ESA Cal/Val Strategy for Optical Land-Imaging Satellites: Overall Approach and Pathway towards Interoperability

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European Space Agency (ESA)

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Outline

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- Vision and Principles
- Generic Cal/Val solution
- Readiness Level
- Conclusion and Outlook

Open Access Review

European Space Agency (ESA) Calibration/Validation Strategy for Optical Land-Imaging Satellites and Pathway towards Interoperability

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Background and Motivations

- The **fleet** of **current and future ESA optical land** imaging sensors (Sentinel-2, Sentinel-3, Proba-V, Flex, and CHIME) will ensure an **unprecedented** observation capability in terms of spatiotemporal and spectral coverage
- Yet, critical questions remain as **how to harness the full potential of such deluge of data**, which are complementary in principle, but inherently **diverse** in terms of: spatiotemporal resolution, radiometric accuracy and sensitivity, spectral coverage
- Likewise, there is a recent increase in availability of **Cal/Val data** for Land, although **inconsistencies** in the used practices and associated quality information still hamper their integrated and synergistic use for satellite products validation at global scale

Vision and Principles

Vision

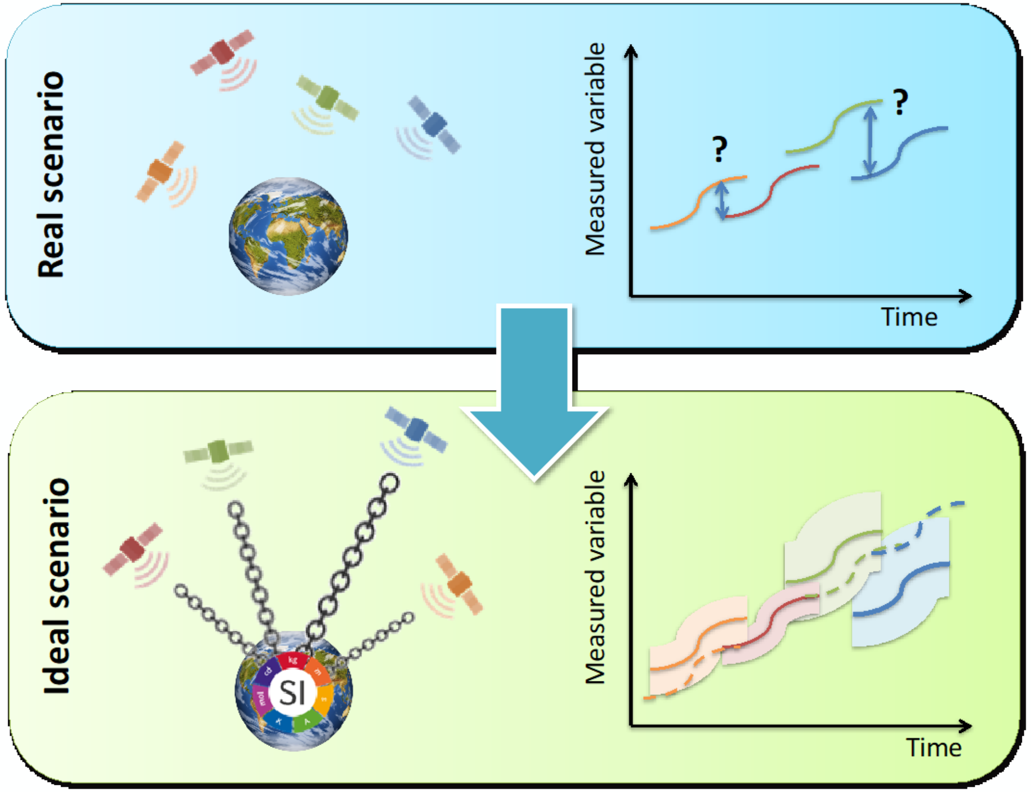
- Work towards **enhancing interoperability** of current and future ESA optical land sensors
- The long-term vision is a **system-of-systems** concept enabling seamless exploitation of current and future EO optical data for downstream applications

Principles (stem from QA4EO)

- Ensuring that EO data is provided with fully **traceable** indicator of their quality, properly documented and quantitatively tied to an international **standard** (ideally to SI)
- **Traceability** and **uncertainty** estimate allows understanding and characterizing cross-mission **biases**, therefore enabling interoperability

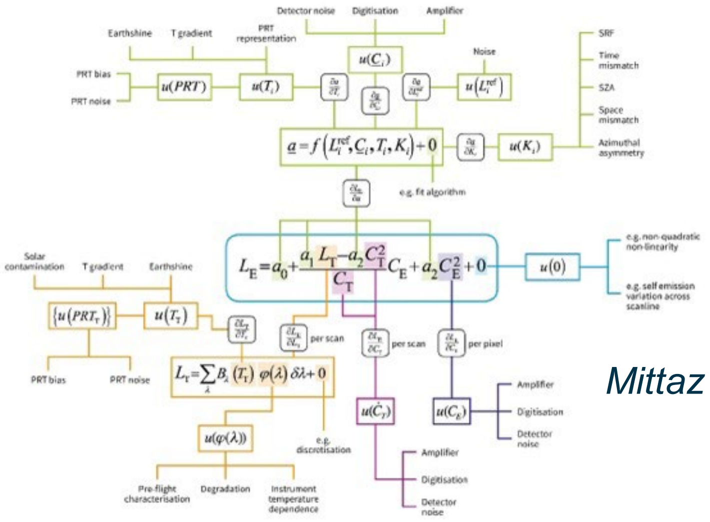
QA4EO
A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

- The Quality Assurance framework for Earth Observation (QA4EO)
- Looks to make the GUM accessible to the EO community

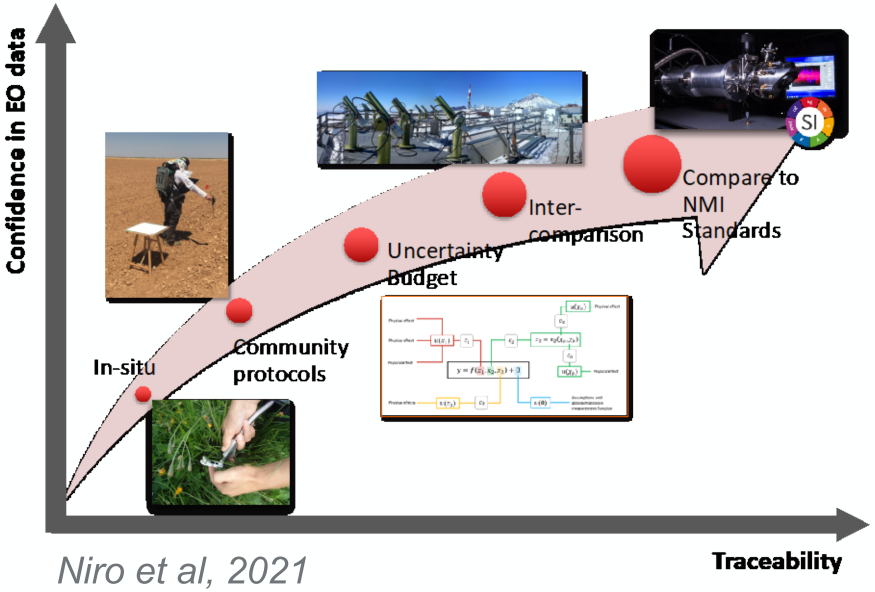


Metrology focus

- Provision of **uncertainty** for both the reference and satellite data is a prerequisite in order to have a rigorous and meaningful validation.
- **Ideally** the reference measurement should be traceable to metrological standards
- In the **real** scenario, Cal/Val data are seldom traceable and uncertainties are often not estimated, this limit their proper use for assessing the quality of satellite-based EO data
- In order to address this gap, ESA is putting forward a new concept in Cal/Val, the ***Fiducial Reference Measurements*** (FRM)
- **What makes a Cal/Val measurement a FRM**:
    - Documented metrological SI-traceability
    - Follow community agreed best practices for measurements
    - Rigorous uncertainty budget, e.g., uncertainty tree diagrams
    - Inter-comparison exercises are regularly performed



Mittaz et al. 2019

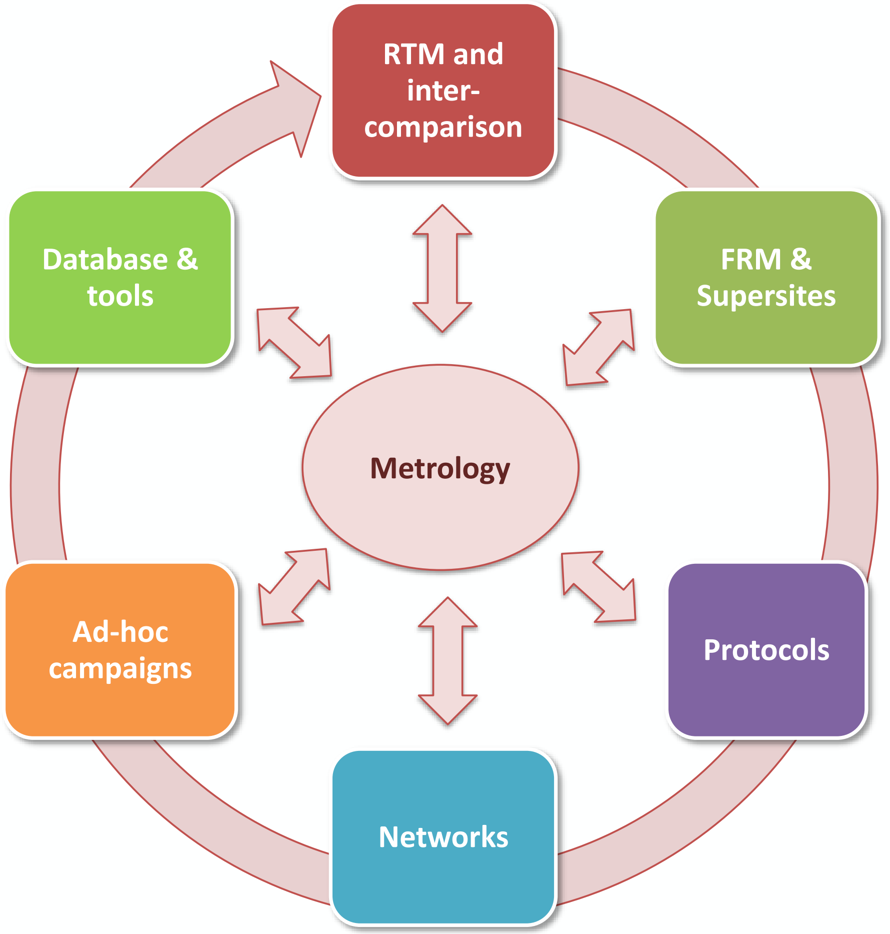


Niro et al, 2021

Building blocks for a generic Cal/Val solution

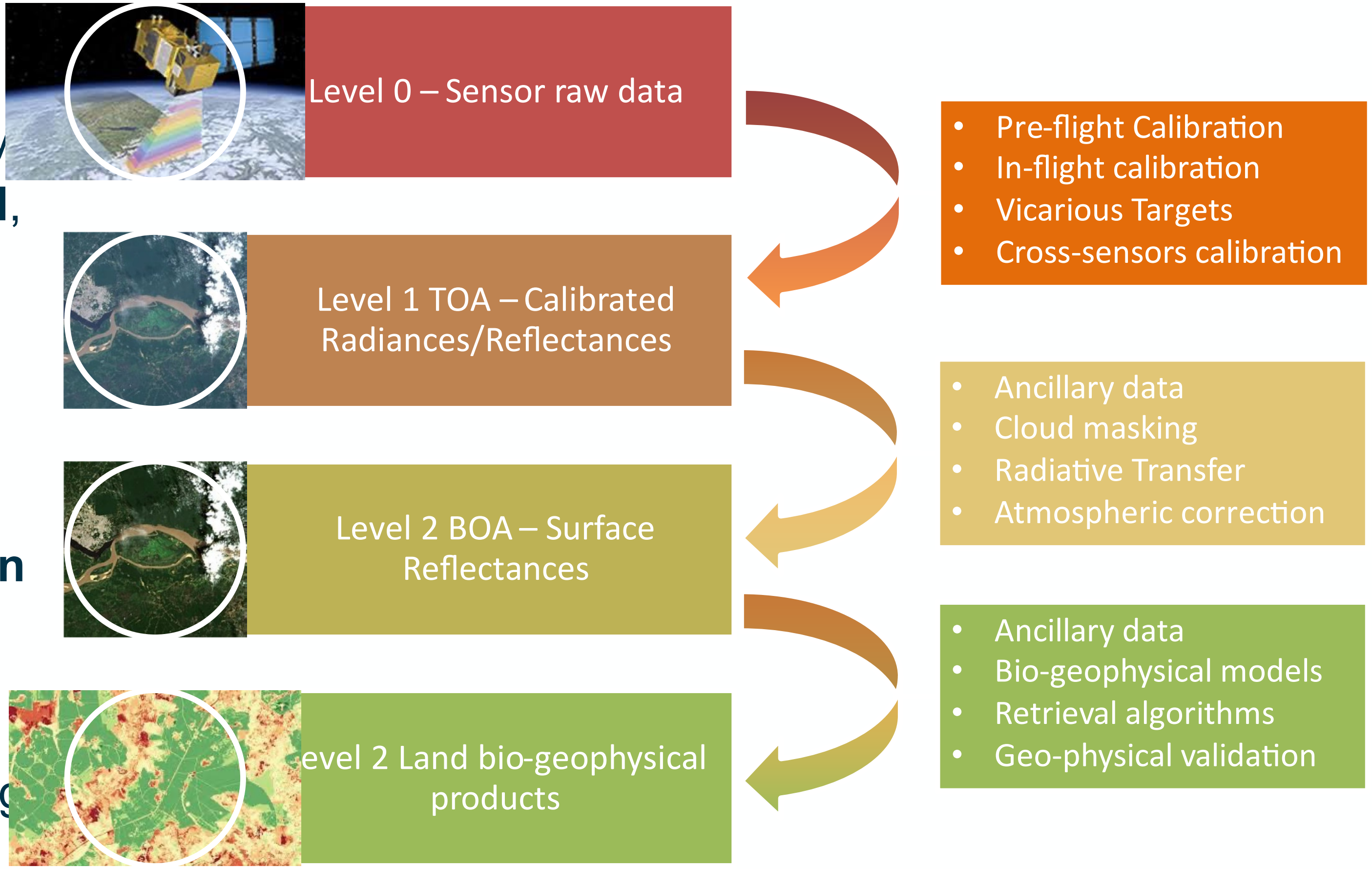
Set of basic elements of a generic Cal/Val solution:

- **Metrology:** providing the overall framework and practices to derive uncertainty quantified EO data
- **RTM & Inter-comparison**: to fully understand the uncertainty budget of the validation and perform benchmarking
- **FRM & Supersites**: well characterized sites (traceability & 3D structure and modelling) to establish the protocols
- **Protocols**: to provide community-agreed practices for field measurements and spatiotemporal upscaling
- **Ad-hoc campaigns**: to test/verify advanced measurement techniques, and in-depth validation at local scale
- **Networks**: to enhance geographical coverage for assessing satellite uncertainties over global conditions
- **Database and tools**: to facilitate uptake of Cal/Val data within the community using standardized procedures



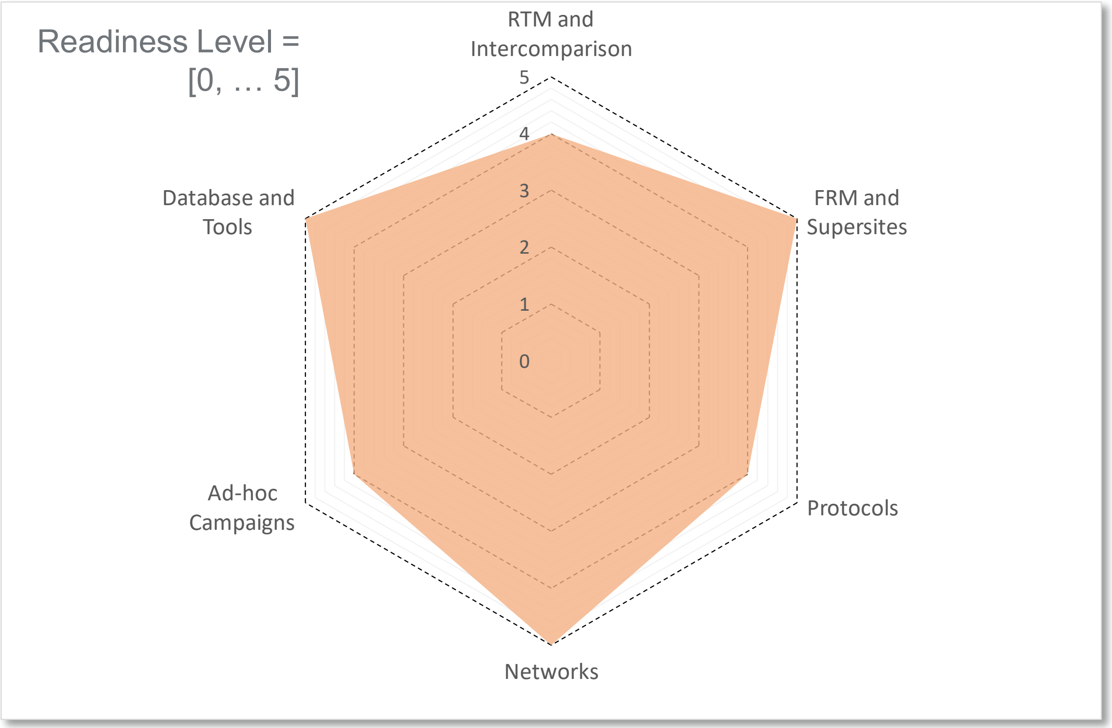
End-to-end approach

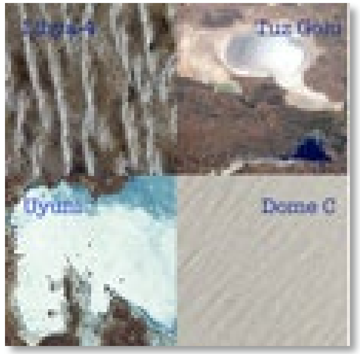
- ESA adopts an **end-to-end** approach to satellite data performances assessment, this approach is followed since mission design phase
- Products quality and cross-sensors consistency need to be quantified at each **processing level**, starting from L1 TOA → L2 BOA → L2 bio-geophysical products
- This approach allow for full **traceability** and detailed characterization of the various uncertainty contributions, and their **propagation** along the chain
- In order to quantitatively estimate uncertainties at each level, we need to **verify** that the building blocks of the generic Cal/Val solution are available and mature to sustain operations



Readiness Level for L1 TOA products

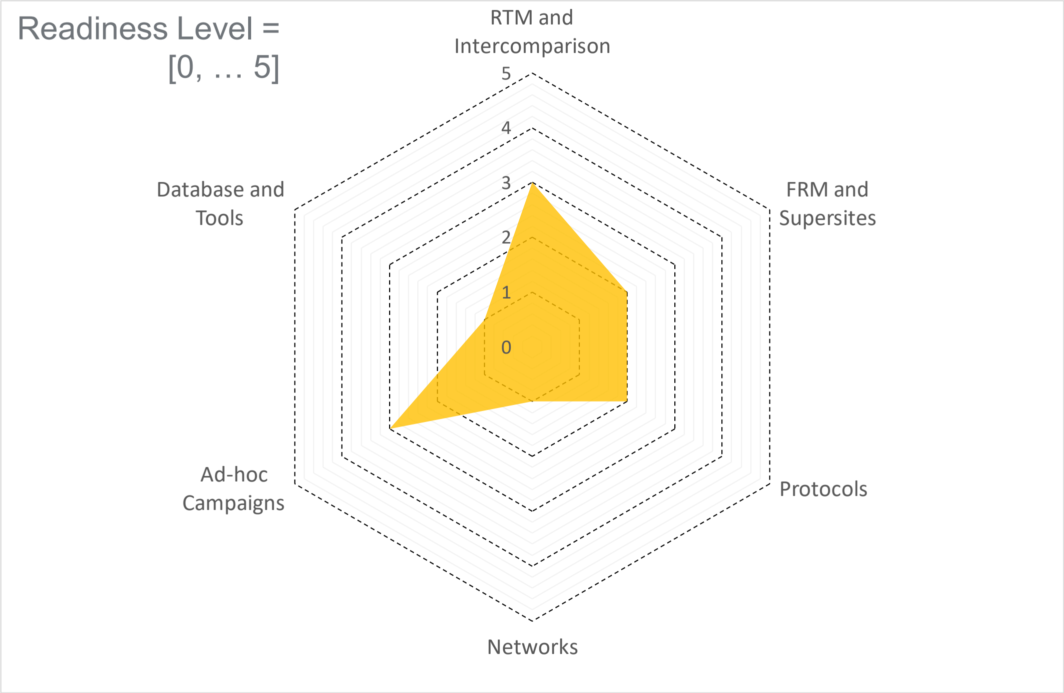
- If we verify the generic Cal/Val solution at **Level 1** (TOA radiometry) we observe that we have a very **good level of readiness**
- All **building blocks** are in place, some of them fully operational (GSICS, RadCalNet, DIMITRI), some under development (Eradiate)
- We have **good confidence** on our ability to assess TOA radiometry and understand and characterize cross-mission **biases** at TOA level
- **Protocols** were developed since many years and consolidated in the frame of CEOS-IVOS, GSICS
- **Database** and **tools** are also routinely used to assess radiometry of current ESA optical sensors
- The final step, aiming at attaining full **traceability** in space is also planned and underway (NASA Clarreo Path Finder, ESA TRUTHS)





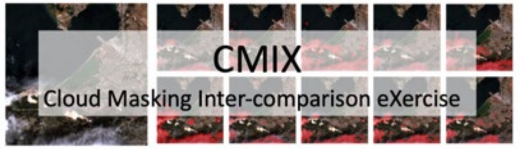
Readiness Level for L2 BOA products

- **Conversely** to L1, the readiness level at L2 BOA is still **poor** in many aspects, since protocols are still not consolidated, uncertainties not properly characterized and there is no operational network
- Ensuring consistency at BOA level is however crucial since this product is **input** to a wide range of land bio-geophysical algorithms
- **ESA** in the frame of **CEOS-WGCV** devoted great effort in recent years to address some of these challenges, supporting a number of activities to fill the gaps (ACIX, CMIX, SRIX4Veg, Eradiate), but much has to be done yet
- The main priority for the years to come will be to consolidate best **practices**, prepare the ground for an operational **network** and accurately characterize **uncertainty** budget at BOA level



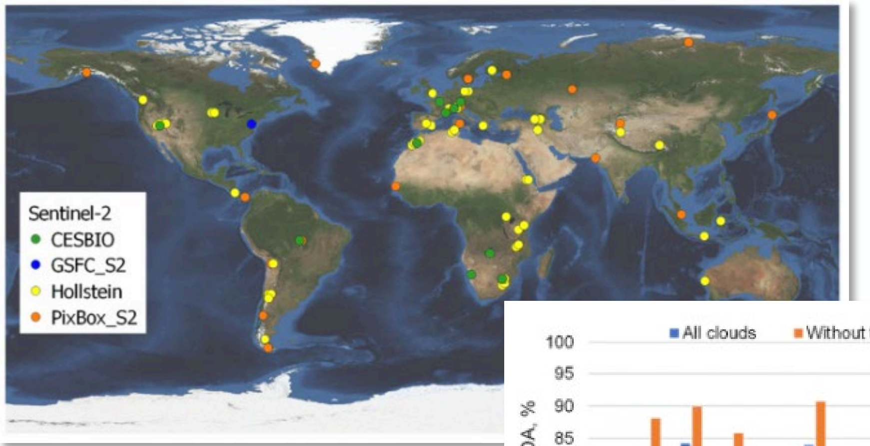
ERADIATE

HYPERNETS

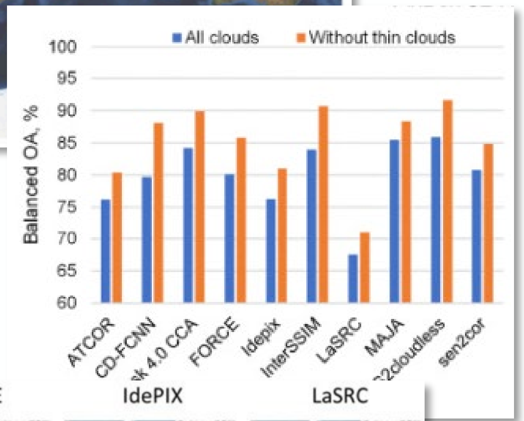


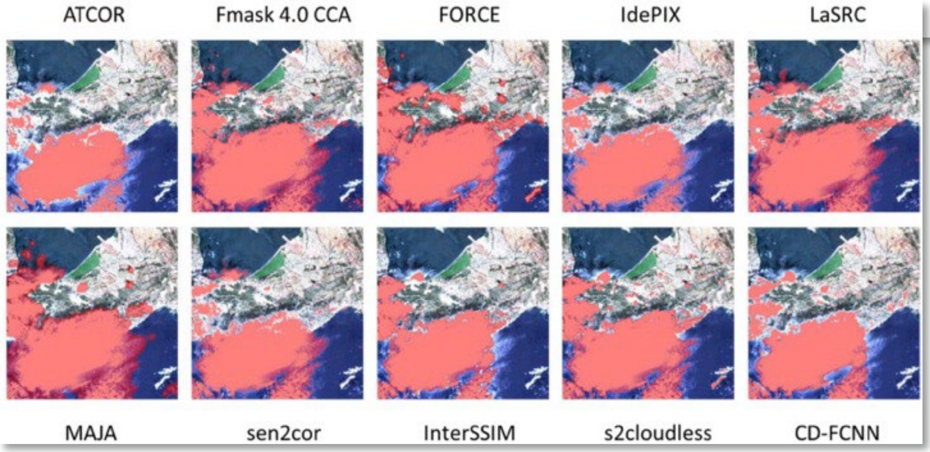
Focus on Level 2 BOA : cloud mask

- Cloud mask still remain one of the major sources of uncertainty in L2 BOA products, this **uncertainty** propagates down in the chain to L2 bio-geophysical products
- In order to tackle this issue, **ESA** jointly with **NASA** initiated an intercomparison exercise of cloud masks (**CMIX**), with focus on L-8 and S-2, aiming at understanding strengths and limitations of current cloud mask approaches
- One of the outcomes of CMIX was that while cloud mask usually agree for optically thick clouds large **discrepancies** appear for optically thin, or semi-transparent clouds
- Overall, our ability of inter-comparing cloud-masks is currently hampered by the lack of a community-agreed cloud **definition** and of an independent ground-based **reference dataset**
- These challenges will be tackled in the frame of next phase, **CMIX-II**: 1st preparatory WS, 20-21 June 2022 (ESRIN)



Skakun et al, 2022





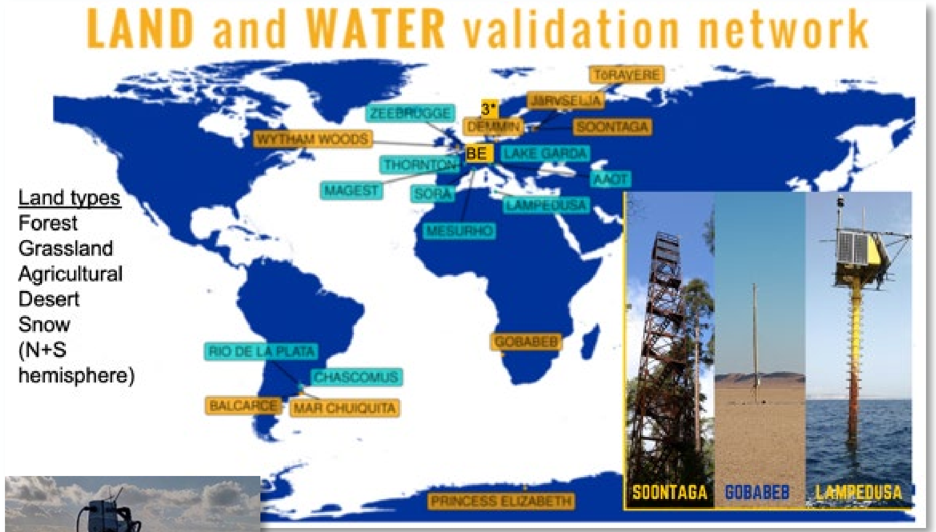
Focus on Level 2 BOA : Atmospheric Correction

- Progresses still need to be made in fully characterising **uncertainty budget** associated to the AC
- In order to address this need, ESA jointly with NASA, started an intercomparison exercise of different AC codes with focus on L8 and S2 mission (**ACIX**)
- ACIX-I was successful in identifying strengths and weaknesses of current AC codes, using as reference data, a set of synthetic SR computed with 6SV RTM over **AERONET** sites
- Within ACIX-II the number of AERONET sites was enlarged to assess algorithms' performances at global scale
- Yet, limitations were identified :
  - The **lack** of a consensus in the used **RTM** for the simulation of the synthetic SR reference dataset
  - The lack of an independent **ground-based reference** dataset for direct validation of SR

https://calvalportal.ceos.org/acix-ii-land

Focus on Level 2 BOA : HYPERNETS

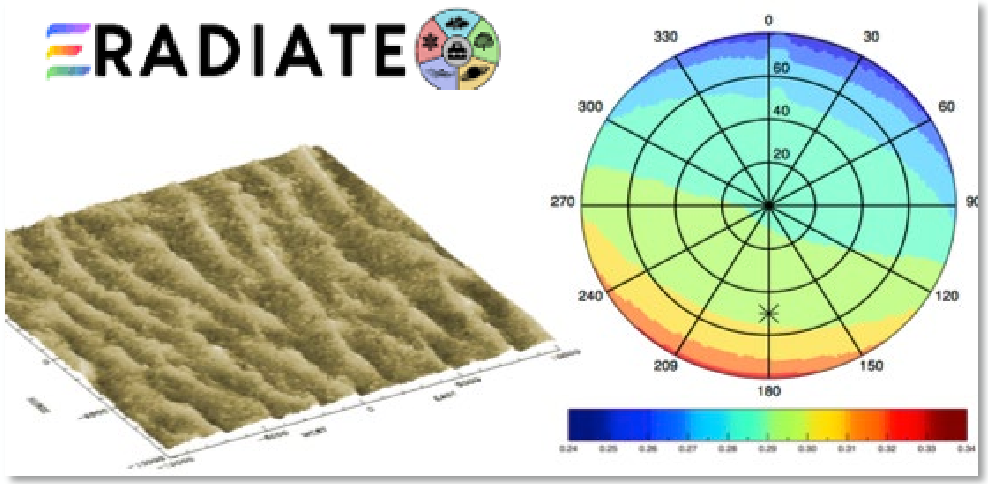
- Following ACIX recommendations, ESA in collaboration with EC, promoted a project (**HYPERNETS**) for developing a ground based network for L2 BOA products validation
- HYPERNETS aims at developing a global automated network of ground-based **hyperspectral radiometers**, measuring water and land bidirectional SR
- The radiometers will be equipped with a **pointing** system allowing full characterisation of surface BRF
- HYPERNETS network will support the needs of any space-borne optical sensor, including current and upcoming **hyperspectral** missions (PRISMA, EnMAP, CHIME)
- HYPERNETS will fill a long lasting **data gap** in the land domain, and in the water domain it will allow to overcome the **limitations** of current multi-spectral based networks (AERONET-OC), i.e., minimising uncertainties induced by band adjustment approaches

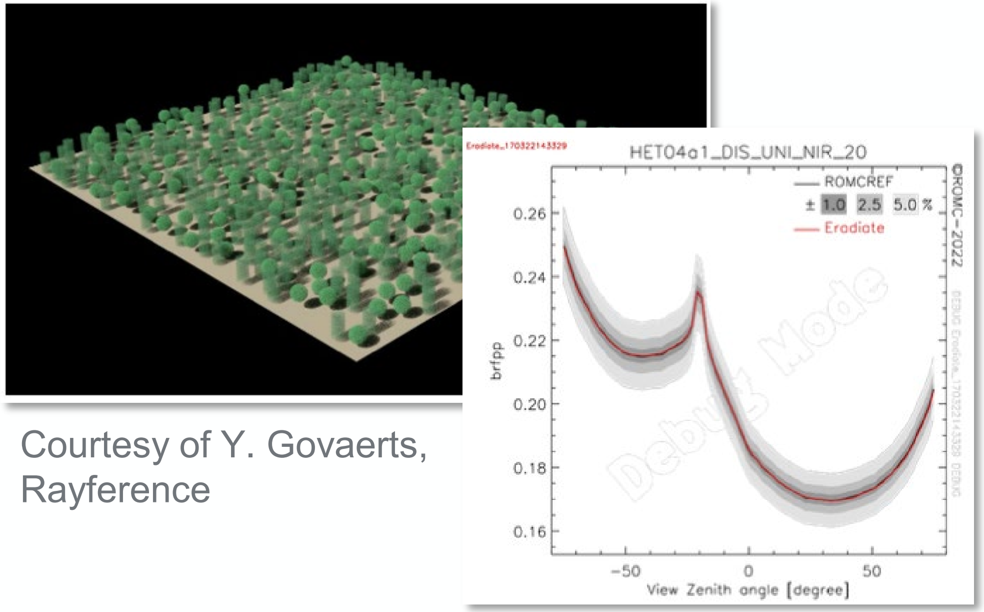


Courtesy of K. Ruddick, RBINS

Focus on Level 2 BOA : Eradiate

- Another recommendation raised within ACIX was the lack of a community agreed **RTM** for Cal/Val applications
- There is a large variety of RTMs, yet, when applied to common Cal/Val problems (e.g., **PICS**), we observe **discrepancies** (up to 4%) and we are not able to fully characterize them
- In order to address this challenge, ESA in collaboration with EC is supporting the development of a new **Monte-Carlo** Ray-Tracing **3-D RTM** (Eradiate), aiming at lowering uncertainties of simulation down to 1%, so that to answer the needs of the climate and Cal/Val community
- Eradiate will also contribute in advancing our understanding of the uncertainty budget associated to AC in the frame of RAMI4ATM EC project. The primary goal of **RAMI4ATM** will be to document the variability between coupled surface-atmosphere RTMs under well-controlled, but realistic, conditions.

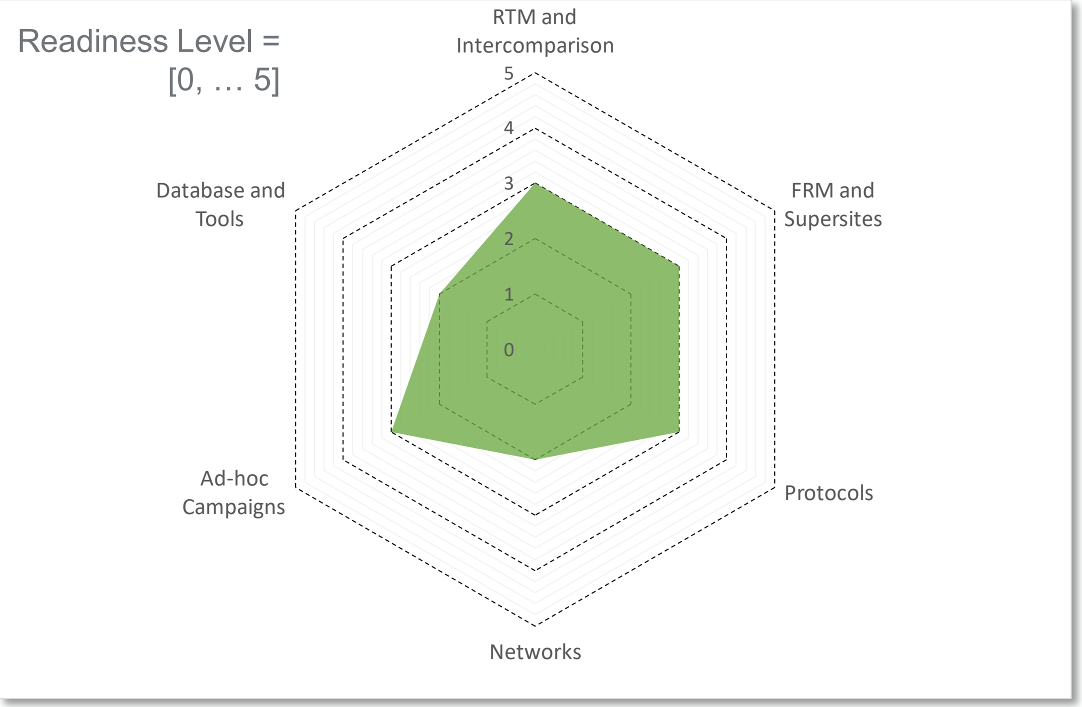


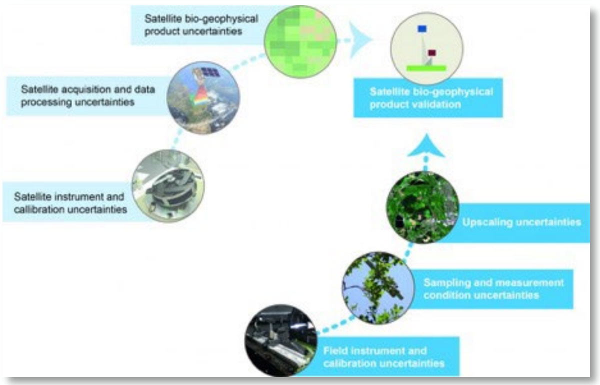


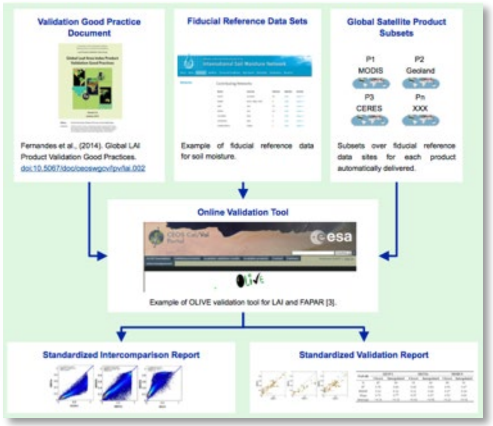
Courtesy of Y. Govaerts, Rayference

Readiness level for L2 bio-geophysical products

- Most of the existing networks **not primarily designed** for Cal/Val, namely, put little attention on uncertainty estimation as well as on spatial **representativeness**, which are crucial aspects for satellite Cal/Val
- Furthermore, there is a **disparity** in the used protocols, and quality control approaches
- **Gaps** (geographical and thematic) also remain, so that we cannot just leverage on existing infrastructures, we need to foster cooperation to fill gaps
- **GBOV** made significant progresses in harmonizing protocols, format and upscaling procedures across existing networks
- ESA in the frame of **CEOS-LPV** is contributing in the effort of harmonizing protocols, promoting their usage, standardizing Cal/Val procedures

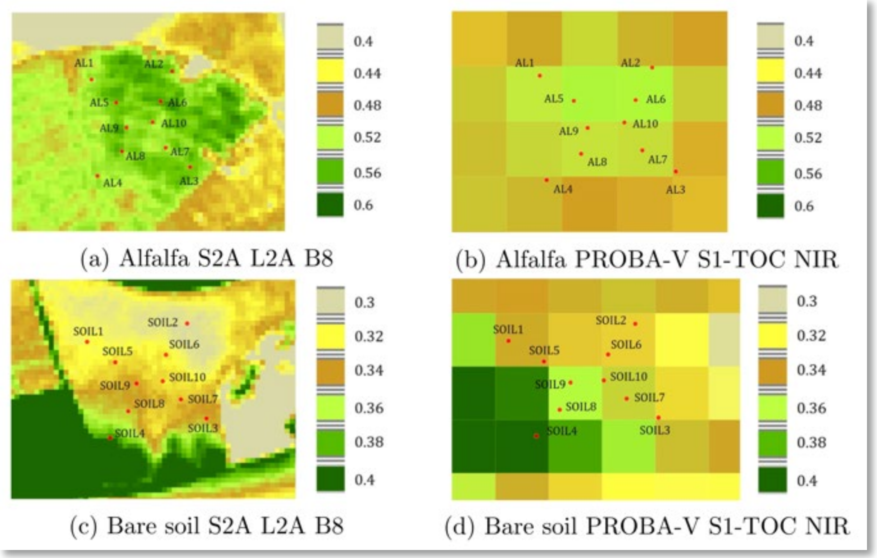




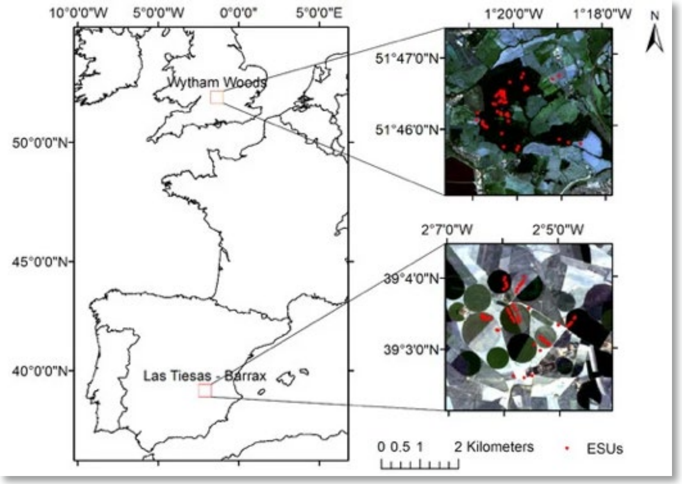


FRM4VEG

- **ESA** in close cooperation with **CEOS-LPV,** is actively working for enhancing readiness level for L2 vegetation products, both in terms of protocols and sites characterization (FRM4VEG)
- FRM4VEG was initiated in 2018 with the objective of establishing the protocols required for **traceable** in-situ measurements of **vegetation-related** parameters to support the validation of S-2, S-3, and PROBA-V products
- The **1st phase** of FRM4VEG project was concluded at the end of 2019 with the elaboration of initial best practices for in-situ measurements and methodologies for validation of satellite-derived SR, fAPAR and Chlorophyll content
- The 1st phase also included the preparation and execution of two **field campaigns** over two vegetated and well characterized sites (FRM sites): **Wytham Woods** forest site (UK) and **Barrax** agricultural site (Spain).



Origo et al. 2020

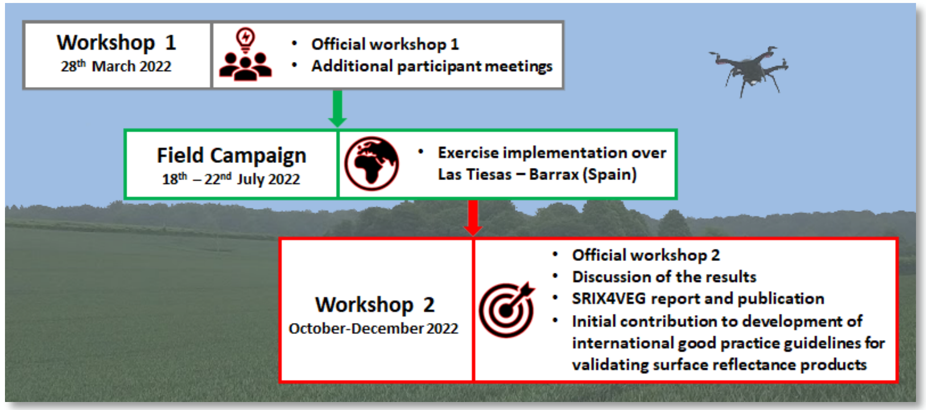


Brown et al. 2021

fiducial reference measurements for vegetation

SRIX4VEG

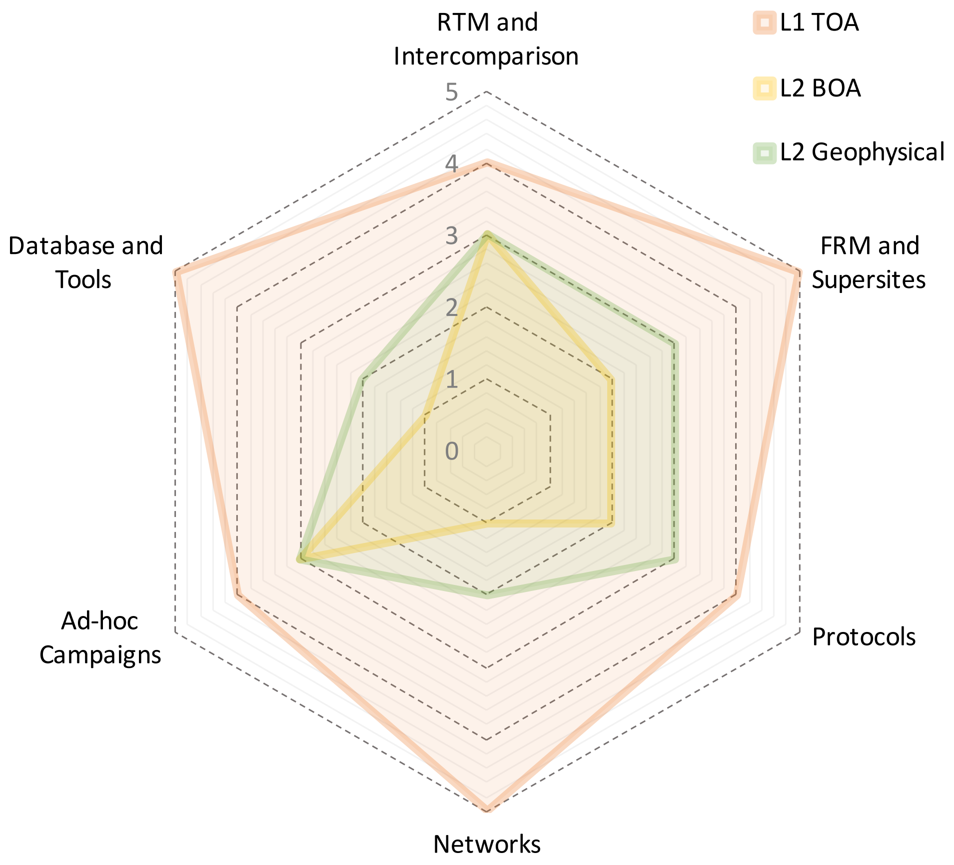
- As part of FRM4VEG Phase 2, a Surface Reflectance Inter-comparison Exercise (**SRIX4VEG**), endorsed by the CEOS-WGCV, will be performed
- SRIX4VEG will include a field **inter-comparison campaign** (**July 2022, Barrax**) calling for the contribution of different Cal/Val teams around the world with the objective of working towards the definition of community-agreed guidelines for **UAV-based SR** product validation
- **Hyperspectral** information collected from UAVs is expected to become a major source of SR validation data in the near future. However, unlike traditional data collection approaches (ASD field survey), a UAV **best practice** protocol does not currently exist
- SRIX4VEG will **fill a crucial data gap** and contribute in enhancing readiness status for SR validation



https://frm4veg.org/srix4veg/

Summary and Outlook

- ESA formulated a **generic framework**, underpinned by six basic elements, to express the maturity of Cal/Val solution
- This allows for identifying data and methodological **gaps** (after **consultation** with the science community), so that to define/prioritize **ESA Cal/Val strategy**
- Among the most urgent gaps, there is a clear need for a global **network** of SR ground-based measurements and there is a lack o consolidated best practices for SR Cal/Val
- ESA initiated a series of **projects** (ACIX/CMIX, Eradiate, HYPERNETS, SRIX4VEG) to tackle those gaps, with the aim to **enhance** readiness level in the next 2-3 years → This will enable improved **interoperability** across missions
- ESA is also contributing to CEOS-LPV in the continuous effort of **harmonizing** best practices for terrestrial ECVs, filling gaps and improving protocols, working towards an **operational system** of globally representative FRM sites for Land



Q&A

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Niro, et al. "European Space Agency (ESA) calibration/validation strategy for optical land-imaging satellites and pathway towards interoperability." *Remote Sensing* 13.15 (2021)