CANVAS (QA4SAR): Calibration and Validation for SAR

ESA FRM Workshop - NPL - May 2026

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Intro

Aim: To create a harmonized Quality Assessment framework for SAR data for past, present and future SAR.

This includes L1 and L2 products (over land and ocean) for which we will:

- Harmonize and consolidate Cal/Val procedures with gap analysis
- Create a Guidance for Uncertainty Metrics (GUM)
- Define Fiducial Reference Measurements (FRM)
- Create or extend open-source software for SAR Cal/Val
- Demonstrate the tool capabilities

As L2 products we consider:

- Soil Moisture (SSM)
- Wet Snow (SWS)
- Ocean Surface Vector Wind (OSVW)
- Significant Wave Height (SWH)

Rl2Ocean: ROSE-L L2 ocean processor

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Norwegian Meteorological Institute

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

ICM Institut de Ciències del Mar

CSIC

TU Delft

CNR ISMAR ISTITUTO DI SCIENZE MARINE

esa

RL2*OCEAN* is under a programme of, and funded by, the European Space Agency (ESA). Views expressed do not reflect the official opinion of the ESA.

RL2Ocean Project Goals

- Development and consolidation of ocean algorithms
  - Ocean wind speed and direction
  - Sea state
  - Line-of-sight surface currents
- Production model for oceanographic products
  - Shall support operational, on-demand and re-processing needs
  - Shall meet the requirements of the Collaborative Ground Segment (CGS) and the Copernicus Marine Service
- Calibration and Validation (Cal/Val)
  - **Develop** cal/val strategy
  - **Plan** for cal/val activities to be carried out during the in-orbit commissioning (IOC)
  - Depending on a successful launch, **execute** the Cal/Val activities and monitoring plans during the IOC and operational phases
- Open science
  - Aid the adoption and integration of ROSE-L L2 products in the user community
  - Support collaboration and innovation in the scientific community
  - Provide open data and software (primarily Python) to facilitate interoperability and reuse

ROSS: Rose-L Ocean Science Study

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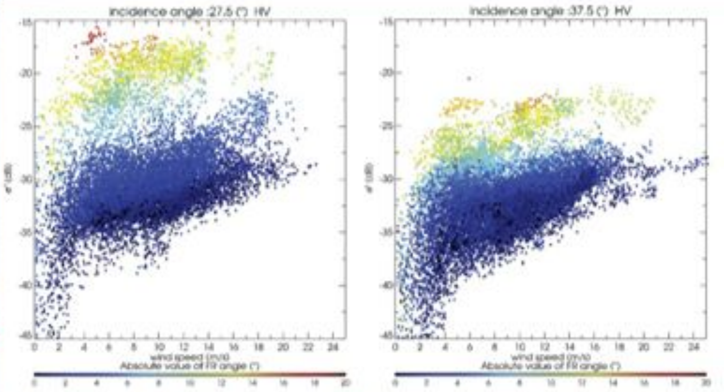
ROSE-L Ocean Studies – Challenges

L-BAND SPECIFIC CHALLENGES

- **Geophysical Model Functions (GMFs)** for translation of SAR indicators into wind speed and direction. Models based on ALOS or Aquarius NRCS as starting point. However, consolidation is needed for use in operational context
- **Modulation Transfer Functions (MTFs)** needed for Swell parameters retrieval in L-band. The L-band roughness, especially the tilting component, is near the transition between long (swell) and short (wind forcing) scales, i.e. decimeter to decameter (dmDm) length scales (Hwang and Ainsworth, 2020, L-Band Ocean Surface Roughness)
- **Impact of ionosphere** on product accuracy, in particular on inversion of GMF model inversion for cross-pol channels (but potential impact also on cross-spectra)
- **ROSE-L Wave Mode is a burst/ScanSAR-like mode**, with Doppler Centroid variations along azimuth and 10 m resolution in azimuth (vs 5 m of S1 WV)



From Isoguchi et al. 2019. "Effect of Faraday Rotation on L-Band Ocean Normalized Radar Cross Section and Wind Speed Detection"

MULTI-CHANNEL PROCESSING

- The adoption of **MAPS in receive** can **degrade the quality of imagery** and spectra for moving targets (ocean surface but also vessels and ice bergs)
- **Potential issue** for ROSE-L RIWS and WV modes over oceans but also other missions using or planning to use MAPS

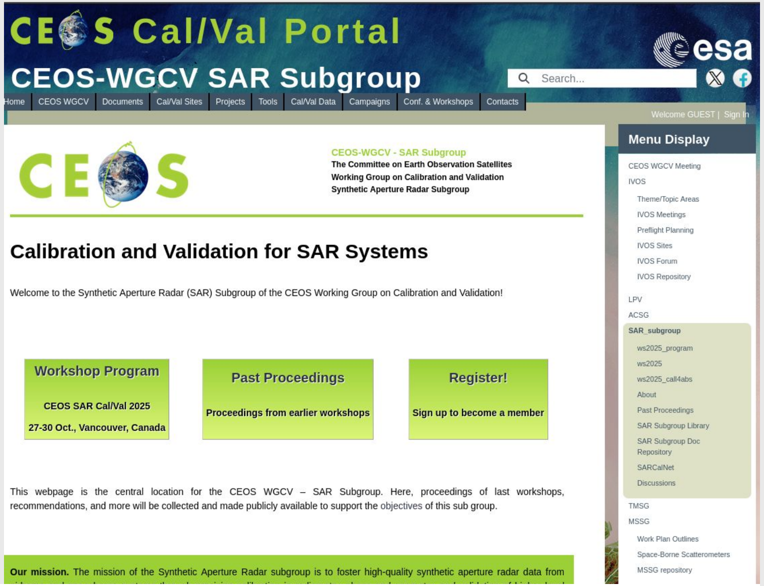
Calibration targets and sites

Artificial targets

Corner reflectors
Transponders
Geodetic control points

Natural distributed targets

Rainforest
Dry desert regions
Salt flats
etc



SAR L1 calibration

Level-1 calibration	Assessment	Target type	Best examples
Geometric	Absolute & Relative location errors	Corner reflectors, transponders, geodetic control points	**DLR SAR Calibration Center (FRM4SAR), Bonn Test Site, Rosamond Corner Reflector Array, Surat Basin**
Radiometric	Absolute calibration Long-term consistency	Known radar cross section points, stable distributed targets	**Australian corner reflector array (AGOS), BAE corner reflector, Metasensing CR Arrays in Netherlands, Salar de Uyuni, Amazon rainforest**
Impulse Response Function	Resolution, sidelobes, related focusing metrics	Bright isolated point targets	
Polarimetric	Channel imbalance, cross-talk, phase bias	Dihedral/trihedral reflectors, polarimetric transponders	**JAXA Calibration Field, Alaskan Calibration Sites**
Interferometric	Phase consistency	Highly coherent sites, stable point targets	**Etna volcano, Upper Rhine Valley, Belledonne Test Site**

Maturity matrix for artificial point targets

Grade
Not assessed
Not assessable
Basic
Good
Excellent
Ideal

Self-Assessment						Independent Assessor
Nature of FRM	FRM Instrumentatio	Operations/ Sampling single instrume	Data	Metrology	Completeness, coverage and distribution	Verification
Descriptor	Instrument documentation	Automation level	Data completeness	Uncertainty characterizatio	Validation capacity	Guidelines adherence
Location / availability of FRM	Evidence of target characterizatio	Traceable surve collocation	Availability anc usability	Traceability documentation	Geographical coverage Temporal sampling	Utilization feedback
Type of target site	Maintenance plan	Temporal stabi monitoring	Data format	Comparison calibration of F	Centralized data, processin quality assessment anc adherence to community standards	Metrology verification
Range of supported Level-1 quantities	Operator expertise	Guidelines on deployment / orientation / acquisition geometry	Ancillary data / metadat completeness	Adequacy for i class of instrumei / measura	Timeliness	Independent endorsement
Complementary observations	Target configuration and scalability	Repeatability o acquisition conditions	Licensing and access conditions	Representativer of compariso process	Intercompariso history	Independent verification
					FRM CLASSIFICATION	A

We follow CEOS FRM Assessment Framework

But, we did not used the Maturity Matrix Tool

FRM definitions and requirements

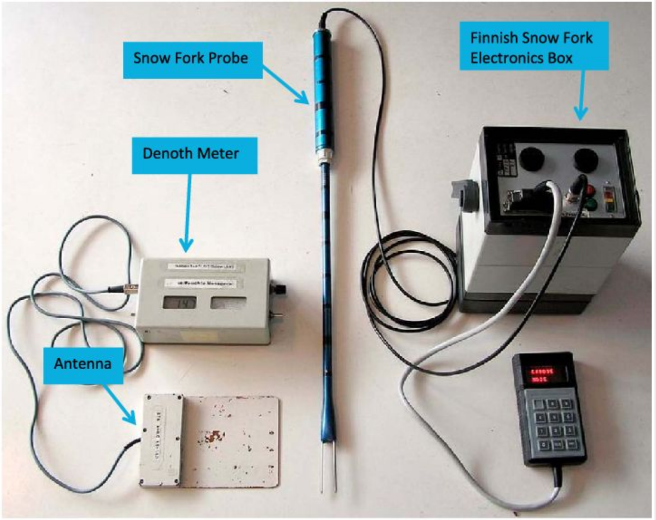
In-situ measurement: observations directly obtained at the location where the phenomenon of interest occurs.

Reference data: high-quality, independent, and reliable data used as standard to evaluate, calibrate or validate.

Fiducial Reference Measurement (FRM) requirements:

- Traceability to SI units
- Stability and representativeness of the measurement site
- Documented and validated uncertainty budgets
- Availability of high-quality metadata and survey protocols
- Repeatability and sustainability of measurements
- Calibration history and intercomparison activity

FRM SAR L2 land products



Wet snow

- Binary product
- Difficult to measure with an instrument
  - Denoth-meter
  - Snow fork
  - Snow depth + temperature
  - Hand test
- Also known as Liquid Water Content in snow (LWC)

Soil Moisture

Let’s not reinvent the wheel!! FRM4SM (presented yesterday)

FRM definition suitability for L2 ocean products

- FRM requirement about in-situ measurements:
  - “FRM measurements are independent from the satellite geophysical retrieval” (Goryl et al. 2023)
  - “Stability and representativeness of the measurement site”
- Tailoring for L2 ocean parameters:
  - Additional FRM wind source: scatterometers
  - Additional FRM SWH source: altimeters
- Include the World Meteorological Organization (WMO) Global Climate Observing System (GCOS) requirements for winds and SWH

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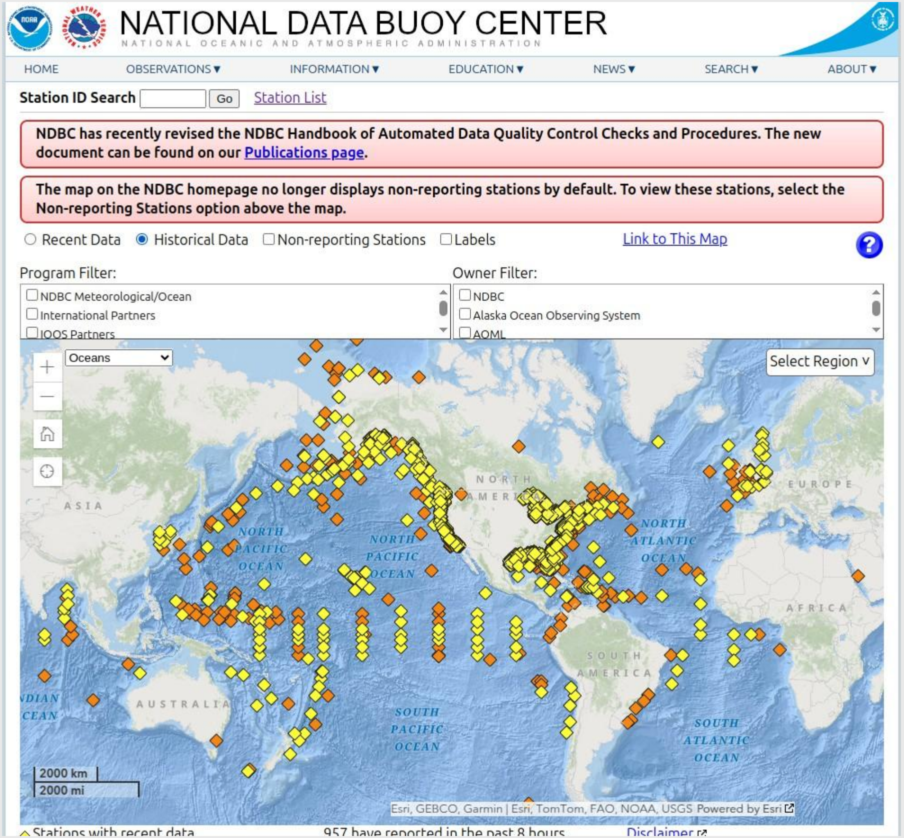
Proposed FRM: National Data Buoy Center



- OSVW
- Wave spectra (→ SWH)
- Ancillary information to compute stress-equivalent winds
- Several programs: NDBC, TAO, etc. covering the entire globe
- Availability of historical data
- Quality Control (NDBC Technical Document 09-02)
- Available also from ECMWF-MARS archive + CMEMS

https://www.ndbc.noaa.gov/

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Wind speed shift in TAO array

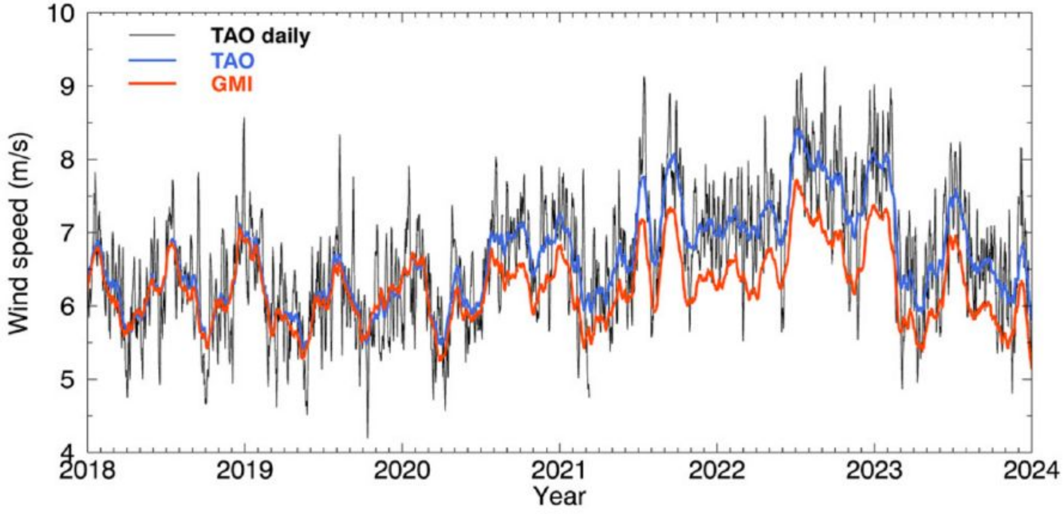

FIG. 2. Averaged time series for the buoy wind speed collocated with GMI rain-free wind speeds within 30 min and 25 km, for the period 2018–23. Here, the buoy winds are converted to a reference height of 10 m, and daily time series for individual buoys are averaged over all the buoys in the TAO array. The black line refers to the daily variability of the buoys, while the colored lines refer to a 30-day running mean, for easier visualization of the difference between GMI (dark orange) and buoy (blue) wind speed time series. In mid-2020, the GMI and buoy average wind speed time series started to diverge, showing a bias of about 0.5–0.8 m s^{-1}. Similar biases were observed even when comparing satellite winds to individual TAO buoys and for different satellites.

L. Ricciardulli, A. Manaster, and R. Lindsley, “Investigation of a calibration change in the ocean surface wind measurements from the tao buoy array,” Bulletin of the American Meteorological Society, vol. 106, no. 2, pp. E242 – E260, 2025.

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Buoys for OSVW and SWH

- Pros:
  - Wind accuracy: (0.1 ms−1, 6o) (Schlundt et al., 2020)
  - Maintained according to WMO standards (NDBC, TAO, PIRATA, etc..)

- Cons:
  - Presence of “gross errors” in measurement files
  - Measurement shifts due to periodic payload services (Ricciardulli et al. 2025)
  - Impact of these shifts on long-term stability
  - Lack of data standardization (file format, QC, metadata info, etc..)
  - Too many non-coordinated providers
  - Geographical distribution

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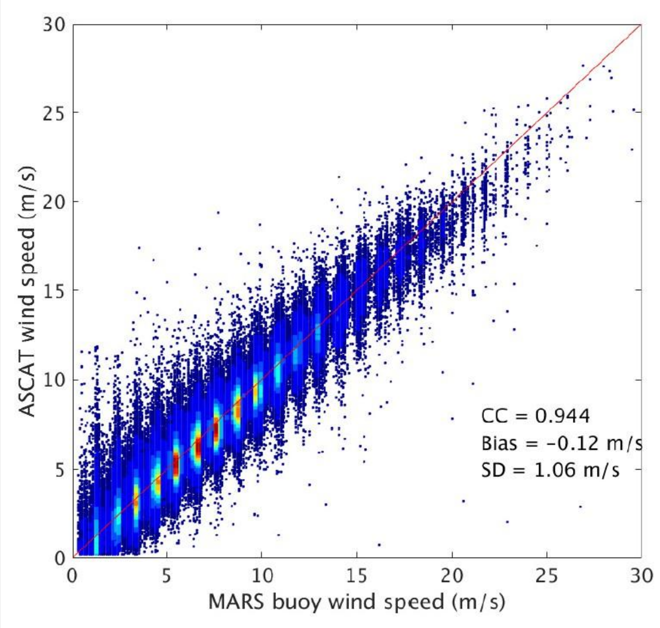
Proposed FRM: Scatterometer-derived winds



Scatter–density plot of ASCAT U10S wind speed versus MARS buoy U10N wind speed. The scores of the CC, the bias, and the SD of the speed differences are shown in the legend. A total of 300,000 collocations are shown over the period 2009-2014. [4]

- Accuracy: ±1 ms^{-1}, ±20^o
- Accuracy stability over decades
- Large constellation: 8 scats
- Collocated with ECMWF U10S winds
- Period: 2007-present
- Data available @ ICM-CSIC

[4] F. Polverari et al., "On High and Extreme Wind Calibration Using ASCAT," in IEEE Transactions on Geoscience and Remote Sensing, vol. 60, pp. 1-10, 2022, Art no. 4202210, doi: 10.1109/TGRS.2021.3079898.

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Scatterometer-based FRM for OSVW

- Pros:
  - Compliance with GCOS requirements
  - Availability of Climate Data Record (CDR) datasets (Verhoef et al., 2017, Ricciardulli & Manaster, 2021)
  - Homogeneous geographical distribution
- Cons:
  - Lack of multi-mission intercalibrated datasets
  - Coarser spatial resolution compared to SAR

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Altimeter-based FRM for SWH

- Pros:
  - Compliance with GCOS requirements
  - Availability two Climate Data Record (CDR) datasets (Ribal & Young., 2019, Dodet et al., 2020)
  - Availability of CMEMS INSTAC “near-real-time, single-mission, along-track bias corrected and noise- filtered SWH product” (Charles et al., 2023)
  - Homogeneous geographical distribution

- Cons:
  - Slightly coarser spatial resolution compared to SAR
  - Mis-match of climate trends between the two CDRs. Causes:
    - Non-homogeneous retracking algorithm
    - Different calibration sources
    - Different altimeter sources

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Maturity matrix: Buoys for OSVW and SWH

Legend

Grade
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Basic
Good
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Ideal

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Range of instruments	Maintainance plan	ATBDs on processing / software	Data format	Comparison/ calibration of FRM	Centralized data, processing, quality assessment and adherence to community standars	Metrology verification
Complementary observations	Operator expertise	Guidelines on transformations to satellite pixel	Ancillary data	Adequacy for intended class of instrument/ measurand	Timeliness	Independent verification
					FRM CLASSIFICATION	**B**

Maturity matrix: Scatterometer-based FRM for OSVW

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Maturity matrix: Altimeter-based FRM for SWH

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Future FRM assessments for ocean

Ocean L2 products

- wind stress
- extreme winds
- hub height winds (?)
- wave period
- wave height (swell/wind dominated seas)
- wave direction
- wave directional wave spectrum
- wave age
- LoS wave Doppler
- LoS surface current

Potential FRM

- Buoys (beyond wind vector and SWH)
- SFMR
- Dropsondes
- IWRAP
- Radiometers (?)
- HFR
- Drifters (?)
- Saildrones (?)

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Conclusions

FRM4OCN ??

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Questions?

Backup slides

GCOS requirements for winds

Variable	Horizontal Resolution (km)	Temporal Resolution (h)	Uncertainty (2σ)	Stability per decade
Speed (ms^{-1})	10 (100) [500]	<1 (1) [3]	0.1 (0.5) [1]	0.1 (0.25) [0.5]
Direction	10 (100) [500]	<1 (1) [3]	1^o (5^o) [10^o]	1^o (2^o) [5^o]

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GCOS requirements for SWH

Variable	Horizontal Resolution (km)	Temporal Resolution (h)	Uncertainty (2σ)	Stability per decade (cm)
SWH	1 (25) [100]	1 (3) [24]	5%	1 [10]

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EDAP & EDAP+ legacy

Quality assessment undertaken during EDAP+ project

The SAR Calibration Toolbox (SCT) includes a tool for each of the quality parameters

Missing L2 land and L2 ocean products

*IRF: Impulse Response Function

Table 1-1: Parameters for the assessment of SAR data quality

Quality parameter	Metric	Data type	Cal. Sites
IRF	Spatial resolution	Point Target	Mission dedicated sites: Rosamond Corner Reflector Array (California) Surat Basin (Australia)
	Peak-to-Side Lobe ratio	Point Target	
	Integrated Side Lobe ratio	Point Target	
Geometry	Localization	Point Target	
Radiometry	Calibration constant	Point Target	
	Polarimetric imbalance	Point Target	
	Elevation Antenna Pattern	Rain Forest	Amazon, Congo Sahara Greenland
	Azimuth scalloping	Rain Forest	
	Beam-to-beam offset	Rain Forest	
	Equivalent Number of Looks (ENL)	Rain Forest, Desert, Ice Sheets	
	Noise level	Low backscatter	Calm sea areas (e.g., Doldrums) Lakes (for small swaths, e.g., Mono Lake - California) Deserts
Interferometry	Coherence	High coherence areas	Salar de Uyuni

EDAP & EDAP+ legacy

Data Provider Documentation Review		
Product Information	**Metrology**	**Product Generation**
Product Details	Sensor Calibration & Characterisation	Image Formation & Calibration Algorithm
Availability & Accessibility	Geometric Calibration & Characterisation	Geometric Processing
Product Format, Flags & Metadata	Metrological Traceability Documentation	Retrieval Algorithm
User Documentation	Uncertainty Characterisation	Mission-Specific Processing
	Ancillary Data	

Detailed Validation					
Measurmenet	Absolute Radiometric Calibration Method	Radiometric Stability Method	Sensitivity Validation Method	Polarimetric Accuracy Method	Interferometric Accuracy Method
Measurmenet	Absolute Radiometric Calibration Results Compliance	Radiometric Stability Results Compliance	Sensitivity Validation Results Compliance	Polarimetric Accuracy Results Compliance	Interferometric Accuracy Results Compliance
Geometric	Spatial Resolution Method	Geolocation Accuracy Method			
Geometric	Spatial Resolution Results Compliance	Geolocation Accuracy Results Compliance			

Missing L2 land and L2 ocean products