validation**, being the reference code for traceability • The objective of Eradiate is not to be fast, but to be equally accurate for a wide range of spectral domains and applications • There is a need to **benchmark RTM codes** that are used for AC; Eradiate can facilitate this by simulating highly realistic satellite observations in a fully controlled experiment • There is currently a **need to define a new standard atmosphere** for Cal/Val applications • Eradiate is also being used for building the operational LUTs, for future S2 and FLEX

1.2.2 Future operational validation needs and outlook

Sebastien Clerc (ACRI-ST) – A new holistic approach to Copernicus products validation: Copernicus Cal/Val Solution H2020
• Currently in Europe there is **no single entity** responsible for the provision of Cal/Val data; No coordination body to ensure that all this data is provided to the community in a coordinated manner; **Synergies and opportunities are not fully exploited** • **Heterogeneity** in the currently available Sentinels products is a **limitation** when considering the need for synergy in Cal/Val infrastructure. • Space Agencies (ESA, EUM) express their Cal/Val needs and define their solution to address them (LAW, FRM), but there is a **lack of a long-term perspective** • This H2020 project aims to address this need by defining an **innovative strategy** for Cal/Val in a synergistic manner covering the validation requirements of all existing and planned

Sentinels Copernicus satellite missions, with focus on core-products

- Improving algorithms should also be a goal of the validation; AC is critical, validation of **directional reflectances** is the crucial first step before tacking vegetation products
- **Cloud masking** can be a major contribution to the uncertainty budget in this case. Geo-location accuracy is also very important contributor.
- High quality FRM are crucial to anchor satellite-based data to traceable in-situ observations, but other data sources should be explored, including inter-comparison with other satellites, in order to extend spatio-temporal coverage

1.2.3 Land validation in an operational context

Fernando Camacho (EOLab) – CEOS LPV Supersites and Pathways towards an Operational Validation System for Land ECVs

- **Variety of approaches and reference data** used for validation currently **hampers** the **comparability and inter-operability** of satellite-based land products
- There is a need to **promote the use of standardized, publicly available and traceable procedures** and references for validation of satellite-derived terrestrial ECVs. CEOS-LPV works towards addressing this need in collaboration with Space Agencies.
- CEOS-LPV super-sites are addressing this need, by identifying a set of Land sites that can fulfill the requirements of multiple EO missions. **LPV super-sites** are super-characterized in terms of canopy structure and bio-geophysical variables (including use of 3D RTM), they are active and ensure long-term sustainability, they are supported by Lidar/airborne observations.
- In many networks there is little attention to uncertainty, not all of them are suitable for Cal/Val. However, some of these networks are willing to make their protocols suitable for Cal/Val, to improve uncertainty estimation; **fiducial procedures and protocols need to be shared**
- It is **recommended to build network of LPV super-sites in Europe** with long-term perspective and following metrological practices (FRM) for the continuous validation of several terrestrial ECVs
- ESA is encouraged to **promote synergies** across various Cal/Val activities and with established networks and to **promote the adoption of FRM protocols** within existing network and sites
- ESA should also work on **filling the gap of currently available LPV protocol**, notably for **SR, phenology, FAPAR**, and work with other Agencies to promote their adoption with the community
- **On-line validation tools,** based on community-agreed protocols (e.g. **SALVAL** tool) are highly needed; notably, the **OLIVE** tool should be upgraded and maintenance secured to allow

for continuous operational validation of LAI/FAPAR.

- ESA/LPV is encouraged to keep a **repository of Cal/Val data under FAIR principles** to collect and share Cal/Val data acquired within different projects.

Christophe Lerebourg (ACRI-ST) – GBOV – Global Land Validation for Copernicus Land Monitoring Service products

- Stem from the need of long-term, global and consistent reference data for operational validation of **Copernicus Global Land products**
- There is a **critical Geographical data gap** (Africa, South-America, Asia) and issue with **timeliness** of Cal/Val data availability, which currently hampers its use in an operational service.
- Another crucial **data gap** is the availability of **hyperspectral and multi-angular reflectance measurements**
- **GBOV is working towards filling this data gap**, to cover additional biomes (crop in particular) and geographical areas with 6 new vegetated sites in Africa, Australia and Europe.
- GBOV relies on availability of long-term established networks, e.g., NEON, ICOS; however most of the existing network not originally designed for Cal/Val; yet, network and site PIs are keen to work towards the implementation of Cal/Val protocols
- GBOV is providing up-scaled products at medium resolution, using S-2 for upscaling, **consistent protocols are used across the different sites** to ensure homogeneous Cal/Val procedure. GBOV is aiming to become the **central repository** for Land Cal/Val data.
- **Most of the sites and networks used within GBOV rely on non-EU infrastructure**: there is therefore a major **risk of losing capacity at EU level** in the future.

Jadu Dash (Uni. Southampton – Land Cal/Val activities in the frame of the Sentinel-3 Mission Performance Center (MPC)

- In the past decade we observed a large increase of global satellite-based land products, which are now available for an operational use. Yet, in order to meet stringent climate-related requirements, the issue of traceability and uncertainty estimated is becoming crucial
- The main challenge when comparing to in-situ data is the spatio-temporal mismatch and the issue of **upscaling/aggregating**, FRM4VEG is working to address this challenge using S2 to scale up the in-situ measurements to the S3 pixel scale
- Another main challenge is **temporal sampling**, we **need automated, global and temporally continuous in-situ dataset** to understand how satellite-based products perform over time
- Innovative approaches, such as **automated digital hemispheric photography (DHP)** or wireless quantum sensors, help addressing this gap for LAI, FIPAR, FCOVER continuous

validation

- Use of automated sensors allow for **upscaling in the temporal domain**, as compared to the traditional ESU-based spatial upscaling, multi-temporal series can provide a mean to derive multi-temporal transfer functions, supported by RTM simulations, for Cal/Val purposes
- Cost-effective **UAV-based sensors** can additionally provide the means to solve the spatial representativeness of in-situ DHP measurements
- The **challenge for the future will be to put all the elements together** (automated sensors, UAV, networks, FRMs) in order to build an integrated solution for Land Cal/Val

1.2.4 Recent advances in Land Cal/Val activities

Marc Bouvet (ESA) – RadCalNET protocols and lessons learnt from an operational global network

- RadCalNet is a CEOS-WGCV network of land based test sites to provide satellite operators with **SI-traceable spectrally resolved TOA reflectance** for post-launch **calibration** of optical sensors. The network comprises at the moment 5 sites, two more are in preparation.
- RadCalNet network demonstrates that **enforcing a common instrument**, measurement principle and calibration approach is **not necessary**, requesting for uncertainty and traceability of the acquired measurements was sufficient. This approach has the **advantage** of robustness and confidence in the data, since systematic uncertainties across the network are minimized.
- **Selection of the right umbrella** (CEOS) is crucial when building an international network to get over national/regional interest and to enhance motivations in joining the network
- RadCalNET provides data only at 10nm and at nadir; it was a compromise for giving the data for free; the site owner can distribute directional data at higher spectral resolution on-request.
- Involvement of a **metrology entity** is essential to drive the definition and evolution of the network.
- Setting up a new site takes time, but there is also support for new candidate sites' preparation through the **acceptance review process** (particularly for uncertainty budget review).
- RadCalNET was primarily designed for radiometric calibration purposes, so it includes spatially **homogeneous sites** with minimal interference from atmosphere, cloud, aerosol, BRDF, etc.

Kevin Ruddick (RBINS) – HYPERNET network for Land Surface Reflectance Validation: status and way forward

- Lesson learnt from ACIX: **Surface reflectance data are urgently needed** for validating satellite-based products and AC algorithms over land and water, we cannot rely solely on modeling of atmospheric path radiance using AERONET input data

- Correcting optical remote sensing data for impact of **sun-sensor geometry** is essential if we want to study bio-geophysical inter and intra-annual trends. This calls for the need of **multi-angular surface reflectance** measurements for BRF characterization. Using an automated system we can perform multiple acquisitions covering a wide range of sun-view geometries
- **Hyper-spectral** measurements have some obvious advantages for Cal/Val as they can be used for **multi-mission validation**, addressing the limitations of multi-spectral measurements, notably minimizing the uncertainties associated to spectral band adjustment
- The H2020-funded HYPERNETS project was initiated to address this data gap. The considered instrument is an evolution of Waterhypernet **PANTHYR VNIR system**; the land-version of the sensor has also a SWIR channel, to address the need of land applications. Furthermore, an advanced system is under development, which will be deployed at later stage.
- The **acquisitions protocol** for multi-angular observations over land is now **being consolidated**, though, there is currently a need to agree the protocols for measurement and uncertainty estimate of SR, feedbacks from **FRM4VEG** are expected.
- **Sustainability (long-term) is the main priority**, we need to stabilise the funding of site operators. This type of recommendation need to be reported at EC level

Benjamin Brede (WUR) – UAV-based and low-cost networks approaches for Land Cal/Val

- Active **Lidar systems**, both terrestrial (TLS) and UAV-based (ULS), are now becoming essential tool for **3D characterisation** of a land Cal/Val site and a for unbiased estimation of AGB especially for large trees
- **Lidar** techniques reached a good level of maturity for **LAI estimation**, they have the clear advantage of being illumination-independent
- **UAV-based** sensors are crucial for addressing the issue of **spatial representativeness** of in-situ measurement by sensing at spatial scale more comparable to satellite pixel
- **Automated cost-effective** sensors are now becoming very popular for Land Cal/Val since they allow **temporal scaling**; several COTS solutions exist, such as PASTIS, automated DHP, VEGNET; future evolution will include use of wireless network, **working towards a *community sensor* with open source code** and cost-effective components
- **Inter-comparisons** between these new sensors and traditional techniques will be essential to improve reliability of such new devices, working towards an integrated solution, which brings together FRM, networks and automated devices.
- **LPV protocols should be updated** to take account of new measurement technologies like automated sensors, UAV-based sensor etc.

Juan Pablo Arroyo Mora (NRC) – UAV-based spectrometric measurements for Land

Cal/Val under different illumination conditions
• **UAV-based hyper-spectral system** covering full VNIR-SWIR spectral range (400-2500 nm) provides very useful for satellite-based products validation by **enhancing spatial and spectral upscaling**, example provided for a meadow ecosystem • Acquisition of UAV-based measurements under cloudy conditions (**diffuse illumination**) proven to be valuable to complement vegetation analysis, although extreme care should be paid to correcting atmospheric impact • **Field campaigns** are still an important element of the overall Land Cal/Val strategy, as long as they follow well-established best practices, since they can expand the spatial extent and enhance validation of satellite EO products (**better understanding**) • Current technological advances (UAV, low cost devices) will allow in advancing the understanding of **spatial/spectral scalability and uncertainty budgets**, i.e. how to scale up uncertainty and not just measurements. • Yet, there is a **significant knowledge gap** about best practices as well as lack of vendor transparency (sensor characterization) for these new devices. Knowledge gap needs to be closed for both the scientific community and also for the end users.

2 NEEDS AND RECOMMENDATIONS

The participants were invited to provide their views and recommendations on critical topics through a questionnaire. The answers to the questionnaire will be used to shape the ESA Land Validation strategy for the coming years and were elaborates in a set of recommendations.

Topic	*Status and needs*	*Recommendation*
Surface Reflectance	Lack of ground-based surface reflectance measurements over land is currently limiting our capability to validate BOA products and assess quality of AC algorithm. Such measurements should ideally be: continuous (increase match-up), hyper-spectral (multi-mission) and multi-angular (BRF characterisation).	**[LPV-REC-01]:** ESA in cooperation with CEOS-LPV, to work towards setting-up a global network of ground-based surface reflectance measurements. Key requirements for the network are to ensure continuous, hyper-spectral and multi-angular surface reflectance measurements. The on-going ESA-funded HYPERNET-VN project is the first essential step for reaching this goal, although long-term sustainability should be secured.
Geographical Coverage	There is a clear gap in geographical coverage, notably in Africa, South-America, Asia, for the validation of vegetation parameters, such as LAI, FAPAR.	**[LPV-REC-02]**: ESA in cooperation with CEOS-LPV to contribute to the on-going effort (e.g. GBOV) in filling the geographical gap for validation of vegetation parameters, mainly in Africa, Asia and South-America.
FAPAR, LAI	For some variables, notably for vegetation parameters (FAPAR, LAI), current validation capacity in Europe solely relies on non-EU networks, notably NEON, which is representative of only North America biomes.	**[LPV-REC-03]**: ESA to support and promote within the EC a EU-funded network with long-term perspective for validation of satellite-based vegetation parameters.
Networks readiness	Existing networks are not primarily designed for validation purposes; as a matter of fact, the lack of uncertainty information and the disparity of used protocols still limit their integrated usage in satellite-products validation	**[LPV-REC-04]**: ESA in cooperation with CEOS-LPV to foster the adoption of Cal/Val best practices across existing networks and to support the adaptation of these networks (upgrade protocols, improve uncertainty estimation) for meeting Cal/Val needs.
Networks inter-operability	The heterogeneity in data format, documentation, quality information, metadata availability in current networks is still limiting their integrated usage for satellite products Cal/Val	**[LPV-REC-05]**: ESA to support on-going effort (GBOV) in requesting Cal/Val data providers to meet community agreed standards for quality information, metadata, and documentation.

Topic	*Status and needs*	*Recommendation*
Networks Maturity	Assessing maturity of existing networks to support Cal/Val needs is a laborious work. Moreover, this assessment should ideally be reported to networks' owners for helping them to converge to common quality standards, so that to facilitate inter-operability.	**[LPV-REC-06]**: ESA to promote the adoption of Maturity Matrix concept across existing and future networks with the aim to enhance inter-operability.
Long-term Sustainability	Sustainability long-term still represents a major concern for existing and future Cal/Val networks; lack of sustained funding is particularly urgent for operation and maintenance activities at the sites as well as for adapting measurement protocols.	**[LPV-REC-07]**: ESA to reinforce cooperation with national networks and promote within EC the need for long-term sustainability. ESA to consider this need in the early phases of a satellite mission, namely, at the time of Exploitation Plan definition.
Future ESA missions	ESA in collaboration with EC is developing a suite of innovative space-borne sensors focusing on land, namely: BIOMASS, FLEX, LSTM and CHIME. There is a need to enhance preparedness to support Cal/Val needs for these new missions.	**[LPV-REC-08]**: ESA in cooperation with CEOS-LPV to improve readiness of ground-based infrastructure to support Cal/Val needs of current and future missions (BIOMASS, FLEX, LSTM, CHIME). The strategy should enable synergies across missions, such as using super-sites for measuring multiple geo-physical variables (multi-mission sites).
Copernicus missions	There is currently a lack of an integrated solution addressing Cal/Val needs of current Copernicus Sentinels. Synergies are under exploited with risk of duplicating the efforts and increasing cost in validation activities.	**[LPV-REC-09]**: ESA to support on-going work (CCVS) towards an integrated solution for sustaining Cal/Val needs of Copernicus Sentinels. This includes promoting synergies across existing ESA Cal/Val projects (e.g., FRM4VG, LAW) and working towards filling the gaps.
Validation of SNAP-derived products	Built-in algorithms are currently available within SNAP, allowing retrieving geo-physical products from Sentinels data, such as LAI from S2. The validation of these products was the subject of various scientific studies, however, there is a lack of an integrated strategy for validating SNAP-derived geo-physical product.	**[LPV-REC-10]**: ESA to work towards improving uncertainty estimation and documentation about validation results for SNAP-generated geo-physical products, notably S2 LAI.

Topic	*Status and needs*	*Recommendation*
FRM readiness	Provision of FRMs in a sustainable way over globally representative network of sites is necessary for operational land Cal/Val system (to reach stage 4) and could be built based on contribution from Agencies and EO programmes.	**[LPV-REC-11]**: ESA to continue support FRM4VEG project, working in the transition from research to an operational system of permanent FRM sites and to further expand their geographical coverage in the longer term.
Protocols readiness	Community-Agreed-upon protocols need to be developed for some terrestrial ECVs, notably for SR, FAPAR, and phenology.	**[LPV-REC-12]**: ESA to contribute to fill this gap (e.g. FRM4VEG protocols for SR, FAPAR) and collaborate with other CEOS agencies to buy-in consensus and promote wide adoption by scientific community.
Protocols maintenance	CEOS-LPV protocols are living documents, this entails periodic revision process to keep pace with evolution of used methodologies and technical solutions, notably UAV-based systems, automated sensors, Lidar systems (TLS, ULS).	**[LPV-REC-13]**: CEOS-LPV in collaboration with Space Agencies to work towards revising existing protocols to include recent technological advances, such as, UAV-based, automated sensors, and Lidar systems.
Advanced technology systems	Advanced technological solutions, such as UAV-based, automated systems, allow for addressing the issue of spatio/temporal upscaling from in-situ point-measurement to the satellite pixel scale. Lidar systems have the additional advantage of being illumination-independent and allow for detailed characterisation of the site as well as for estimation of vegetation parameters (LAI, AGB). Yet, the accuracy of these systems needs to be carefully characterized and benchmarked against traditional methods.	**[LPV-REC-14]**: CEOS-LPV in collaboration with Space Agencies to promote inter-comparison exercises and evaluation studies to better characterize the accuracy of advanced technological solutions (UAV-based, automated DHP, Lidar, low-cost sensors) against traditional methods, both for Cal/Val and for vegetation parameters estimation (FAPAR, LAI).
Progresses on retrievals and definition	Concerning bio-geophysical retrievals, progresses still need to be made to better resolve the contribution of the different elements of the canopy, e.g., green and senescent parts, to the LAI, PAI and FAPAR estimation. Furthermore, there is often inconsistency in the variable definition (e.g., FAPAR/LAI green Vs. total), this should be carefully taken into account when inter-comparing different products.	**[LPV-REC-15]**: ESA to sustain progress in vegetation variables retrieval and modeling approaches (LAI, FAPAR) and promote inter-comparison exercises to advance in understanding the discrepancies in the currently used retrieval algorithms.

Topic	*Status and needs*	*Recommendation*
Progresses on RTM	Radiometric accuracy of optical imaging systems has significantly improved over last decade with the target to reach 1% with TRUTHS. Still, RTM accuracy is not ready to cope with such new requirements. Issues remain with respect to understanding discrepancies between commonly used RTMs and traceability of used input data, e.g., atmospheric profiles.	**[LPV-REC-16]**: ESA to sustain progress in understanding discrepancies in commonly used RTMs for optical sensors and in improving traceability of the used input data. The Eradiate project is currently aiming to fulfill these needs through benchmarking exercises and focus on traceability.
Progress on satellite-derived BRDF data	On the satellite side, there is a lack of BRDF characterisation data. The only reference to date is the MODIS-derived BRDF products. A similar product based on S3 measurements should be developed.	**[LPV-REC-17]**: ESA to sustain progress in developing BRDF products based on S3. The ESA-COPA project is currently preparing the ground for addressing this need.
Progress on uncertainty for cloud mask	Progress on uncertainty assessment for cloud masks and classification layers is clearly needed. Innovative approaches could be useful to reduce reliance on costly human validation activities.	**[LPV-REC-18]**: ESA to sustain progress in improving validation approaches and understanding uncertainties related to cloud-mask. The CEOS-CMIX initiative is currently addressing this need.
Cal/Val database	The uptake of Cal/Val data from the EO satellite community is strongly limited by the difficulty in discovering, accessing, and using the available measurements, in particular for field campaign. The adoption of FAIR (Findability, Accessibility, Interoperability, and Reusability) guiding principles and the setting up of a centralized repository will greatly ease uptake of Cal/Val data.	**[LPV-REC-19]**: ESA in coordination with CEOS-LPV to sustain the effort in setting up a centralized repository of Cal/Val data for Land, following the FAIR guiding principles, to collect data acquired within current and future initiatives (FRM4VEG, JECAM, FLEX Cal/Val campaigns).
Cal/Val tools	Online validation tools based on community-agreed protocols are needed to allow transparent and standardised validation. The OLIVE tool was valuable example in this respect, but it is currently not maintained and need to be updated.	**[LPV-REC-20]**: ESA in cooperation with CEOS-LPV to support the upgrade and secure the maintenance of the OLIVE tool.
Cal/Val sites collection	BELMANIP collection of sites should be updated/improved. The updates should include using more recent land cover maps and optimizing the sampling for S2 resolution.	**[LPV-REC-21]**: ESA in cooperation with CEOS-LPV to support the evolution of BELMANIP sites collection to optimize the sampling for S2 resolution.

Topic	***Status and needs***	***Recommendation***
Cal/Val platform	A dedicated cloud-based platform with focus on Land Cal/Val would ease the validation process by providing a centralized access to Cal/Val reference data, satellite match-up and tools to perform products quality assessment.	**[LPV-REC-22]**: ESA to prepare the ground for a Cal/Val could-based platform for Land, providing centralized access to reference datasets, satellite match-up and tools to assess the uncertainties of the relevant EO products.

3 PROCEEDINGS

Philippe Goryl (ESA, Italy) thanked and welcomed the participants to the meeting. He pointed out the difficulties of a virtual workshop (WS) regarding people interaction and he encouraged questions and discussions. He explained that the main objective of the WS is to define and shape the ESA's long-term strategy for the land product validation. Firstly, the focus will be on optical sensors (in the visible domains) and later on other sensors, like BIOMASS. Special focus will be given on the primary product of optical sensors, i.e. Surface Reflectance, and some land products, i.e. FAPAR, LAI, etc.

A report will be prepared after the WS, all the participants are invited to contribute with their recommendations and a publication may come out of it eventually. The participants were limited to the collaborators from contracts with ESA and EC or close collaborations, and could attend the WS with invitation only.

P. Goryl explained the different components of a validation strategy: a proper uncertainty characterisation based on metrology (including FRM, and radiative transfer modelling, which plays an important role in uncertainty definition) is needed to characterise a measurement; knowing the uncertainty, we know how and what we validate; then we should apply metrology standards on a network of measurements that ESA would like to support, e.g. HYPERNETS, which will play a key element in the strategy, as well as innovative methods such as UAV. All these measurements should be available for users, within a central database (such as GBOV), which can also be exploited in an international context like the MPC. All these approaches need to be done in international cooperation, in particular CEOS WGCV (mainly LPV). This WS should address one by one these aspects:

1. State of play and data gaps
2. FRM, Super-sites and networks
3. Recent technological advances and field campaigns
4. Theory and methods
5. Traceability and uncertainty
6. Synergies and interoperability
7. Database and tools

Seed questions that address these points have been shared and P. Goryl encouraged presenters to keep these questions in mind while presenting.

3.1 Land validation in a metrological context

Nigel Fox (NPL, UK) presented 'Fiducial Reference Measurements (FRM): on the need of a metrological approach to Cal/Val'. Metrology provides data stable over time, insensitive to method of measurement, uniform worldwide and based on references that can improve. The EO measurements need to be treated as any other measurement, so that can be trusted. The CEOS endorsed Quality Assurance framework for Earth Observation (QA4EO) states that all data and derived products shall have associated with them a fully traceable indicator of their quality, documented and quantitatively tied to an international standard, ideally SI. In order to have trusted measurements three principles must be followed:

- Traceability: an unbroken chain of uncertainties (transfer standards, documented procedures, rigorous uncertainty analysis and audits)
- Rigorous uncertainty analysis: GUM. An example of evidenced traceability for AVHRR was presented as part of Fiduceo; an attempt to put together a framework to describe a full breakdown of the measurement process, so to be easier for a user to understand where problem might be and where each uncertainty component comes from.
- Evidenced comparison (i.e. with lab results comparison)

N. Fox also explained that we need traceable uncertainties to allow trust in data. RadCalNet is a good example of a network built following metrological rigour. The network delivers harmonised, interoperable reference values that we can compare and assess traceability for different sensors.

Fiducial Reference Measurements (FRM) are a subset of in-situ measurements (L1/L2) than can be compared to those independently derived from a satellite to validate sensor performance, bridge any potential data gaps, facilitate interoperability between sensors and anchor FDRs (provided they are of sufficient accuracy). FRMs must have documented evidence of metrology traceability to SI, be independent of any satellite geophysical retrieval process, be carried out following community agreed protocols.

How do we present this quality information to users? They do not want to know all the uncertainty process, but if the data fit for their purpose. A useful tool in this respect is the maturity matrix, which provide easy access to users as to whether it is fit for purpose.

N. Fox summarised the main points of his presentation in the following:

- SI traceability, including robust uncertainties, is now recognised as critical for climate, especially for risk/cost sensitive info. It is an end-to-end process, starting from L1 and continues to L2 products and it is well documented.
- Post-launch Cal/Val methods must be SI-traceable
- Concept of FRM provides a mechanism and template for consistent satellite validation
- Network of FRM quality sites (underpinned by comparisons) provide QA framework for suitability product interoperability and user confidence

In the discussions, it was mentioned that the evidencing uncertainty process, besides the presented AVHRR case, was done for SLSTR, OLCI and Sentinel-2 and in some way for other sensors in the Fiduceo project (e.g. Meteosat). NPL is working hard to evolve this process to go to the higher-level products, not just L1 products.

Concerning FLEX and any other new missions, the approach should be to tackle the traceability challenge well in advance rather than retrospectively. In order to do that, we need information from the instrument/data provider on time and full transparency on pre-launch characterisation results.

Joanne Nightingale (NPL, UK) presented 'FRM4VEG ESA project: towards traceability for Cal/Val measurements of vegetation parameters'. Satellite derived data/products are increasingly driving the info/knowledge required for decision making, so quantitative assessment of the quality of these data will become even more critical. The concept of FRMs was presented and conformity testing was explained as the process that determines whether the estimated target quantity falls within the range of tolerable values.

FRM4Veg is focused on establishing the protocols required for traceable in-situ measurements of vegetation-related parameters (surface reflectance, FAPAR, LAI, CCC) to support Sentinel-2, -3, PROBA-V and new missions' product validation. Phase 1 is concluded with two field campaigns, the initial protocols and validation methodology completed. Phase 2 will start in February 2021 and will last for 2 years; it will include one field campaign, evolution of the protocols and plan for ESA permanent sites.

The challenges in Land validation were discussed, namely: the variety of data products created with independent or multiple EO data sources and based on different retrieval algorithms; the lack of long-term monitoring sites suitable for satellite product validation, the inconsistency of measurements of the same parameter taken at individual sites by different teams and the absence of consistent, updated and internationally agreed protocols.

The ideal validation scenario (FRM) includes end-to-end traceability, uncertainty characterisation and propagation and full documentation with use case examples. Regarding FRM4VEG, protocols and procedures are available on line, e.g. manuals for calibrating field instrument, conducting campaigns etc. In FRM4VEG Phase 2, a Surface Reflectance Inter-Comparison eXercise for Vegetation (SRIX4Veg) is planned for Summer 2022.

In the discussion, the importance of FRM4VEG project was pointed out together with its role in future applications, e.g. HYPERNETS. It was also mentioned the need to integrate the validation networks into the mission exploitation plan definition, in order to ensure their long-term operation, as they are critical for the end products.

It was indicated also that CEOS-LPV protocols should be living documents. FRM4VEG and CEOS collaboration results are expected to provide valuable elements for updating such documents. F. Camacho (CEOS) confirmed that there is an action to update LAI protocol.

Concerning different protocols and instrumentation used in different networks, it was stated theat they can be integrated as long as they provide accurate uncertainty estimates. FRM4VEG actually will be trying to put all the different measurements together.

Yves Govaerts (Rayference, Belgium) presented 'Eradiate: a new 3D RTM supporting traceability for Land Cal/Val applications'. In his talk he indicated that there is an increase of radiometric accuracy from space: currently 2-3%, but it's expected to reach 1% in few years with missions dedicated to calibration, i.e. TRUTHS, CLARREO. Therefore, we need RTM accuracies of 1% to support the analysis and verification of these data. This requires improvement of surface and atmosphere characterization, surface BRF, accounting for topography, molecular absorption, rigorous calculation of coupling (e.g. between surface and atmosphere), polarisation, and traceability of all RTM datasets to original datasets so that users know exactly which datasets are used, i.e. solar irradiance.

A review of existing models followed and Eradiate was introduced as a new open-source 3D RTM based on advanced 3D Monte Carlo Ray Tracing rendering techniques. It will be publicly released at the end of 2021 for contributors. Eradiate is intended to serve a wide range of EO domains, including modules from land, atmosphere, ocean, cryosphere and planetary science. One objective of Eradiate is to contribute to the RAMI-V exercise in order to benchmark and gain confidence in the model. The different model elements and example of applications were presented. One important aspect is the validation of Eradiate, including comparison with lab experiments (i.e. in

MetEOC4), model IX (i.e. RAMI) and comparison with satellite observations (e.g. RadCalNet). There is a need to expand RAMI and compare model simulating realistic satellite observations, i.e. typical geometry of illumination and observation, typical spectra bands, RAMI scenes with standard atmosphere.

Eradiate intends to support the traceability of space observations to SI-standard by providing accurate simulations of satellite observations, a way to upscale ground observations to TOA simulations, datasets in Eradiate will be fully traceable to original datasets and it will be compared with laboratory measurements.

In the discussions the 'open publicly' specification of Eradiate was explained as the possibility to review the model and send back contributions. The rationale is that people from different communities could contribute with their expertise. In particular the code will be on GitHub and all the pull requests will be reviewed and possibly accepted.. There is also a plan to help contributors to improve their pull requests.

The need for harmonizing the assumptions used in RTMs, such as surface modelling or atmospheric composition, was also discussed, in order to intercompare the accuracy of the current RTMs. RAMI exercise organised by JRC addresses partly this topic and it could be used as a framework. However, the composition of the surface or atmosphere is not assumed. It was agreed that we should improve transparency on the used assumptions, so to understand the differences between models. There is a need to define exactly the standard atmospheres and profiles in the future of Cal/Val activities.

If Eradiate is the reference code, it will be part of the E2E validation process for many sensors, i.e. SLSTR, OLCI, MSI, etc. The systematic use of Eradiate to validate LUTs derived with various RTMs in ground segment processors was also discussed.

3.2 Future operational validation needs and outlook

Sebastien Clerc (ACRI, France) presented: 'A new holistic approach to Copernicus products validation: Copernicus Cal/Val Solution H2020'. CCVS H2020 is the innovative solution addressing Cal/Val needs of all Copernicus \ and High Priority Candidate missions. The first phase is the analysis phase, where the Cal/Val requirements for Sentinel missions will be consolidated and the new requirements will be defined; the requirements will be linked as far as possible to measurement equation. The Cal/Val sources will be also described in this phase.

The second phase is the synthesis phase, where we should focus on R&D activities, instrumentation and Cal/Val methods, as well as suggestions for a Copernicus network of in-situ measurements and organisation/coordination of data distribution. A Reference Scenario for Implementation will be also proposed, where the coordination with all stakeholders is needed, a practical implementation scenario is defined and its sustainability/schedule aspects is analysed.

In the preliminary considerations on Cal/Val of Sentinel products, the good structure of Cal/Val community in terms of contributions was mentioned, e.g. ESA, EUMETSAT for operational Sentinel Cal/Val; Copernicus services for validation of Copernicus products. However, the picture is not so clear in terms of data provision for Cal/Val, with some exceptions including ESA LAW, PANDONIA, SeRAC, St3ART. The Copernicus programme has no mandate/responsibility to provide Cal/Val data for the Sentinel missions. The Agencies contribute through different programmes, like RadCalNet (CEOS), FRM projects (ESA) or GSICS (EUMETSAT). However, no single entity is responsible for the provision of Cal/Val data for sentinel missions and there is no coordination body to ensure that the data are collected in a coordinated manner. The Agencies can express their Cal/Val needs, but they don't have funding to address them. The Member states provide useful data, but not necessarily to address Cal/Val needs, i.e. traceable, documented, open, timeliness, long term stability, etc. Additionally, synergies and opportunities are not fully exploited.

Concerning the validation of Sentinel Land products, the core products are heterogeneous between missions. There are also different approaches within the Sentinel family; the separation between core product and Copernicus service varies between missions, and although this can be justified with respect to maturity, community etc., it does not favour a holistic approach.

The CCVS validation goals are to verify the product uncertainty versus the mission requirements (fitness for purpose), to trigger calibration activities and detect instrument anomalies and to improve processing and retrieval algorithms. For the calibration data sources, the need to be stable and well characterised (ideally SI traceable) was mentioned, although for validation purposes, the data sources need to be representative of product usage, i.e. atmosphere, vegetation, geographical representation.

A scheme of validation needs for different levels (from apparent properties to inherent properties) was presented. There is a need to look at all steps along the way, i.e. a) atmospheric correction requires more validation (high amplification of measurement uncertainties) which clearly needs more sites/validation activities at this level (TOA, BOA), b) BRDF retrieval/correction, c) vegetation model inversion. There are cases where direct approaches (e.g. using machine learning) are followed and some intermediate validation steps can be omitted. Beyond the mentioned scheme, geolocation accuracy and cloud masking (can be a major contributor to uncertainty) are presented as additional validation needs.

CCVS as Coordination and Support action will facilitate R&D and innovation. The CCVS team is looking for inputs from the community regarding best practices, recommendation, ideas, new products, methods, deployed instrumentation, etc. In Phase 1 (mid 2021) several WSs for the different mission types will be organised. In Phase 2 WS (tentatively during LPS 2022) the preliminary Copernicus Cal/Val solution will be presented and feedback will be collected.

In the discussion, there was a recommendation to integrate the uncertainty in the output products of SNAP, e.g. LAI from S2. However, there is not an agreed strategy on this direction so far. Some projects have a validation strategy, but for the rest there is not a general guideline, so it is difficult for the user to find out the uncertainty of a product. Therefore, it was recommended to highlight this issue at Sentinel Cal/Val WGs.

3.3 Land Validation in an operational context

Fernando Camacho (EOLAB, Spain) presented 'CEOS LPV Supersites and Pathways towards an Operational Validation System for Land ECVs'. The LPV validation requirements include the characterisation of the in-situ measurements and/or validation datasets a) at satellite product resolution (upscaling) including uncertainty estimates (when appropriate for the product) and b) over globally representative network of sites. This resulted in LPV validation operational framework, including good practice document, fiducial reference datasets and global satellite product subsets, all available in an online validation tool to provide a standardised validation report.

Examples of LPV Supersites were presented selected from existing networks, i.e. TERN, NEON, and ICOS, which are well-established networks with long-term perspectives and local collaborators. However, their protocols were not designed to fit validation requirements and there is little attention to uncertainties. Nevertheless, TERN and ICOS have expressed their willingness to make their protocols suitable for Cal/Val and to improve uncertainty estimation; the fiducial procedures and protocols need to be shared when they are available.

The validation state of several ECVs was described, i.e. LAI, LST, surface albedo, soil moisture and biomass, with reference to the corresponding validation components and the pathways to operational validation. In particular, the LPV Protocol needs to be revised to include FAPAR and new technologies. Different quantities of LAI/ FAPAR can be considered (i.e. green/total, FIPAR/FAPAR). A critical component is the mis-match between what we measure from satellite and in-situ. There is also a critical need for provision of LAI, FAPAR in-situ data over Europe for operational validation. GBOV provides good upscaling data but only over US sites. FRM protocols needs to be implemented in all these cases.

Online validation tools should be upgraded (i.e. OLIVE) and then maintained to ensure continuous operational validation. Concerning LST protocols, FRM procedures and protocols are developed, but there is need for more stations over homogeneous sites (particularly over EU). With respect to Surface albedo, there are multiple ground sites providing in-situ data, but there is need for more sites over under-represented areas (Asia, Africa, S. America). Surface albedo validation (SALVAL) tool is today available and open. Soil moisture operational validation protocol is ready to reach Stage 4 validation. The final draft version of aboveground woody biomass validation protocol is available for public review (extended until 15th December). There is a requirement for higher quality reference data and the validation tool will be integrated in the MAAP platform. A recommendation was made to create a CEOS Forest Biomass Reference System, a network of 100 biomass reference measurement (BRM) sites. No space agency alone can do this, but each Agency can make a contribution by e.g. funding national supersites or by adopting reference sites.

To conclude, provision of FRMs in a sustainable way over globally representative network of sites is necessary for operational land Cal/Val system (to reach LPV Stage 4 validation). Such a global network could be built based on contribution from agencies and EO programmes. It is recommended to contribute to build a network of LPV supersites over EU, with long-term perspective. ESA is encouraged to promote synergies between several ESA land Cal/Val activities (e.g. TLS for BIOMASS, FLEX, FLOXbox) and to increase synergies with established networks and their local collaborators. ESA is also encouraged to promote the adoption of FRM protocols among existing networks (GBOV, ISMN, ICOS, TERN).

Community-Agreed-upon protocols need to be developed for some ECVs. ESA should contribute to fill this gap (e.g. FRM4VEG protocols) and collaborate with other CEOS agencies to buy-in consensus and promote wide adoption by scientific community. Online validation tools based on community-agreed-upon protocols are also needed to allow transparent and standardised validation. For LAI/FAPAR, CEOS Cal/Val OLIVE tool need to be upgraded/redesigned to be functional. After that, maintenance needs to be secured. ESA/LPV community is encouraged to keep a repository database under FAIR principles to collect and use the LAI/FAPAR data collected in different initiatives (e.g., FLEX, FRM4Veg, CNES, JECAM…).

In the discussion, it was mentioned that the validation of S2 LAI/FAPAR products has been done already and the corresponding publication was shared (https://doi.org/10.1080/2150704X.2020.1767823). Regarding the protocol public review, it is limited to those signed up to the CEOS LPV mailing list. The documents are available on google.doc, the comments are collected and then the protocols are presented within CEOS-LPV for the final endorsement.

Christophe Lerebourg (ACRI, France) presented 'GBOV – Global Land Validation for Copernicus Land Monitoring Service products'. GBOV stems from the need to provide a long-term reference database using consistent protocols for validation of Copernicus Global Land products. The database includes 84 sites and 2 sites with time series (covering 2013-2019, extension to 2020 in 2021). However, there is a geographical gap (South America, Asia and Africa poorly represented) and a difficulty to go to near real time.

Concerning short wave radiometry sites, there are 23 sites in total (mostly in N. America, EU, AUS), but there is lack of ground instrumentation covering hyperspectral, multi-angular reflectance measurements.

There are 23 NEON sites (mostly in N. America) that provide data for the validation of vegetation products. In this case, the geographical gap remains an issue, but there is also need for homogenised protocols for FAPAR and DHP. Understory signal is not a mandatory component of most networks and although NEON provides a wealth of data, it's the unique provider of long-term time series and only represents US ecosystems. The sites for soil moisture validation provide a large dataset but they are not designed for EO data validation, e.g. lack of 5cm depth measurement, distribution of the network, etc. For LST validation, instrumentation and protocols consistency remains an issue, but timeliness is generally good. GBOV and LAW are providing consistent instrumentation and protocols and the community (ICOS) is willing to collaborate.

In the next steps, the instrumentation of the current sites will be upgraded and the geographical gap will be reduced, by adding six new vegetation sites. In particular there is an on-going work with colleagues in Australia to develop an instrument specifically for vegetation. Furthermore, the University of Southampton is developing an automated DHP system to enhance temporal sampling.

An example of validating global LAI and FAPAR products using GBOV was presented. DHP images (>70,000) were processed to provide 4,178 PAI and FIPAR reference measurements at 20 NEON sites (with quality indicators). The impact of neglecting forest understory was evaluated and, in some cases, the bias was quite significant. There are efforts to convince ICOS and TERN to include it, so we can implement it in the measurement protocols and procedures. Copernicus products are providing better agreement compared to reference PAI and FIPAR maps (up-scaled using S2).

In the summary, it was highlighted that GBOV can rely only on long term established networks to generate validation data. GBOV also provides up-scaled products generated with consistent protocols and it is developing its own network, principally for vegetation products, with consistent instrumentation and measurement protocols. The feedback from the community is very positive and there is rarely an issue on data access and distribution. However, the Near-Real-Time data delivery remains an issue. The fact that a lot of the stations are not funded by ESA/EC can put in risk the mid/long term data availability of Cal/Val data for Copernicus.

Jadu Dash (Univ. Southampton, UK) presented 'Land Cal/Val activities in the frame of the Sentinel-3 Mission Performance Center (MPC)'. Within S-3 MPC, two main approaches are followed: indirect evaluation/verification, where the temporal consistency, comparison with MERIS climatology and L3 composites are analysed and direct validation, where validation netowrks and field campaigns are included.

MTCI and OTCI global composites for MERIS climatology (indirect validation) are available at 500m (8day) from S-3 MPC on the same grid as MODIS. Globally, both products are strongly correlated with low absolute difference and absolute bias. The major differences are observed in managed land.

The history in direct validation approaches was presented. During the 1980-2000 there were not many operational products and validation was ad-hoc. In the period 1998-2018, global products were available and CEOS-LPV standard protocols were established. From 2017 to date, there is an increase in operational use and traceability. Accuracy/uncertainty are key requirements as well as FRMs, but we need infrastructures.

Concerning FAPAR, S-3 MPC started to generate maps of uncertainty of the up-scaled pixels and developed procedures to compare uncertainties of the ground measurements and satellite-based measurements. Comparisons of OLCI GI-FAPAR and FIPAR from GBOV (LP4) were presented, as well as for sites in Nebraska which has continuous measurements (but with no upscaling).

In the future, we need to move towards automated and temporally continuous in-situ data collection for validation. The periodic field campaigns are useful, but they fail to adequately characterise temporal dynamics and thus information on the performance of satellite products over time is lacking. However, the main challenge is to assess how reliable these measurements are in comparison to ad-hoc campaigns.

Regarding automated measurement techniques an automated DHP for LAI, FIPAR and FCOVER was presented. It was Implemented in Wytham woods (UK) and Hainich (Germany). The comparison with manual sampling shows a very strong relationship between automated and manually acquired LAI. This system has been moved into the GBOV and is being installed in other sites. Wireless quantum sensors are used for the automatic measurement of FAPAR. Such automated systems were established in Valencia and Tumbarumba sites, using sampling protocol similar to manual measurements (row structured sampling). It was mentioned that the automated in-situ data are useful for temporal characterisation, while field campaigns are very much complementary, allowing to understand spatial variation (and potentially identify/correct for biases in the automated measurements). The potential of using low-cost UAVs was also indicated with the possibility to expand DHP measurements from point to site/moderate resolution product scale. The results show good reliability in filling in the scale gap that currently exists. UAV4VAL Dragon project could help with the scale gap. To conclude, in the longer-term we should move to an automated global land validation system.

3.4 Recent advances in Land Cal/Val activities

Marc Bouvet (ESA, The Netherlands) presented 'RadCalNet protocols and lessons learnt from an operational global network'. RadCalNet is a CEOS WGCV initiative to provide satellite operators with SI-traceable TOA spectrally resolved reflectances. There are currently five sites at four locations, with two more to be in preparation. RadCalNet uses MODTRAN5 to calculate TOA reflectance from surface reflectance. The corresponding uncertainty results from the propagation of the surface/atmosphere uncertainties to TOA uncertainties via pre-computed LUT from Montecarlo MODTRAN runs.

In order to accept new sites, a well-defined procedure is followed: documents should be submitted describing the site, the instrumentation, processing and uncertainty analysis. Then RadCalNet WG reviews the data and documents provided by the site and discusses this iteratively with the site owner (peer review process). The site's documentation and the peer review comments are submitted to the WGCV RadCalNet Review Panel to make a recommendation to CEOS WGCV on site admission. Following approval by the CEOS WGCV, the site is a RadCalNet site, data is made public and the site-owner becomes a member of the RadCalNet WG. RadCalNet documentation provides all the information on how to become a site and how to set the site up: selection, characterisation, instrumentation and data processing, uncertainty analysis, etc.

In the lessons learnt, long-term commitment/funding of all members was needed to maintain the site and process, archive and distribute the data. Choosing the right umbrella was crucial to get over national/individual entities and to attract funding. CEOS was the best way to attract and justify budget from Space Agencies worldwide. Imposing a common instrumentation and calibration approach was not necessary, but to count for the uncertainty budget and traceability was essential. Robustness and confidence (no hidden systematic uncertainty in the measurements) were the advantages of such an approach.

To monitor RadCalNet project, three annual (online) meetings are arranged with all parties involved to talk about instrumentation, data processing, data distribution, etc. User workshops are organised to get feedback on the product suitability and recommendations for improvements and to interact with site owners. Moreover, there is a forum for communication with the user community. Funding through multiple agencies/entities contributions is crucial to continue operating.

To grow the network, from setting up a new site to its integration in RadCalNet is a long process (years), but there is support for new site establishment, using the guideline documents. There is also support for new candidate sites' preparation through the acceptance review process (particularly for uncertainty budget review).

The motivation for a site owner to be part of RadCalNET was also questioned. The calibration and validation of their own sensors, e.g. La Crau by CNES, the scientific interest in establishing the sites and developing the methodologies for developing the instrument, the visibility and recognition at international level through CEOS (rubber stamping your site and its quality) and exposure to metrological methodologies were some of the reasons mentioned.

The possibility to include vegetation sites as future sites for RadCalNet was also part of the discussion, as they could be very useful for assessing quality of atmospherically corrected L2 products. The problem in this case is that vegetation sites have no homogeneity and RadCalNet is a radiometric calibration network, so homogeneity is needed to limit adjacency effects and reduce uncertainty in TOA.

Kevin Ruddick (RBINS, Belgium) presented 'HYPERNET network for Land Surface Reflectance Validation: status and way forward'. There is a necessity for an automatic data acquisition and for hyperspectral data. Correcting sun-sensor geometry is also essential, so multiple sun/viewing geometries are needed to develop and validate BRF models. HYPERNETS is a network for the validation of surface reflectance of all spectral bands for all optical missions. According to its SR acquisition protocol, downwelling irradiance, nadir upwelling radiance and angular upwelling radiances will be measured; FRM4VEG is expected to contribute in consolidating the protocols for SR. The Cal/Val network plan includes annual absolute calibration and monitoring, full characterisation and monitoring to trigger re-characterisation. The protocols will be different for the Land and Water validation network. Tests will be run in 2021-22 considering long-term sustainability. The new system will be available only in 2022, but the old PANTHYR VNIR system can be adapted meanwhile for Land sites.

An autonomous hyperspectral network is the most cost-effective solution for SR validation as it can serve for various missions. However, there is need for consolidation of protocols and uncertainty estimation (FRM4VEG). The priority of validation site operations is to stabilise funding. In case of HYPERNETS, it is not sure yet how the funding will be ensured for long-term operations, but it is being investigated. The Copernicus programme and EU were recommended as potential solutions in the future; to be identified in the frame of CCVS and be reported at EC level. Regarding the data availability to users, for Water sites the data will be accessible in 2021 and for Land in 2022, through a centralised processing, archiving and distribution system, like RadCalNet.

Benjamin Brede (Wageningen University & Research, The Netherlands) presented 'UAV-based and low-cost networks approaches for Land Cal/Val'. LiDAR measurements can be the input to automated individual tree segmentation algorithms for plot scale analysis. They are also important input for LPV super-site classification. Considering LAI retrieval, similar method as that proposed by Wilson (1963) and used by DHP (i.e. point quadrat method) can be implemented. LiDAR is illumination independent; a very strong asset for surface reflectance comparing to other LAI and FAPAR methods.

UAVs for spatial scaling are flexible platforms for multiple sensors and can map at satellite footprints. UAV-LiDAR measurements are not affected by cloud and illumination; moreover, large areas can be covered in a timely manner. The problem is when you do not have field data matching up to the satellite observations, so dense temporal sampling is really necessary. Examples of low-cost sensors were given: PASTIS57, VEGNET, TreeTalker TT, Automated DHP, etc.

Campaigns for site characterisation with TLS/UAV-LiDAR and synergies with AGB were recommended. Inter-comparisons between LiDAR and traditional sensors will be essential to improve reliability of such new devices. Similarly, inter-comparison between low-cost and traditional approaches was suggested. MLPV guidelines should be updated to take account of new measurement technologies like automated sensors, TLS etc.

In the discussion, the important contribution of low-cost sensors was mentioned for scaling up the number of ground measurements. However, for Cal/Val purpose we also need to think how we could better calibrate them, characterise their error sources etc. In addition, automatic systems are very interesting, but some spatial sampling is mandatory to assess LAI, especially when deriving it from DHP and Poisson model to meet the turbid medium assumption. It seems also easier to automatize the processing for upward looking images (contrast between sky and vegetation), but much more difficult for downward looking images (crops with confounding effects between shadowed soil and vegetation).

Pablo Arroyo-Mora (National Research Council Canada, Canada) presented: 'UAV-based spectrometric measurements for Land Cal/Val under different illumination conditions'. Recent technological advances and field campaigns cost and need time; they offer detailed characterisation of the site of interest, but they provide limited spatio-temporal coverage. The objective of the presentation is to showcase the utility of a UAV full range (400-2500 nm) pushbroom hyperspectral system under various cloud conditions to capture a phenological event at an endangered meadow ecosystem. The atmospheric compensation used in the case was described: SUN radiation transfer model (ATCOR) and the empirical line correction (ELM) for DIFF and VAR conditions. The analysis involved the computation of Signal to Noise Ratio and Vegetation Indices, as well as the extraction of Endmembers using SMACC. The results analysis show that atmospherically corrected low altitude UAV- HSI acquired under cloudy conditions is useful for vegetation analyses as long as the unique challenges imposed by the illumination conditions are considered.

The presentation was concluded replying to some overall questions:

- How can field campaigns contribute to the overall global validation strategy? If these campaigns follow well-established methods (minimal best practices), they can expand the spatial extent and enhance validation of satellite EO products (better understanding)
- How can we best use current technological advances (UAV, low cost devices) for complementing land Cal/Val strategy? Still under development but in context of EO has to be focused on advancing the understanding spectral scalability and uncertainty budgets, i.e. how to scale up uncertainty and not just measurements.
- How can we enhance reliability, robustness and traceability of these new technological devices? There is still a significant knowledge gap about best practices as well as vendor transparency (sensor characterization). Knowledge gap needs to be closed for both the scientific community and also for the end users.
- Are the FRM guidelines applicable to such new devices? Shall we define a tailored-FRM concept, or use FRM as transfer standard in the traceability chain? On-going work (NRC, NPL, NEON, CABO etc).

3.5 Final discussion

In the discussions at the end of the WS, the main issues regarding LPV were mentioned and recommendations were provided.

The important topic of SR validation and the lack of networks and protocols was discussed. If we want to validate surface reflectance and link to ESA land-focused missions, perhaps we should not distinguish between products. We should look for synergies in acquiring multi-mission Cal/Val reference data. ESA should have an infrastructure, which can fill the needs of multiple missions in particular of the future land-focused missions. We need a set of super-sites to support multi-mission validation, especially in the Copernicus context. HYPERNETS is expected to fill this gap acquiring multi-mission Cal/Val data. Funding for the network's sustainability is the main problem in this case.

FRM4VEG, LPV super-sites and GBOV are very complementary; GBOV provides already some FRM in it, so some of GBOV products are FRM-compliant. However, its not only about providing uncertainty; it's about providing evidence of this uncertainty; we should be striving for providing such evidence, it is actually the final goal and we are not there yet. In FRM4VEG, FRM approach to UAV SR is applied. There are measurements though, which are not FRM, e.g. low-cost devices with little knowledge about sensor calibration, but can still be used for Cal/Val in an integrated approach.

Regarding RTMs, the most important recommendation is to have inter-comparison of RTMs in agreed set of conditions, as done in the past. It is better to have a community agreement in performances of different RTMs. For vegetation we need 3D RTM and Eradiate is expected to fulfill the need for harmonisation.

The estimation of foliage absorption for FAPAR was also mentioned and the need for advance of in-situ protocol. How can we actually measure foliage absorption within the leaves? In NPL they can validate uncertainty if they have two independent roots of estimating uncertainty; the challenge when they go to satellite pixel scale is all the component of uncertainty, such as AC, undetected clouds, etc.

The potential of GBOV as a centralized repository for storing land Cal/Val data was discussed. Can we foresee ELDC (EVDC for Land)? ESA is taking the lead to have a Land-dedicated Cal/Val repository centre, but internal discussions will be needed. There is a clear need for such Land Cal/Val data centre, storing not only network, but also campaign data for Land.

APPENDIX A: PARTICIPANTS

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APPENDIX B: ACRONYMS AND ABBREVIATIONS

AC	Atmospheric Correction
AGB	Above Ground Biomass
Cal/Val	Calibration/Validation
CCVS	Copernicus Cal/Val Solution
CEOS	Committee on Earth Observation Satellites
DHP	Digital Hemispherical Photography
EO	Earth Observation

ESA	European Space Agency
EVDC	ESA Atmospheric Validation Data Center
FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FCOVER	Fraction of Vegetation Cover
FIDUCEO	Fidelity and uncertainty in climate data records from Earth Observations
FIPAR	Fraction of Intercepted Photosynthetically Active Radiation
FRM	Fiducial Reference Measurements
GBOV	Ground-Based Observations for Validation
GI-FAPAR	OLCI Global Vegetation Index
GUM	Guide to the Expression of Uncertainty in Measurement
ICOS	Integrated Carbon Observation System
ITT	Invitation to Tender
LAI	Leaf Area Index
LPV	Land Product Validation
LST	Land Surface Temperature
MPC	Mission Performance Center
MR	Medium Resolution
MTCI	MERIS Terrestrial Chlorophyll Index
NEON	National Ecological Observatory Network
OLIVE	On Line Validation Exercise
OTCI	OLCI Terrestrial Chlorophyll Index
PAI	Plant Area Index
QA4ECV	Quality Assurance for Essential Climate Variables
RadCalNet	Radiometric Calibration Network

RTM	Radiation Transfer Model
SoW	Statement of Work
S-2	Sentinel-2
SR	Surface Reflectance
TERN	Technologies for Earth Observation and Natural Risks
TLS	Terrestrial Laser Scanner
TOA	Top of Atmosphere
UAV	Unmanned Aerial Vehicles
WGCV	Working Group for Calibration and Validation