VH-RODA and CEOS SAR 2019 Workshop Summary

Author(s): ***Alessandro Piro***
Task [6] Lead

Accepted: ***Clement Albinet***
EOP-GMQ EDAP Technical Officer

Distribution: ***Kevin Halsall***
EDAP Project Manager

AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
1.0	17/01/2020	First issue

TABLE OF CONTENTS

1. INTRODUCTION

The **Very High-resolution Radar & Optical Data Assessment (VH-RODA)** and **CEOS WGCV SAR 2019 workshop** has been held in **Frascati, Italy from 18–22 November 2019**.

The Workshop, hosted by ESA/ESRIN, has provided an open forum (new space and institutional) for the presentation and discussion of current status and future developments related to the calibration and validation of space borne very high-resolution SAR and optical sensors and data products.

1.1 Workshop Topics

The Coordinated Optical/Radar Workshops have addressed the following topics:

- Processing algorithms
- Calibration requirements and definitions
- Calibration targets and sites
- Calibration methodology and techniques
- Innovative instrument concepts
- Analysis Ready Data (ARD)
- Calibration of future missions
- Radiometric Validation
- Cross Calibration / Validation
- Fields campaigns / In-situ measurements / FRM
- Operational quality control
- Calibration database
- Product Validation
- Artificial Intelligence for Cal/Val
- Digital Elevation Model (DEM)

The high-level structure and organization of the workshop is reported in the following structure table, where three main macro sections can be identified:

1) *Plenary Sections* with high level presentations on missions/instruments:
2) *Parallel Technical Sections* with the in-depth analysis and discussions on specific technical topics;
3) *Closure Section* with:
    - Two dedicated summary sections (Optical and Radar) on the presentations;
    - A panel discussion organized as open forum in order to stimulate the exchanges among the different communities.

Monday	Morning	Big Hall		11:30 - 13:00 Registration	
	Afternoon	12:30 - 13:30 Introduction and Welcome			
		Big Hall		13:30 - 15:20 Institutional / Commercial panel #1	
				15:40 - 18:00 Institutional / Commercial panel #2	
		Ice Breaker			
Tuesday	Morning	Registration (cont)			
		Big Hall		08:30 - 10:40 Institutional / Commercial panel #3	
				11:00 - 13:00 Institutional / Commercial panel #4	
		Registration (cont)			
	Afternoon	**OPTICAL SENSORS sessions**		**CEOS SAR WGCV sessions**	
		Big Hall	14:00 - 18:20 Radiometric Calibration – Radiometric Validation	Magellan	14:00 - 18:20 Calibration Techniques
Wednesday	Morning	Big Hall	08:30 - 10:50 Analysis Ready Data	Magellan	08:30 - 10:50 Calibration of Future Missions #1
			11:10 - 13:00 AI for Cal/Val		11:10 - 13:00 Calibration of Future Missions #2
	Afternoon	Big Hall	14:00 - 15:40 Geometric Aspects	Magellan	14:00 - 15:40 Calibration Techniques
			16:00 - 18:40 Quality Control		16:00 - 18:30 Analysis Ready Data #1
Thursday	Morning	Big Hall	08:30 - 11:00 In-situ Measurements / FRM	Magellan	08:30 - 10:30 Analysis Ready Data #2
			11:20 - 13:00 Inter-Satellites Comparison: Methodology & Results		10:50 - 13:00 Processing and Algorithm
	Afternoon	Big Hall	14:00 - 15:40 Calibration of Future Missions	Magellan	14:00 - 15:40 Cross-Calibration and Validation
			16:00 - 18:00 VHR DEM for Optical data / Harmonization		16:00 - 18:00 Discussion
Friday	Morning	Big Hall		08:30 - 09:45 Optical Summary Sessions Reporting	
				09:45 - 11:00 SAR Summary Sessions Reporting	
				11:15 - 13:00 Panel Discussion	

The number of participants has been 150.

2. SUMMARY OF SAR SESSIONS

Institutional / Commercial panel #3 *Bruce Chapman (NASA/JPL), Michael Eineder (DLR)*	
Summary	**The COSMO-SkyMed Program: VHR modes in the first and second generation**: ▪ COSMO/SkyMed 2nd generation satellites to be launched 2019ff, offering bandwidths up to 1GHz. Availability for science / civilian applications not yet defined. HH or VV polarisations. **ICEYE and the Sentinels: complementary constellations:** ▪ ICEYE: 3 X-band satellites in orbit, more to follow in the next years offering very frequent access to selected sites. Many images shown and first calibration activities performed. VV, 17-days repeat, R or L. 5 satellites by 2020, 10 satellites by end of 2020, eventually 18 satellites. **Radarsat-2 Image quality and calibration overview:** ▪ RADARSAT-2: System is carefully monitored and processing/calibration adapted to compensate degradation. Quality still good after 11 years operations. 750,000 acquisitions. Some interference with other C-band satellites, and surface RFI. **Airbus SAR constellation:** ▪ Airbus/Hisdesat: TerraSAR-X and PAZ products are highly compatible due to same orbit and processing systems. E.g. PAZ geolocation quality in centimeter range, similar to TerraSAR-X. HRWS, 1.2 Ghz bandwidth, 4 satellites, launch 2025. **A decade of Terrasar-X and TanDEM-X operation: a retrospective on the performance of the SAR system and an outlook to the future** ▪ TerraSAR-X and TanDEM-X satellites in good conditions after 12 / 9 years. Consumables might hold until 2029. Careful USO frequency monitoring performed which is required for bi-static interferometry and for precise geolocation. A HRWS high-resolution bi-static system could continue the German X-Band line for image and DEM generation. **Discussion** Orbits should be carefully controlled (tube) and measured (2-frequency GNSS) for InSAR ▪ Efforts should also be invested into AI-methods for data exploitation in ground segments ▪ But the focus of CEOS WG Cal/Val should remain on data quality USO frequencies of future InSAR capable SAR-systems should be monitored during operations. ESA will foresee a coupling between GNSS and SAR oscillators in future systems Efforts should be made in cross-calibration of products from different missions ▪ Optical sensors are pushing for more intercomparison

Institutional / Commercial panel #4 *Nuno Miranda (ESA), E. Lopinto (ASI)*	
Summary	**PAZ: 1 year after operation** ▪ Routine monitoring of quality indicators attitude, internal Calibration ▪ System calibration: ➢ Noticeable improvement in channel imbalance, isolation better than 24dB ➢ Centimetre geometric accuracy achieved. Work in progress for the geocoded products ➢ Radiometric stability of 0.2dB after 18 months ▪ Cross-calibration campaign will be made with TS-x/TD-X **RadarSat Constellation Mission** ▪ Mission facts, including mission coverage. Mostly Canada and European seas in ship detection mode ▪ Mission integrated in the different services of Government of Canada ▪ CP completed with issues on attitude pointing and scansar resolved ▪ Data policy document released promoting free and open data **ALOS-2** ▪ Mission summary and facts ▪ Timeline with ALOS-2, ALOS-3 (optical) and ALOS-4 (SAR) ▪ ALOS-2 have completed its mission lifetime and entered is post operational phase → reduction of duty cycle from 50 to 30% ▪ Summary of recent results on radiometric, geometric and polarimetric calibration ▪ Presentation of ALOS-4 ▪ JAXA is promoting free and open data access policy and presented a plan for the different mission ▪ JAXA is promoting ARD and is currently making an effort towards it **SAOCOM** ▪ Summary of mission facts, ground segment, product characteristics and product family that goes up to L2 ▪ Calibration sites shown ▪ First results shown in SM and how they will ease decision making ▪ Intensive SM campaign made and it has been confirmed that results can be made available ▪ Acquisition scenario explained ▪ Including the scenario and commercial restriction over Europe let to the ASI decision **Sentinel-1 mission status presentation** ▪ Recall of the mission key facts, acquisition scenario and core product family that encompasses L2 over ocean ▪ Sentinel-1 is providing a long term perspective to the users allowing to build operational services ▪ Free and data open policy, Data quality, data availability and easy access are have demonstrated to be real enablers ▪ Cal/Val organisation during phase E2 presented relying a lot on expertise that can't be found in a unique provider. ▪ Cal/Val sites relying largely 'freely available sites' but for the radiometric calibration with transponders

	▪ Instrument performance monitoring. All SAR operators have reached a certain level homogeneity in the parameters monitored ▪ Radiometric calibration results shown and further detailed in the afternoon ➢ Strong improvement of the radiometric accuracy can be achieved by performing noise removal ▪ Ground based Interferences are major source of annoyance for the users and needs to be further considered in the processors **PAZ calibration results after one year of operation is reaching very good level of performance**. ▪ INTA intending to run an in deep comparison exercise with respect to its sister missions **RCM overall mission status and objectives given** ▪ Overall presentation of the mission and of the activities performed since launch ▪ Commissioning phase completed a week ago start of the phase-E1

Calibration Techniques #1 ***Takeo Tadono (JAXA), Marco Lavalle (NASA/JPL)***	
Summary	**3 talks reported on the SAOCOM-1A commiss. phase and Cal/Val:** ▪ SAOCOM-1A, L-band, 50 MHz, launched Oct 2018 ▪ CONAE and Aresys reported on independent assessments ▪ SAOCOM-1A is in good conditions and stable, and has good initial calibration results in terms of radiometric calibration, pointing, IRF, Geometric and polarimetric calibration ▪ Rain-forest gamma-nought profiles consistent with expected trends ▪ Some tens of meters (compared to a native SLC resolution of 10 x 5m) is currently observed for the geometric calibration due to quality of orbits **1 talk showed a new approach to polarimetric calibration in the presence of ionosphere** ▪ Theoretical approach showing ambiguity between estimating the Faraday rotation angle and the cross-talk and channel imbalance parameters ▪ Idea is to use azimuth sub-bands to resolve the ambiguity ▪ Results shown with ALOS-1 and ALOS-2 **1 talk showed results of KOMPSAT-5 geolocation accuracy** ▪ Assessment using Corner reflectors installed in Mongolia, Italy, US and Germany ▪ Geolocation from CRs showed good performance (< 2m), except for Germany CRs, where peak response could not be detected due to unmatched K5 beam with CR elevation.

Calibration Techniques #2 *Nuno Miranda (ESA), Mélanie Lapointe (CSA-ASC)*	
Summary	**The talks have been related to the:** ▪ Radiometric and Geometric calibration of Sentinel-1 ▪ RCM commissioning phase results ▪ Impact of ground based RFI into SAR data ▪ Inter-satellite interferences **Inter-satellite interferences** ▪ Inter-satellite Interferences appear to be only a small portion of the interferences (mostly from ground systems). ▪ Mitigation can be put in place through coordination between agencies ▪ Mechanism exists to predict the occurrences between space borne system based on geometric information (orbit). However, detection of actual occurrence requires to access/query the observation scenario, which is not always available ▪ Characterisation of the actual source is only possible by analysing the RAW data **Ground based interferences** ▪ For Sentinel-1, rank echoes were found to be reliable noise measures that can be used to map RFI sources globally ▪ Sentinel-1 noise levels have been translated into brightness temperature measures using AMSR-2 radiometer data. *From a user's perspective, it would be useful if the images with interferences were flagged in the metadata.* **S-1 Calibration results** ▪ Radiometric accuracy of Sentinel-1 is within the requirement (1db (3sigma). Improvement have been made for S-1 A with a recent updater of the EAP. Same process is on-going for S-1B ▪ Geometric accuracy is within the requirements and exceed the specification if further correction APD, solid earth corrections are implemented **RCM complete initial system calibration during commissioning** ▪ Results achieved are as expected ▪ Calibration will be improved during the coming months

Calibration of Future Missions #1 *Paul Rosen (NASA/JPL), Martin Suess (ESA)*	
Summary	**The 2019 UAVSAR SouthEast time-series campaign can deliver unique L-band Quad Pol time series for algorithm development and validation for future missions** ▪ Morning and evening data takes of various ecosystem targets with different look direction to simulate ascending/descending orbit ▪ Ground truth will be free and open ▪ Reflector-based systems with a feed-array can be vulnerable to TR module loss, so mitigation is of interest ▪ Placing the feed-array out of focus can mitigate the effect of a TR module loss at the cost of the initial antenna gain

	▪ After loss of a TR module the local gain loss can be almost recovered after re-optimizing the beam forming coefficients **SweepSAR (Scan on Receive) system can fill the transmit pulse gaps through constant variation of the PRI.** ▪ A proper PRI sequence can ensure that no more than one consecutive azimuth sample is lost. ▪ For reduction of the azimuth ambiguity artifacts the PRF needs to be increased. ▪ No further discussion of calibration issues with this technique **Artificial passive calibration targets are a challenge in P-band due to their required size** ▪ Specific transponders can be used but they are also challenging at these frequencies ▪ Satellite or radio astronomy antennas can also be used as artificial calibration targets **Many SAR sensors are addressing sensor pointing calibration through the use of Doppler estimation from the radar data** ▪ CEOS could recommend/catalog areas where Doppler estimation is considered robust, in a similar fashion to CR or Amazon sites

Calibration of Future Missions #2 ***D. Geudtner (ESA), S. Coté (CSA)***	
Summary	**First talk reported on the SAR pointing calibration needs for ocean surface radial velocity estimation.** • Estimation of ocean surface radial velocity based upon the Doppler Centroid Anomaly (DCA) approach requires very precise pointing knowledge, which cannot be provided by state-of-the-art AOCS • Sentinel-1 RVL product is affected by small residual Doppler ramps due to an effective azimuth antenna steering rate (deviating from the commanded one) for TOPS, and variations in DC bias and slopes, potentially caused by tapered antenna pattern (gain and phase) • Single-platform Along-Track Interferometry (ATI) might be an alternative to DCA for measuring ocean surface radial velocity. • RADARSAT-2 is used as a test platform to assess the performance (complementarity) of ATI vs DCA for measuring ocean surface radial velocity. **Second talk presented an account of many of the internal calibration improvements to be integrated into S1-C/D design, lessons learned from S-1A/B experience.** • Design changes allow improvements of radiometric stability and accuracy, simplification of internal calibration and transmit hardware, • Rearrangement of interleave calibration sequences enable more interleaved noise measurements to improve product de-noising. **Third talk identified 2 classes of options for eventually placing Sentinel-1C into the current Sentinel-1A/B constellation (before Sentinel-1A is replaced).** • One option improves revisit and shorten the repeat pass interval (InSAR) to 4 days, while the other option would improve revisit, but maintains the current repeat pass interval of 6 days.

	• Ground station contact limitations were also considered in the analysis. **Fourth talk proposed an internal calibration concept for multi-channel SAR systems.** • It enables a real-time calibration during transmit and receive, as required for the elevation Scan-On-REceive (SCORE) technique, which is anticipated for future spaceborne SAR instruments • A model and simulation tool were created to estimate the errors in such a calibration system and assist the design. **Final talk gave an overview of the Radar Observation System for Europe (ROSE-L), one of the 6 high priority candidate missions considered by the EC.** • ROSE-L is expected to provide L-band data for Copernicus services to enhance applications, such as sea-ice classification, soil moisture monitoring, land use classification, and flooding monitoring below vegetation.

Calibration sites and techniques I ***Jens Reimann (DLR), Medhavy Thankappan (GA)***	
Summary	**Accurate Passive Targets for Radiometric and Polarimetric SAR Calibration:** ▪ Improved RCS knowledge of CR due to full-wave simulation, point target simulation including surface deformation **Special considerations for TwinSAR-L baseline calibration method with known heights of point targets or reference DEM:** ▪ DEM Performance for various SNR values and surfaces has been analyzed **Updates to the Australian corner reflector array coordinates and resulting improvements in absolute location error of SAR products:** ▪ Improved geolocation knowledge for a large number of CRs in Australia with an accuracy of 2-4 cm **A bar-shaped permanent target for image resolution assessment of high resolution microwave sensors:** ▪ New Approach for resolution determination in SAR data similar to targets used for optical sensors **Discussion summary:** ▪ CRs (and sites) are designed for different purposes (e.g. Geometric Cal, Radiometric Cal, or Polarimetric Cal) ▪ Accuracy of all target characteristics for a site have to be provided ▪ Reference targets have to be maintained regularly by site owners (e.g. re-surveyed, cleaned, repaired/replaced) ▪ Satellite operators should use established reference targets regularly, to enable cross-calibration of multiple sensors

Analysis Ready Data #1 *Ake Rosenqvist (JAXA/soloEO), Andreia Siqueira (Geoscience Australia)*	
Summary	**LSI-VC and WGCV activities related to CEOS Analysis-Ready Data for Land (CARD4L) presented.** Presentations describing each the four SAR-related CARD4L specifications currently under development: ▪ Normalised Radar Backscatter ▪ Geocoded SLC ▪ Polarimetric Radar ▪ Interferometric Radar **Emphasised that CARD4L** is a voluntary effort, and for every data provider to decide which (if any) product(s) to implement Main aim to broaden the SAR user community by provision of data products that do not require EM expert knowledge. **Importance of consistent ARD products for multi-sensor, wide-area, high-temporal applications demonstrated.** **Discussion summary:** ▪ **CARD4L** – iron out general confusion ▪ **DEM**: Use of the same DEM across different sensors to ensure product interoperability – general consensus that it would be ideal however this is not feasible. ▪ **Product gridding**: Need for common spatial reference points or gridding for products ▪ **GSLC**: Slow adoption until SW becomes available to utilise **InSAR specs:** ▪ Characterization of phase

Analysis Ready Data #2 *David Small & Franz J Meyer*	
Summary	**CARD4L Product Assessment Process & JAXA self-assessment for PALSAR and PALSAR-2 products** ▪ Provided summary of how a provider could get CARD4L approved ▪ Showed JAXAs work on preparing CARD4L-compliant ARDs from PALSAR & PALSAR-2 [global NRB mosaics; PALSAR-2 ScanSAR; PALSAR FBS] ▪ Presented JAXA self-evaluation of CARD4L compliance for NRB mosaic **Capella's VHR SAR constellation for multi-temporal change detection** ▪ Capella aims to launch constellation of 36 X-band small SARs → imaging revisit of from 2 days to a few hours depending on latitude & 4h for InSAR ▪ Denali pathfinder launched in Dec'18, Sequoia to be launched in Jan'20 ▪ Sample simulated data products shown at 0.5m-2m resolution ▪ Exciting applications highlighted (change detection; hazard mapping ...)

	A Copernicus DEM from WorldDEM Data ▪ Airbus' various WorldDEM flavors were presented (core; WorldDEM; DTM) ▪ Workflow to get from WorldDEM to edited Copernicus DEM shown ▪ Copernicus DEM freely available at 90m – higher res under restricted license **On-the-fly processing & display of S-1 data** - Serge Riazanoff (VisioTerra) ▪ Web service to do on-the-fly geocoding and calibration of S-1, ENVISAT, ERS data shown ▪ Goal: Make EO data/processing available to users with limited compute/internet resources ▪ Online demonstration of visualization of New Zealand oil spill with S-1 data **Time-series and Applications of Advanced S-1 ARD for Africa** ▪ Developing ARDs to help new communities in Africa onramp SAR data ▪ Processing of SAR data to monthly/yearly mosaics for several test sites ▪ Examples for use in forest loss, inundation - flood monitoring - change detection ▪ Good evidence of usage of targeted end users **ARD Services and other user support-related activities at the NASA ASF Facility** ▪ ASF holds 8.5PB SAR data in archive (PALSAR1, S-1, …NiSAR coming) ▪ Hyp3 Interface to amazon WS hosted processing for L1, L2 products ▪ Examples shown from RTC time series, InSAR products, change detection maps ▪ Automatic processing flows with sarviews-hazards.alaska.edu ▪ Traceability & reproducibility boosted with python-based Jupyter notebooks ▪ L3 processing with OpenSARLAB; Classroom use independent of local compute setup

Processing and Algorithm ***Marc Rodriguez-Cassola (DLR), Riccardo Piantanida (Aresys)***	
Summary	**SAR Processing By Chirp Scaling Algorithm (CSA)** Based General Algorithm have been presented together with test results. The generation of the **Copernicus DEM** from WorldDEM data is presented. The implementation and validation results of the **TDBP processing algorithm** (in the time domain) has been presented. The motivations for **ETAD (Extended Time Annotation Dataset) for Sentinel-1** together with atmospheric data corrections and data quality preview have been presented. Extraction of **GCPs in SAR images** and extract their 3D position using radargrammetry at decimeter accuracy, point identification and horizontal accuracy have been presented.

Cross-Calibration and Validation *Björn Rommen (ESA), Yuhsyen Shen (NASA/JPL)*	
Summary	**GNSS-Based Clock Synchronisation: A Performance Assessment** ▪ Highlights: Propose having onboard GNSS receiver and radar receiver using same USO for enabling multi-static radar missions. Performance assessment done using GNSS raw data simulation. Relevant for ESA's Earth Explorer 10 Candidate Mission Harmony. ▪ Discussion and comments: despite the complexity of the topic, the talk engendered a lot of conversations and food for thought. Clear is that the topic deserves a further elaborated context, that will be provided within Harmony feasibility assessment. **Cal/Val Approach for DInSAR Deformation Rates Products using GNSS Data** ▪ Highlights: Using changes detected with ground-based GNSS receiver regional network to validate and couple surface changes detected by DInSAR. Two different examples used were North Anatolian Fault (requiring mm/year over wide extent) and German ground motion service. ▪ Discussion and comments: the connection of GNSS rates with subsidence from DInSAR was generally accepted as a valid approach that deserves to be considered for missions addressing surface deformation processes. **SAR Cross-Calibration Using Natural Targets** ▪ Highlight: Preliminary effort to cross-calibrate S-1 and GaoFen-3 RCS over Baotou Calibration Site and using different homogeneous regions. ▪ Discussion and comments: the attempt to cross-calibrate various C-band SAR missions using distributed targets was appreciated. The work was considered as a preliminary work needing to include additional considerations and better representation of the used modelling approaches (e.g., Dubois model was referenced) in order to allow a proper assessment. **Extended the Ice Watch System as a Citizen Science Project** ▪ Highlight: Promoting Citizen Scientists (tourists) when visiting Artic regions record and upload observations for correlation with SAR detected sea ice flow or ice type. ▪ Discussion and comments: The presented approach taken from a recently started activity is intended to assist in the provision of "in-situ" observations to corroborate with SAR ice detection and classification. The collected contemporaneous in-situ with the SAR observations is supposed to help in machine learning approaches through generation of a training data set. **Discussion summary:** In the discussion slot, there was general consensus on the need of a consistent use of terminologies (calibration, validation, cross-calibration, cross-validation) by the community – as this was seen to cause some confusion. Also, it was felt that accepted approaches for cross-calibration and validation - when properly documented - could be referenced by the community.

CEOS discussions	
Discussion	**Work Plan for CEOS SAR Cal/Val** ▪ Inventory of existing calibration targets and their availability for joint use ▪ Standards for international joint use of SAR calibration targets ▪ Pursue coordination between agencies to reduce interference between sensors ▪ Evaluation of CARD4L product family specs ▪ Revamped webpage coming with revised target database, and new document repository

3. SUMMARY OF OPTICAL SESSIONS

Institutional / Commercial panel #1 *Giuseppe Ottavianelli (ESA), Patrice Henry (CNES)*	
Summary	▪ Data quality assessment is a complex effort, especially when harmonising data coming from a constellation of proprietary and/or third-party providers. ▪ Activities are sometimes performed by external partners (whether public/commercial) and sometimes developed in-house depending on the criticality of the know-how to be developed. Methodologies are not always published. ▪ Certainly, depending on the user, there are different needs with respect to data quality information. Nonetheless, there is a need to: a) increase the level of data quality related information in each product, b) harmonise the way this quality information is presented across all data providers. For example, a long term objective could be to provide the Relative Spectral Response Function in each product and make sure that the measurement accuracy and related traceability is also provided, following the QA4EO principle. ▪ Sentinel 2/3 data is often used as reference data for inter-calibration. ▪ Public agencies shall strengthen their key role to: ➢ facilitate inter-comparisons and methodologies testing and harmonization, ➢ Provide ground based instrumented sites supporting Cal/Val activities, with results free and open for all missions. CEOS plays a key role in the coordination of these efforts.

Institutional / Commercial panel #2 *Philippe Goryl (ESA), Nigel Fox (NPL)*	
Summary	**Main messages from presentations** ▪ The sessions addressed the High Resolution missions from the public sector (Agencies), including Hyperspectral mission (Prisma) ▪ Dedicated Cal/Val programmes are in place for these missions following best practices CEOS WGCV well established best practices: ➢ RadCalNet ➢ PICS, Rayleigh, DCC, Glint ➢ MTF and image quality methods ➢ Stars and moon ▪ The session also highlighted the long experience and expertise of Agencies in the Cal/Val domain. Image quality is considered as a specific skill and there is need and interest for share experience from one mission to the other ones. ▪ The need for SI-traceability and measurement, uncertainties evidence is well understood and should be communicated.

	▪ It was noted that it is not possible to produce a global seamless data product from multiple sensors using current approaches without noticeable artifacts **<u>Lesson learnt from JACIE</u>** ▪ Cal/Val community has gone from wondering whether low-cost sensors will work to helping ensure they are fit for purpose. Users in the 90s were not sure that low cost and/or commercial sensors would provide usable imagery →*Joint Agency Commercial Image Evaluation (JACIE) Team was the US Government's response to evaluate this* ▪ Key lesson learned from JACIE was **<u>communication</u>** ➢ Moved towards improving communication between the users and providers ➢ Work to "operationalize" some of JACIE work (Data Buys, reporting, etc.) ➢ Results need to be presented in a more consistent, useful manner ▪ JACIE is a good forum for Public institutes and NewSpace exchange. VHR RODA could complement. VHR RODA and JACIE should work together.

Radiometric Calibration / Validation ***Kurtis Thome (NASA), Sebastien Clerc (ACRI-ST)***	
Summary	**<u>Talks summary</u>** ▪ All talks highlighted quantitative uncertainties with discussions of causes of uncertainties ▪ Sensors discussed in the session had better than 20-m spatial resolution ▪ Several organizations are achieving requirements without the use of on-board calibrators ▪ Absolute calibration and sensor-to-sensor harmonization were covered ▪ Methods being implemented for radiometric and spatial calibration and product validation followed well-established approaches ▪ Reporting of results is an important step for all groups ▪ Use of stellar targets is not widely used but results show that bright stars provide a reliable reference for MTF and radiometric calibration of VHR sensors ▪ Validation site and calibration/validation database discussions made clear the utility of making results, processing methods, data available to the community ▪ Audience questions/comments prompted for clarifications of some methods and their utility for a broader range of sensors ▪ CEOS WGCV IVOS is a useful forum for the information presented in this session ▪ Inclusion of dark sites for validation and calibration ▪ Discussion on sufficiency of CARD4L quality requirements led to discussion on ARD in general **<u>Takeaway messages</u>** ▪ Early studies indicate that radiative transfer models may be a significant source of atmospheric correction uncertainty ▪ Surface reflectance validation is strongly affected by sensor view angle effects relative to the validation measurements

	▪ Methods, data, and processing approaches are available to interested users, but require modification to tailor processing to specific sensors ▪ It is important to ensure that interested communities are aware of the availability of venues such as IVOS (within CEOS WGCV), JACIE, and VH-RODA and that best practices need to be made better known by having the IVOS community to attend meetings with broader attendance ▪ Communicating calibration protocols is necessary but the process must still allow, and at some level encourage, alternate methods and approaches as long as they include appropriate uncertainty studies ▪ Government continues to be a major user for commercial data but specific standards desired by government users will not be implemented unless they are required ▪ While bright scenes remain important for calibration, darker scenes can show artifacts that are not noticed in other scenes. Methods are needed to find such sites and to help exploit existing methodologies that already make use of darker scenes ▪ It is important that the current state of a Cal/Val site is known to the community (maintenance, accessibility, quality, etc.) **<u>Recommendations</u>** ▪ An agreed upon reference for sensor intercomparison of VHR sensors is needed ▪ A community effort is needed to develop accepted methods for determining anchor points for sensor inter-calibration ▪ Sites currently suitable for surface reflectance validation should be identified and their data made widely available ▪ Additional sites for surface reflectance validation are needed to ensure sufficient sampling of various surface reflectance values and atmospheric conditions ▪ Sensor programs should incorporate tandem phase operations when possible to improve sensor inter-comparisons

Analysis Ready Data ***Stephen Hosford (CNES), Eric Vermote (NASA/GSFC)***	
Summary	▪ Broad coverage of the issues for provision of ARD – Cal/Val, atmospheric/geometric correction approaches, CEOS ARD for Land, User perspectives ▪ Data is becoming a driver of the global economy and satellites are a source of useful (but complex) data for this economy ▪ Their complexity is a barrier to use - clear need to make the use of complex space data easier ▪ CARD4L is one flavour of an ARD product for Land which requires atmospheric and geometric corrections to produce surface reflectance, surface temperature and normalised backscatter products ▪ Many algorithm and auxiliary data options exist to obtain an Optical SR product, this means product interoperability is challenging ▪ Intercomparison exercises help to characterise and consolidate the many available approaches

	▪ Novel Cal/Val approaches can help us reach consensus more quickly and can help converge toward community approaches to uncertainty characterisation ▪ An ARD approach is essential for creating a multi-source observatory that can monitor diurnal variation in ocean colour.

AI for Cal/Val ***John Mrziglod (ESA), Andreia Siqueira (Geoscience Australia)***	
Summary	▪ Sensor-independent deep learning algorithms can help to overcome the lack of labelled datasets for specific sensors (e.g. using Landsat data helps with cloud masking of Sentinel-2 scenes) ▪ Active learning systems allow to improve and to refine models (e.g identifying the occurrence of specific anomalies within the Landsat data). This can be applied in operational EO production services as well as for bulk archive reprocessing. ▪ Smallsats offer more looks and faster access to information which potentially can support users to make better decision. ▪ Big constellations of smaller satellites require automated calibration and validation systems to be controlled efficiently. ▪ Development of miniaturised calibration sensors for many different satellite types could help to bundle calibration efforts – applications include spectral calibration, radiometric calibration and flat field correction.

Geometric Aspects ***Valentina Boccia (ESA), Jon Christopherson (USGS)***	
Summary	▪ Sentinel-2 Geometric calibration is good. S2A slightly better and less variable than S2B. ▪ Sentinel-2 based GRI over globe released in 2019, replacing Sentinel-2 EOX. GRI accuracy is good; at worst (North America) is still 7.3M CE95. Groups that have been using the Sentinel-2 EOX mosaic should switch to the Sentinel-2 GRI for improved accuracy ▪ Lunar imaging can be used for medium-resolution satellite spatial performance characterization and but is unsuitable for VHR satellites due to terrain features along the lunar limb ▪ A variety of ground control must be assembled for VHR data (<1m), no consistently accurate worldwide source ▪ Better and more consistent ground control needed worldwide at even higher resolutions

Quality Control *John Swinton (Telespazio-VEGA UK), Sam Hunt (NPL)*	
Summary	▪ EDAP geometric validation method presented, with first results for PlanetScope sensor ▪ Perspectives on Cal/Val, with examples of application to Sentinel optical sensors ▪ Description of contents of quarterly image quality reports for Planet sensors. ▪ Presentation of method to assess mission quality ▪ Description of QC activities in S2 mission, including description of s2check tool ▪ Description of Cal/Val activities for undertaken for Landsat missions at USGS ***Discussion Topics*** ▪ What would the ideal Cal/Val system look like? ▪ Cal/Val activities typically make use of a very small subset of the total imagery obtained by satellite sensors, e.g. bright, homogenous scenes. Can we leverage a greater quantity of satellite data for Cal/Val activities (not just typical homogeneous scenes)? ▪ To some extent QC activities still rely on image-by-image checking by experts - to what extent can we get the human out of the loop in this? ▪ How to best report Cal/Val results for large constellations of satellites?

In-situ Measurements / FRM *Cindy Ong (CSIRO, Australia), Joanne Nightingale (NPL)*	

Summary	▪ **Need for standards and guidance for in situ reference measurements for satellite calibration and validation**
	  ▪ To ensure consistency between sites and temporally (i.e. FRMs and CSIRO SR guidebook)
	  ▪ Testing various RT codes over Libya-4
	  ▪ BHR/DHR modelling for per pixel uncertainties on Albedo products over 2 sites (Australia/EU sites) via GBOV
	
	▪ **Impact of RadCatNet is Huge!**
	  ▪ Successful demonstration of international community working together (through CEOS)
	  ▪ Practical approach to site selection (SI traceability > perfect site)
	  ▪ Protocol development
	  ▪ Architecture of system and efficient data processing and delivery to users (345!)
	  ▪ Being used to Cal/Val data from Chinese VHR satellites (Baotou).

Inter-Satellites Comparison *Sebastien Saunier (Telespazio-VEGA, UK), Marc Bouvet (ESA)*	
Summary	▪ It was discussed **how the new space and old space should/could work together in an EO sector** where an increasing number of missions / sensors are being launched by the private sector. ▪ **The role of space agencies could be:** 1) To define standards for reporting quality of EO optical data, 2) To develop tools (open source software / documented methodologies); 3) To propose guidelines & best practices to perform QA. ▪ **Private sectors**: players from the private sector are likely to either keep their QA activities as internal activities or outsource them to other players in the private sector. ▪ It was sensed that it is not the role of space agencies to do the QA of missions from the "new space". ▪ It was mentioned that the EO sector is no different from any other in the industry domain. ▪ It doesn't matter how QA / in-flight calibration is performed for a given mission as long as protocol is traceable and measurements are provided with uncertainties. Also, every player in EO field can do his own QA ▪ The fora do discuss how QA and inflight calibration should be done and shared between old space and new space are numerous. ▪ They are likely not restricted to CEOS/WGCV. There should be continuous exchange of information and continuous work being carried out between the old space and new space in other frame works (e.g. JACIE, VHRODA, scientific conference).

Calibration of Future Missions *Amanda Regan (ESA), Takeo Tadono (JAXA)*	
Summary	▪ **The Calibration and Validation Plan of ALOS-3 -** available data products, operating modes and Cal/Val aspects. ▪ **The TRUTHS mission (NPL),** Climate and calibration focus. Cross calibration with Sentinel-2. Newspace small satellites = a robust pre-flight characterisation to leverage TRUTHS capability. The hyperspectral spectrometer is based on CHRIS-PROBA heritage. ▪ **A survey of in-flight radiometric calibration methods - applicability to Nanosatellites** (Agenium Space and GEO4I). Applicable methods for cubesats were discussed e.g. dark acquisitions over Ocean, yaw steering acquisitions (AMETHIST Method), Use of On-Board Calibration Units, acquisition on uniform desert sites, acquisitions on targeted sites (RadCalNet), simultaneous nadir overpasses. ▪ **Direct tasking of VHR optical satellites** (European Space Imaging). Factors affects data quality are typically e.g. sensor quality, atmospheric effects, lighting, processing. An

	overlooked factor = operational procedures. Need for human assisted planning and local tasking to enable intelligent planning and image fusion – enabling e.g. smart cloud recollections and sun glint avoidance.

VHR DEM for Optical data / Harmonization ***Ferran Gascon (ESA), Fabrizio Niro (SERCO@ESA, Italy)***	
Summary	▪ Essential to provide transparent information (metadata) and access to the DEM used, allowing full traceability of the Level 1 processing chain; ▪ **Clear need for harmonization of DEMs across optical missions**, though it is not straightforward, i.e., various missions/applications have different requirements; ▪ ARD requirements can be fulfilled with 10/30 m DEM for most of the cases, however VHR sensors, or some applications may have more stringent needs (1-2m); ▪ Various inter-comparison exercises being made: **EDAP results of SRTM/ALOS/ASTER** showing clear impact on the derived orthorectified products, both for optical and radar; ▪ **The new Copernicus DEM presented**; delivery on December 2019; policy depends on resolution: 90m free & open, 10/30m restricted access; ▪ **DEMIX inter-comparison exercise** lead by JRC will benchmark Copernicus DEM against other commonly used DEMs, consensus on the reference still to be reached; ▪ DEM resolution needs are not uniform at global scale, i.e., particularly stringent over certain areas (e.g., urban), less stringent over homogeneous terrains; ▪ Looking ahead, the DEM, which is currently provided with restricted access (10/30m), will likely have free & open data policy in the future, to keep pace with the foreseen increase of VHR data availability and their potential opening to the community;

4. SUMMARY OF PANEL DISCUSSION

During the last day of the workshop, an open forum with panel specialists has been organized and a discussion on seven topics have been animated with specific questions to specialists and from/to the platea.

1) ARD = Analysis Ready Data	
Questions	There is confusion on the actual **meaning of ARD**. • What is ARD for Commercial Space? • What is ARD for the Institutional Space? How can **Commercial Space participate and be involved** in the definition process of the CEOS ARD Specifications? Should dedicated specifications be defined for **Very-High Resolution missions**? (e.g., via creation of a dedicated sub-group?) What are the next steps that need to be taken to start a **dialogue** between Commercial Space and Institutional Space in practical terms?
Discussion	**Commercial Position:** ARD does not necessary need calibration: ARD can be assimilated to an API for consumers. ESA agrees with the interpretation, but calibration seems to be necessary since is an automatic process, i.e. georeferentiation. ARD can be interpreted as analysis: is subjective (in fact maybe not so generic but it can depend on the type of applications). Optical/Radar ARDs are different. Optical is more interpretable from users, radar is specific with less degree of freedoms. The ARDs are a world where three aspects (and three classes of users) can be identified: ➢ Accuracy (scientific/expert users), ➢ Interoperability (common users, so there may be ready data to be inter-operate, ➢ Standardization (people doing the work should be involved in the standardization of the products) With reference to the processing steps, a fourth level can be identified with the involvement of new users. ESA asks: is there a way to increase dialog between communities? ➢ Interoperability and There is in addition another level of standardization which is the on-board level, trying to make all processing on board. ➢ Another aspect is related to the Corrections. Question related to different kind of ARDs: Why create not useful data for all kind of users? ➢ ARD process is related to its purpose/scope; Recommendation: facilitate and stimulate their utilization in the community. It is not always clear hot to use data.

	In CEOS community, for example, there are calibration and uncertainties, non-always true for optical. ➢ ARD should evolve providing also procedure: ➢ Standard and guidelines probably necessary for common users. Commercial and institutions should work together and a synergy is needed to find a common way. The question might be if commercial companies and institutions want to converge. ESA propose to join the LSI-VC meeting with the ARD commercial workshop to start a kind of dialogue (as for Card4l). But: if the scope is to provide a simple picture, from a commercial point of view, is really necessary focusing the attention on these problems? Concluding, radiometry is another thing: ➢ Attention on what are the scopes/output/products to provide.

2) Geometric Cal/Val:	
Questions	**Calibration:** We all talk about ARD, Datacubes, harmonisation, and the importance of having data that can be easily analyzed and interpreted by non-expert users. A big part of that is "accurate data geolocation". Do you see the need of having a **common reference for geolocating our data**? **Validation:** We all rely on different sources of GCPs to validate our data and often our validation is performed only over the areas of the world where we actually have GCPs available (e.g. open source and/or specific contract with a specific GCP provider). Is there a need for having a **common worldwide database of GCPs**? Need for **common consistent references**? Harmonization of specifications and methodologies for **geometric resolution** (e.g. PSF, FWHM, MTF@nyq, RAIFOV). Should we get together and agree on common strategy?
Discussion	There is an agreement on the needed to have a common reference for geo-located data: in particular on the developing of specific SW, prototypes and verification and testing activities. Recommendation: There is the necessity on the provision of details (where possible and applicable) on calibration sites, GCPs: and experts and industry could co-work. Recommendation: Important to work on maintenance of site. In the CEOS framework there is a group that start to define and test prototype on Cal/Val portal and trying to catalogue fixed geometric target and natural and artificial target; in this way CEOS is trying to do it and encourage the participations of all for contribution. Recommendation: and communities needs to cooperate not for a specific sensor, but as constellation. Another important point: Funding to perform activities on ground.

	For interoperability it is necessary in an ideal world that all data process should use the same DEM and other common references (especially if data are processed and used in i.e. stack). Not simple to implement. Therefore it is essential to report reference in the data. Important is to accurate GCP different and diffused. Work on the characterization, in the analysis and understanding of the issues: identification if problems on sites or on spacecrafts/instruments. ESA asks: what are the main two things we need to invest in short/medium terms: ➢ With the Open Ultra High resolution, GCPs; ➢ DEMs; A missing keyword is FRM and the characterization of the uncertainties.

3) Radiometric Cal/Val:	
Questions	Is the **infrastructure currently in place** for radiometric Cal/Val enough? • What are the **needs** we have today? • Are they different from the ones we had "yesterday"? **Validation Protocols and procedures**: How should they be implemented when dealing with constellations of **tens or hundreds of satellites**? **Network of Supersites**: should it be just an Agency effort, or a joint effort between Institutional Space and Commercial Space? [...Common consistent reference!] Are Companies planning to use **new types of approaches/methods** to validate data?
Discussion	Radiometric is complex and requires cooperation. CEOS for coordination of dialogue for target site for radiometric calibration. How fill the gap? It is important the schedule of the calibration activities, and the communication of the status: ➢ For near real time products needs of very detailed and characterized radiometric references, also harmonized. ➢ Needs of resources for specific calibrator sites

4) Role of the Institutional space:	
Questions	How does Commercial Space conceive the **role of Institutional Space**? • As reference? • If so, reference for what? (For radiometric Cal/Val? For geometric Cal/Val? For protocols and procedures?) • And to which extent... Are there any **gaps** to be filled?
Discussion	➢ As reference (i.e. hyperspectral missions); ➢ Supporting the Infrastructures; ➢ Make community / support harmonization.

5) Quality Control and Reporting	
Questions	We were used to have constellations composed of just a few satellites. Nowadays Companies have constellations of tens or hundreds of satellites! • Can we still **apply the common/historical practices** of Quality Control and Reporting to Commercial Space? • Or should we define **new "good practices"** to handle and measure the **overall/global** quality performance of these new large constellations? What do **Traceability & Uncertainty** mean when we refer to Commercial Space missions? • Can they still be applied on a "satellite-by-satellite" base?
Discussion	**Question: how this argument can be supported by commercial?** Commercial companies have difficulties to share information about satellite by satellite performance. There are to potential solutions: ➢ Provide uncertainty for all products and in this way customers are guided and their needs guaranteed; ➢ And a possible practical solution is to identify 2 typologies of users (and to provide two or more different quality of data, but this implies different costs). **Question to commercial panel if there is possibility to produce the same dataset with two different quality** (One for example with low uncertainty and one with higher uncertainty depending on the community). This solution cannot be considered since it would be a contradiction and would generate an inconsistency with data. Moreover, the quantity of data is high, and the quality control is automatized. For the accuracy it is not possible to make a generalization since there is a strong dependence by satellite and instruments/technologies. There would be the necessity to use additional resources to examine in depth these topic. **Question about the costs: if the QC is included in the design phase.**

	The design of space segment includes testing, verification and validation activities, but it is not sufficient to cover the mission support: the quality control covers different aspects of the mission, of the operation and it requests investment for activities "day per day", development of specific procedures, developments of dedicated SW and tools. From scientific point of view it is necessary to provide a measurements with an uncertainty. Another point of view is to think in a global way: nowadays the single space mission is anyway inserted in global scenario where synergies with other missions/instruments are fundamentals (in terms of cross calibration, data fusion, cooperation, etc.). Recommendation: from agencies and institutions there is the necessity to provide clear methodologies.

6) AI for EO	
Questions	Does Institutional Space have something to **learn from Commercial Space**?
Discussion	Cooperation is the keyword, and the knowledge exchange is bilateral. The communities are very sensible to this topic and cooperation and the sharing of knowledge is important in particular: ➢ Making available technologies, platforms, algorithms; ➢ Stimulating testing and experimentation. ESA has the role to decode new instances and trends, and stimulate new markets and dynamics. **Industry and institutions are called to stimulate interactions, new visions, and inspiration dynamic.** Multi-sensor Analysis is a keyword strictly connected to AI. AI for EO is connected to deep learning from different data, from long time series and data continuity; and it is necessary support AI analysis with the objective of data exploitation. One challenge is to consider and work on all aspects (pixel locations, view angles etc…)

7) The power of a synergetic approach	
Questions	How does Commercial Space see their **present and future contribution** to Institutional Space? How can **communication** between Commercial Space and Institutional Space be improved? • Dedicated forums like VH-RODA and JACIE? • Working groups? • Others?
Discussion	**Recommendations for Agencies:** ➢ Stimulating users to have a standard from institutions. ➢ Continuity with working groups; ➢ There are different kind of users: supporting hackathons? ➢ Collaboration with universities, stimulating research. ➢ There are also problems with licenses, utilization restrictions, stimulating the sharing of results.

5. CONCLUSIONS

5.1 Highlights

The highlights of the workshop are:

- Image quality is considered as a **specific skill** and there is need and interest for share experience from one mission to the other ones.
- The need for SI-traceability and measurement, uncertainties evidence is well understood and should be communicated.
- An agreed upon **reference** for sensor intercomparison of VHR sensors is needed
- Need for **standards** and guidance for in situ reference measurements (FRM) for satellite calibration and validation
- A community effort is needed to develop accepted methods for determining **anchor points** for sensor intercalibration
- Role of space agencies ➔ define **standards** for reporting quality of EO data, develop tools (open source software / documented methodologies), propose guidelines & **best practices** to perform QA.
- Data is becoming a driver of the global economy and satellites are a source of useful (but complex) data for this economy
- Their complexity is a barrier to use ➔ clear need to make the use of complex space data easier ➔ **Concept of ARD**
- Intercomparison exercises help to characterise and consolidate the many available approaches (ACIX, CMIX, DMIX, BRIX…etc.)
- **JACIE (USA) is a good forum for Public institutes and NewSpace exchange. VH-RODA could complement. VH-RODA and JACIE should work together.**

5.2 Actions

At the end of panel discussion, the following actions have been collected:

Action ID	Title	Description	Owner
VH-RODA_Action_01	Workshop Format	To update the workshop format in order to harmonize sessions, synergies and discussions among communities: ➢ SAR / Optical ➢ Commercial / Institutions.	ESA
VH-RODA_Action_02	Initiative Support	Organize/support Hackathons	ESA
VH-RODA_Action_03	Workshop Info Access	Go online with presentations, summary, and actions.	ESA

5.3 Way Forward

Discussion will continue at The 46th Plenary of the Working Group on Calibration & Validation (30th March - 3rd April 2020).

5.4 Access to Info and Presentations

For info and presentations can be found on the VH-RODA ESA official web site:

https://earth.esa.int/web/sppa/meetings-workshops/hosted-and-co-sponsored-meetings/vh-roda

ANNEX A: DETAILED AGENDA

The detailed agenda day per day with the details about the sections and presentations is here reported:

Day 1: Monday, 18th November 2019 – Room Big Hall			
12:30 – 13:30		**Introduction**	
12:30 – 12:40		Welcome	Josef Aschbacher (ESA)
12:40 – 12:50		Introduction, Objectives & Logistics	Philippe Goryl (ESA)
12:50 – 13:10		Presentation of ESA Earthnet Data Assessment Pilot	Clement Albinet (ESA)
13:10 – 13:30		Presentation of NASA/Small Satellites Commercial Data Buy Programme	Kevin Murphy (NASA)
13:30 – 15:20		**Institutional / Commercial panel #1**	**Chair: Giuseppe Ottavianelli (ESA) / Patrice Henry (CNES)**
13:30 – 13:50	1A1	Airbus Optical Constellation	Hervè Foch (Airbus Defence and Space)
13:50 – 14:10	1A2	Next generation EO satellites and Direct Access: challenges and opportunities	Pascal Schichor (European Space Imaging), Ian MacInness (Maxar)
14:10 - 14:30	1A3	Imaging the entire Earth every day and striving for continuous improvements	Ignacio Zuleta (Planet Labs)
14:30 - 14:50	1A4	Understanding current and upcoming Earth Observation data from Deimos Imaging	Mónica Díez (DEIMOS Imaging)
14:50 – 15:20	**1A5**	**Discussion**	**ALL**
15:20 – 15:40		**Coffee Break**	
15:40 – 18:10		**Institutional / Commercial panel #2**	**Chair: Philippe Goryl (ESA) / Nigel Fox (NPL)**
15:40 - 16:00	1B1	The ASI Prisma Mission Status and Perspectives	Ettore Lopinto (ASI)
16:00 – 16:20	1B2	Sentinel-2 Mission overview and Quality Performance	Valentina Boccia (ESA)
16:20 – 16:40	1B3	CNES Experience in Image Quality and Illustration with Pleiades Very High Resolution Data	Patrice Henry (CNES)

16:40 – 17:00	1B4	NASA experience and lessons learnt in data quality and Cal/Val for optical missions	Kurtis Thome (NASA/GSFC)
17:00 – 17:20	1B5	KARI's Satellites and the Introduction of Calibration and Validation of them	DongHan Lee (KARI)
17:20 – 17:40	1B6	JACIE: A Brief History, Achievements, and Lessons Learned	Jon Christopherson (USGS)
17:40 – 18:10	**1B7**	**Discussion**	**ALL**
18:10 – 19:00		**Ice Breaker**	
19:00		**Bus to Frascati**	
19:00		**End of Day 1**	

Day 2: Tuesday, 19th November 2019 – Room Big Hall

08:30 – 10:40		**Institutional / Commercial panel #3**	**Chair: Bruce Chapman (NASA/JPL) / Albrecht Von Bargen (DLR)**
08.30 – 08.40		Introduction	Bruce Chapman (NASA/JPL)
08:40 – 09:00	2A1	The COSMO-SkyMed program: VHR modes in the first and second generation	Axel Oddone (E-GEOS)
09:00 – 09:20	2A2	ICEYE and the Sentinels: Complementary Constellations	Andrea Radius (ICEYE)
09:20 – 09:40	2A3	RADARSAT-2 Image Quality and Calibration Overview	Dan Williams (MDA)
09:40 – 10:00	2A4	Airbus SAR Constellation	Juergen Janoth (AIRBUS DEFENCE & SPACE)
10:00 – 10:20	2A5	A Decade of TerraSAR-X and TanDEM-X Operation: A Retrospective on the Performance of the SAR System and an Outlook to the Future	Allan Bojarski (DLR)
10:20 – 10:40	**2A6**	**Discussion**	**ALL**
10:40 – 11:00		**Coffee Break**	
11:00 – 13:00		**Institutional / Commercial panel #4**	**Chair: Nuno Miranda (ESA) / Alessandro Coletta (ASI)**

11:00 – 11:20	2B1	PAZ Status After First Year of Operation	Juan Manuel Cuerda Munoz (INTA)
11:20 – 11:40	2B2	RADARSAT Constellation Mission: Image Quality and Calibration Status	Melanie Lapointe (Canadian Space Agency)
11:40 – 12:00	2B3	Sentinel-1 A/B mission status: 2019 update	Nuno Miranda (ESA)
12:00 – 12:20	2B4	Summary of Calibration and Research Activities of ALOS-2	Takeo Tadono (JAXA)
12:20 – 12:40	2B5	SAOCOM Mission Overview	Laura Frulla (CONAE)
12:40 – 13:00	**2B6**	**Discussion**	**ALL**
13:00 – 14:00		**Lunch Break**	
VH-RODA Optical Sensors Sessions – Room Big Hall			
14:00 – 18:20		**Radiometric Calibration – Radiometric Validation**	**Chair: Kurtis Thome (NASA/GSFC) / Sebastien Clerc (ACRI-ST)**
14:00 – 14:20	2X1	Radiometric validation of Sentinel-2	Sebastien Clerc (ESA/MPC S2, ACRI-ST)
14:20 – 14:40	2X2	On-orbit star-based radiometric calibration and MTF measurements for PLEIADES HR optical sensors	Aime Meygret (CNES)
14:40 – 15:00	2X3	Absolute calibration and validation of SkySat constellation	Adrian Gonzalez (PLANET)
15:00 – 15:20	2X4	Proba-1: Current Status and Calibration Assessment	Samantha Lavender (Telespazio VEGA UK)
15:20 – 15:40	2X5	Validation of the Maxar Surface Reflectance Product	Fabio Pacifici (Maxar)
15:40 – 16:00		**Coffee Break**	
16:00 – 16:20	2Y1	Spatial Quality from Edge target imaged by KOMPSAT-3	DongHan Lee (KARI)
16:20 – 16:40	2Y2	DEIMOS-2 Post-launch Radiometric Calibration	Jorge Gil (DEIMOS IMAGING)
16:40 – 17:00	2Y3	Inter-satellite characterization methods used at USGS	Jon B. Christopherson (USGS)

17:00 – 17:20	2Y4	Copernicus Ground-Based Observations for Validation (GBOV): a dedicated webservice providing EO Land Products validation data	Christophe Lerebourg (ACRI-ST)
17:20 – 17:40	2Y5	DIMITRI :Database for Imaging Multispectral Instruments and Tool for Radiometric Intercomparison	Marc Bouvet (ESA)
17:40 – 18:20	**2Y6**	**Discussion and Conclusions**	**ALL**
18:30		**Bus to Frascati**	
18:30		**End of Day 2**	

Day 2: Tuesday, 19th November 2019 – Room Big Hall			
CEOS WGCV SAR Sessions – Room Magellan			
14:00 – 15:40		**Calibration Techniques #1**	**Chair: Laura Frulla (CONAE) / Takeo Tadono (JAXA)**
14:00 – 14:20	2C1	SAOCOM Calibration and Validation Activities Results and Way Forward	Juan Pablo Cuesta Gonzalez (CONAE)
14:20 – 14:40	2C2	SAOCOM-1A Internal Calibration Results	Alon Wengierko (CONAE)
14:40 – 15:00	2C3	Results of the SAOCOM Commissioning Phase independent calibration and validation activities	Andrea Recchia (Aresys)
15:00 – 15:20	2C4	Polarimetric Calibration of Spaceborne SAR Data under Faraday Rotation by Means of Sub-bands Analyses	Jun Su Kim (German Aerospace Center, DLR)
15:20 – 15:40	2C5	KOMPSAT-5 Geolocation Accuracy Analysis with Mongolia and CEOS Calibration Site	Horyung Jeong (Korea Aerospace Research Institute)
15:40 – 16:00		**Coffee Break**	
16:00 – 18:20		**Calibration Techniques #2**	**Chair: Nuno Miranda (ESA) / Melanie Lapointe (CSA-ASC)**
16:00 – 16:20	2D1	Sentinel-1 Radiometric and Geometric Calibration	Peter Meadows (BAE Systems Applied Intelligence)

16:20 – 16:40	2D2	Mutual interferences between C-Band SAR: Prediction of occurrences identification of sources	Hajduch Guillaume (CLS)
16:40 – 17:00	2D3	Radar Interference between C-band SAR missions	Berthyl Duesmann (ESA)
17:00 – 17:20	2D4	Cross-Sensor Calibration of Sentinel-1 Noise Level	Niccolò Franceschi (Aresys)
17:20 – 18:20	**2D5**	**Discussion**	**ALL**
18:30		**Bus to Frascati**	
18:30		**End of Day 2**	

Day 3: Wednesday, 20th November 2019

VH-RODA Optical Sensors Sessions – Room Big Hall

08:30 – 10:50		**Analysis Ready Data**	**Chair: Stephen Hosford (CNES) / Eric Vermote (NASA/GSFC)**
08:30 – 08:50	3X1	Analysis Ready Data as addressed by the Committee on Earth Observation Satellites: CARD4L	Stephen Hosford (CNES)
08:50 – 09:10	3X2	Open source tools for VHR processing and ARD generation	Mickaël Savinaud (CS Systèmes d'Information)
09:10 – 09:30	3X3	Field-based Validation of the Digital Earth Australia Sentinel-2 Surface Reflectance Product	Medhavy Thankappan (Geoscience Australia)
09:30 – 09:50	3X4	Production of CEOS Analysis Ready Data for Land (CARD4L): Geoscience Australia's Experience with Optical Data from Landsat and Sentinel-2	Medhavy Thankappan (Geoscience Australia)
09:50 – 10:10	3X5	On Demand Vicarious Calibration for Analysis Ready Data	Christopher Durell (Labsphere)
10:10 – 10:30	3X6	Cloud Masking and Atmospheric Correction Inter-comparison Exercises	Georgia Doxani (ESA / Serco Italia SPA)
10:30 – 10:50	3X7	Towards A Virtual Ocean Colour Geostationary Satellite Using Ocean Colour Constellation Data	Marco Bracaglia (ISMAR-CNR)
10:50 – 11:10		**Coffee Break**	

11:10 – 13:00		**AI for Cal/Val**	**Chair: John Mrziglod (ESA) / Andreia Siqueira (Geoscience Australia)**
11:10 – 11:30	3Y1	Sensor-Independent Deep Learning for Cloud Masking	Alistair Francis (University College London)
11:30 – 11:50	3Y2	Applying Artificial Intelligence Techniques to Earth Observation Data Quality Control Activities	Andrea Melchiorre, Telespazio Vega-UK
11:50 – 12:10	3Y3	The new and increasing contribution of High Resolution SmallSat Optical Constellations fuelling advanced Artificial Intelligence and Machine Learning Analytics	Andrew Hanna (BlackSky)
12:10 – 12:30	3Y4	MATCH - Methods for calibrating compact hyperspectral systems	Marco Esposito (Cosine)
12:30 – 13:00	**3Y5**	**Discussion**	**ALL**
13:00 – 14:00		**Lunch Break**	
14:00 – 15:40		**Geometric aspects (spatial resolution, abs. geoloc., relative. geoloc., orthorectification meth.)**	**Chair: Valentina Boccia (ESA) / Jon Christopherson (USGS)**
14:00 – 14:20	3K1	Geometric validation of Sentinel-2 products	Sebastien Clerc (ESA/MPC S2, ACRI-ST)
14:20 – 14:40	3K2	Geo-locational Accuracy of Orthorectified Vision-1 HR data products	Lisa Haskell (Airbus Defence and Space Intelligence UK)
14:40 – 15:00	3K3	Spatial Quality from Landsat-8 OLI Lunar data (Edge Slope, RER, FWHM, MTF)	DongHan Lee (KARI)
15:00 – 15:20	3K4	Analysis on Refinement of Spatial quality Estimation by Edge target	DongHan Lee (KARI)
15:20 – 15:40	3K5	Geo-locational Accuracy of Orthorectified DMC+ MR constellation data products: Considering the use of Sentinel-2 vs Landsat-8 as Reference	Lisa Haskell (Airbus Defence and Space Intelligence UK)
15:40 – 16:00		**Coffee Break**	
16:00 – 18:40		**Quality Control**	**Chair: John Swinton (Telespazio-VEGA) / Sam Hunt (NPL)**

16:00 – 16:20	3Z1	EDAP Framework for the geometric validation of high resolution optical data	Sebastien Saunier (ESA/EDAP, Telespazio)
16:20 – 16:40	3Z2	Automated Calibration and Data Quality control	Stephen Mackin (EOSense Ltd)
16:40 – 17:00	3Z3	Quarterly Image Quality Reports at Planet	Sara Bahloul (Planet Labs Germany GmbH)
17:00 – 17:20	3Z4	The Most Important Factors Influencing the Overall Quality of Optical Images	Luca Cenci (Serco Italia SPA)
17:20 – 17:40	3Z5	Sentinel-2 Quality Control Plan	Sebastien Clerc (ESA/MPC S-2, ACRI-ST)
17:40 – 18:00	3Z6	Landsat Quality Control	Jon Christopherson (USGS)
18:00 – 18:40	3Z7	**Discussion**	**ALL**
18:40		**Bus to Frascati**	
18:40		**End of Day 3**	

Day 3: Wednesday, 20th November 2019

CEOS WGCV SAR Sessions – Room Magellan

08:30 – 10:50		**Calibration of Future Missions #1**	**Chair: Paul Rosen (NASA/JPL) / Martin Suess (ESA)**
08:30 – 08:50	3A1	The 2019 NISAR Ecosystem Cal/Val Exercise in the SE USA	Bruce Chapman (NASA/JPL)
08:50 – 09:10	3A2	NISAR Radar Antenna Pointing and Antenna Pattern Verifications	Yuhsyen Shen (NASA/JPL)
09:10 – 09:30	3A3	Filling the Gaps in SweepSAR Data	Brian Hawkins (NASA/JPL)
09:30 – 09:50	3A4	Contingency Mitigation Strategies for Reflector Based SAR Systems	Patrick Klenk (German Aerospace Center, DLR)
09:50 – 10:10	3A5	Verification of Pointing Calibration Methods for Kompsat-6	Dochun Yang (Korea Aerospace Research Institute)

10:10 – 10:30	3A6	Elements towards a Cal/Val strategy for ESA's BIOMASS mission	Bjorn Rommen (ESA)
10:30 – 10:50	**3A7**	**Discussion**	**ALL**
10:50 – 11:10			**Coffee Break**
11:10 – 13:00		**Calibration of Future Missions #2**	**Chair: Dirk Geudtner (ESA) / Stephane Coté (CSA-ASC)**
11:10 – 11:30	3B1	SAR Pointing Calibration for Ocean Surface Radial Velocity Estimation: Challenges and Alternatives	Dirk Geudtner (ESA)
11:30 – 11:50	3B2	Sentinel-1C/D Instrument: Improvements on internal calibration and preliminary verification results	Francisco Ceba Vega (ESA)
11:50 – 12:10	3B3	Sentinel-1 C Model insertion into the current A/B constellation: options	Berthyl Duesmann (ESA)
12:10 – 12:30	3B4	An Internal Calibration System Model For The Estimation of SAR Instrument Errors	Jan Paul Kroll (German Aerospace Center, DLR)
12:30 – 12:50	3B5	Copernicus ROSE-L mission	Malcom Davidson (ESA)
12:50 – 13:00	**3B6**	**Discussion**	**ALL**
13:00 – 14:00			**Lunch Break**
14:00 – 15:40		**Calibration Techniques**	**Chair: Jens Reimann (DLR) / Medhavy Thankappan (Geoscience Australia)**
14:00 – 14:20	3C1	Accurate Passive Targets for Radiometric and Polarimetric SAR Calibration	Jens Reimann (German Aerospace Center, DLR)
14:20 – 14:40	3C2	Special considerations for TwinSAR-L baseline calibration method with known heights of point targets or reference DEM	Qi Yang (Aerospace Information Research Institute Chinese Academy of Sciences)
14:40 – 15:00	3C3	Updates to the Australian corner reflector array coordinates and resulting improvements in absolute location error of SAR products	Medhavy Thankappan (Geoscience Australia)
15:00 – 15:20	3C4	A bar-shaped permanent target for image resolution assessment of high resolution microwave sensor	Xinghong Wang (Academy of Opto-Electronics, Chinese Academy of Sciences)

15:20 – 15:40	**3C5**	**Discussion**	**ALL**
15:40 – 16:00			**Coffee Break**
16:00 – 18:30		**Analysis Ready Data #1**	**Chair: Ake Rosenqvist (JAXA/soloEO) / Andreia Siqueira (Geoscience Australia)**
16:00 – 16:20	3D1	CEOS Analysis-Ready Data for Land (CARD4L) SAR product specifications – Status update	Ake Rosenqvist (JAXA / soloEO)
16:20 – 16:40	3D2	Proposed CARD4L Specifications for Differential Interferometric Products	Medhavy Thankappan (Geoscience Australia)
16:40 – 17:00	3D3	Recent progress on Product Family Specifications of CEOS Analysis Ready Data for Land – Normalised Radar Polarimetric Covariance Matrix and Polarimetric Radar Decomposition	Marco Lavalle (NASA/JPL)
17:00 – 17:20	3D4	Updates to the CARD4L specification for a Geocoded Single Look Complex SAR data product	Bruce Chapman (NASA/JPL)
17:20 – 17:40	3D5	Multi-sensor Wide-area Level-3 Radar Backscatter Time Series	David Small (Remote Sensing Laboratories, University of Zurich)
17:40 – 18:30	**3D6**	**Discussion**	**ALL**
18:30		**Bus to Villa Grazioli**	
21:30		**Bus from Villa Grazioli to Frascati**	

Day 4: Thursday, 21st November 2019

VH-RODA Optical Sensors Sessions – Room Big Hall

08:30 – 10:50		**In-situ measurements / FRM**	**Chair: Cindy Ong (CSIRO) / Joanne Nightingale (NPL)**
08:30 – 08:50	4X1	A framework for Fiducial Reference Measurements (FRM) for Vegetation: results and experiences from phase one of the FRM4VEG project	Joanne Nightingale (NPL)
08:50 – 09:10	4X2	Radiometric calibration network for vicarious calibration of Earth observing imagers in the reflected solar	Kurt Thome (NASA/GSFC)

09:10 – 09:30	4X3	Libya-4 Rayference Calibration reference: application to S3A/calibration verification	Yves Govaerts (Rayference)
09:30 – 09:50	4X4	PICSCAR	Beatrice Berthelot (Magellium)
09:50 – 10:10	4X5	A community approach to the standardised validation of surface reflectance data	Cindy Ong (CSIRO)
10:10 – 10:30	4X6	Validation of Space-based Global Albedo Products by upscaling from Ground-based Measurements	Rui Song (University College London)
10:30 – 10:50	4X7	On-orbit calibration and performance assessment of Chinese high resolution satellites based on the Baotou site	Xinhong Wang (Chinese Academy of Sciences)
10:50 - 11:10		**Coffee Break**	
11:10 - 13:00		**Inter-Satellites Comparison : Methodology & Results**	**Chair: Sebastien Saunier (Telespazio-VEGA) / Marc Bouvet (ESA)**
11:10 – 11:30	4Y1	DEIMOS-1 Cross-calibration with Landsat and Sentinel-2	Jorge Gil (DEIMOS IMAGING)
11:30 – 11:50	4Y2	The EDAP Framework to Assess Commercial Satellite Mission Quality	Sam Hunt, Nigel Fox (ESA/EDAP, NPL)
11:50 – 12:10	4Y3	Toward a Consistent Climate Data Record Surface Reflectance Product	Eric Vermote (NASA/GSFC)
12:10 – 12:30	4Y4	Data Harmonization Methodology Based On Simultaneous Nadir Overpasses	Jorge Gil (DEIMOS Imaging)
12:30 – 13:00	**4Y5**	**Discussion**	**ALL**
13:00 – 14:00		**Lunch Break**	
14:00 – 15:40		**Calibration of Future Missions**	**Chair: Amanda Regan (ESA) / Takeo Tadono (JAXA)**
14:00 – 14:20	4K1	Calibration and Validation Plan of the Advanced Optical Satellite (ALOS-3)	Takeo Tadono (JAXA)
14:20 – 14:40	4K2	Traceable Radiometry Underpinning Terrestrial- and Helio- Studies (TRUTHS): Enabling a Space-based Climate and Calibration Observatory – A proposed ESA Earth Watch mission	Nigel Fox (National Physical Laboratory)

14:40 – 15:00	4K3	A survey of in-flight radiometric calibration methods and their applicability to Nanosatellites	Ruiloba Quecedo Rosario (Agenium Space)
15:00 – 15:20	4K4	Direct Tasking of VHR Optical Satellites	Ellis George (European Space Imaging GmbH)
15:20 – 15:40	**4K5**	**Discussion**	**ALL**
15:40 – 16:00		**Coffee Break**	
16:00 – 18:00		**VHR DEM for Optical data / Harmonization**	**Chair: Peter Strobl (JRC) / Ferran Gascon (ESA)**
16:00 – 16:20	4Z1	Shifts in surface, speed or shadows? What do we measure with different time-of-day overpasses of Sentinel-2	Bas Altena (University of Oslo)
16:20 – 16:40	4Z2	Assessment of DEM quality and applications	Serge Riazanoff (ESA/EDAP, VisioTerra)
16:40 – 17:00	4Z3	Euro-Maps 3D – DSM generation and procedures for validation and product finalisation	Lars Uschmann (GAF)
17:00 – 17:20	4Z4	DEMIX : Digital Elevation Model Intercomparison	Peter Strobl (JRC)
17:20 - 18:00	**4Z5**	**Discussion**	**ALL**
18:00		**Bus to Frascati**	
18:00		**End of Day 4**	

Day 4: Thursday, 21st November 2019

CEOS WGCV SAR Sessions – Room Magellan

08:30 – 10:30		**Analysis Ready Data #2**	**Chair: David Small (University of Zurich) / Franz Meyer (University of Alaska Fairbanks)**
08:30 – 08:50	4A1	CEOS Analysis-Ready Data for Land (CARD4L) SAR product specifications JAXA plans for Analysis-Ready Data (CARD4L) standards for PALSAR and PALSAR-2 products– Status update	Ake Rosenqvist (JAXA / soloEO)
08:50 – 09:10	4A2	Capella's VHR SAR constellation for multi-temporal change detection	Davide Castelletti (CapellaSpace)

09:10 – 09:30	4A3	A Copernicus DEM from WorldDEM Data	Vera Leister (Airbus Defence and Space)
09:30 – 09:50	4A4	On-the-fly orthorectification, calibration, RCS equalisation and terrain flattening of Sentinel-1 data	Serge Riazanoff (VisioTerra)
09:50 – 10:10	4A5	Time-Series and Applications of Advanced Sentinel-1 Analysis Ready Data for Africa (SAR-4-Africa)	Jorg Haarpaintner (NORCE - Norwegian Research Centre AS)
10:10 – 10:30	4A6	ARD Services and other User Support-related Activities at the NASA Alaska Satellite Facility DAAC	Franz Meyer (University of Alaska Fairbanks)
10:30 - 10:50		**Coffee Break**	
10:50 - 13:00		**Processing and Algorithm**	**Chair: Marc Rodriguez-Cassola (DLR) / Riccardo Piantanida (Aresys)**
10:50 – 11:10	4B1	A General SAR Processing algorithm for multi beams and multi modes SAR system	Dong hyun Kim (KARI)
11:10 – 11:30	4B2	A Proposal for Interferometric Time Series Product with Reduced Stochastic and Systematic Phase Errors	Homa Ansari (German Aerospace Center, DLR)
11:30 – 11:50	4B3	Implementation and validation of a new SAR data imaging processor based on efficient time-domain focusing core	Francesco Tataranni (INNOVA Consorzio)
11:50 – 12:10	4B4	Towards Operational SAR Imaging Geodesy: An Extended Time Annotation Dataset for Sentinel-1 Image Products	Christoph Gisinger (German Aerospace Center, DLR)
12:10 – 12:30	4B5	Airbus Automatic derived Ground Control Points	Wolfgang Koppe (Airbus Defence and Space)
12:30 – 13:00	**4B6**	**Discussion**	**ALL**
13:00 – 14:00		**Lunch Break**	
14:00 – 15:40		**Cross-Calibration and Validation**	**Chair: Bjorn Rommen (ESA), Yuhsyen Shen (NASA/JPL)**
14:00 – 14:20	4C1	GNSS-based clock synchronisation: a performance assessment	Marc Rodriguez-Cassola (German Aerospace Center, DLR)

14:20 – 14:40	4C2	Cal/Val approach for DInSAR Deformation Rates Products using GNSS data	Alessandro Parrizzi (German Aerospace Center, DLR)
14:40 – 15:00	4C3	SAR cross-calibration using natural targets	Mingkuan Yi (Academy of Opto-Electronics, Chinese Academy of Sciences)
15:00 – 15:20	4C4	Extending the Ice Watch system as a citizen science project for the collection of in-situ sea ice observations	Ole Jakob Hegelund (Norwegian Ice Service)
15:20 – 15:40	**4C5**	**Discussion**	**ALL**
15:40 – 16:00			**Coffee Break**
16:00 – 18:00		**Discussion**	**Chair: Bruce Chapman (NASA/JPL) / Dirk Geudtner (ESA)**
16:00 – 16:20	4D1	CEOS WGCV 45 Plenary	Medhavy Thankappan (Geoscience Australia)
16:20 – 16:40	4D2	Discussion	ALL
16:40 – 17:00	**4D3**	**CEOS Work Plan 2018 - 2020**	**B. Chapman (NASA/JPL), D. Geudtner (ESA)**
17:00 - 18:00	**4D4**	**Discussion**	**ALL**
18:00		**Bus to Frascati**	
18:00		**End of Day 4**	

Day 5: Friday, 22nd November 2019	
Room - Big Hall	
08:30 – 13:00	**Summary** **Chair: Clement Albinet (ESA) / Valentina Boccia (ESA)**
08:30 – 09:45	**Summary Optical Sessions Reporting** • Optical sessions reporting and future perspectives (5 minutes per sessions- chairs)
09:45 – 11:00	**Summary SAR Sessions Reporting** • SAR sessions reporting and future perspectives (5 minutes per sessions- chairs)
11:00 – 11:15	**Coffee Break**
11:15 – 12:45	**Panel Discussion:** Cal/Val Best Practises and common Reference: towards harmonised approaches for New Space and Institutions
	• Jon Christopherson (USGS) • Nigel Fox (NPL) • Kurt Thome (NASA/GSFC) • Bruce Chapmann (NASA/JPL) • Jens Reimann (DLR) • Dirk Geudtner (ESA) • Ignacio Zuleta (PLANET) • Marco Esposito (Cosine) • Andrew Hanna (BlackSky) • Andrea Radius (ICEYE) • Fabio Pacifici (MAXAR)
12:45 - 13:00	**Conclusion**
13:00	**End Workshop**