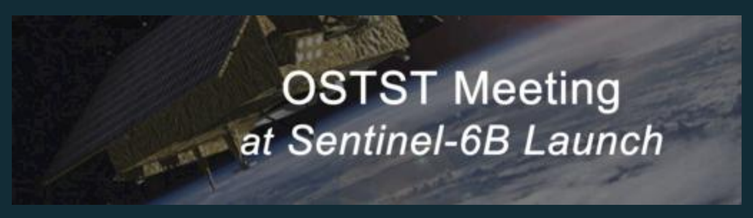

Fiducial Reference Measurements for monitoring satellite altimetry at the ESA Permanent Facility for Altimetry Calibration in Crete and Gavdos

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Abstract

The growing number of altimetry satellites, payloads, manufacturers, as well as accelerated developments in measuring techniques and data processing, urgently call for measures to ensure the quality of satellite products for Earth observation. Such sought indicators of quality to be properly working, must be reliable, indisputable, tied and traceable to reference and international standards (e.g., Système international d'Unités). End-users will thus be able to accurately determine whether EO products meet requirements and are suitable for their applications. At first, each EO mission follows its own in-flight calibration and validation (Cal/Val) to secure quality products. Later after Commissioning, external Cal/Val procedures are pursued with comparisons of satellite observations and products against ground-truth reference measurements. This work describes the way the uncertainty of the reference measurements on ground must be established beyond doubt, and the way external Cal/Val needs to be carried out to properly evaluate the produced satellite observations and products and thus ensure accurate communication between satellite operators and users. This investigation would be based on the reference measurements made at the ESA Permanent Facility for Altimetry Calibration (ESA-PFAC) in Crete and Gavdos, Greece, where all ESA and world satellite altimeters have been calibrated for almost 20 years. The Cal/Val uncertainties will be established according to the ESA principle for Fiducial Reference Measurements and the guidelines of the Bureau International des Poids et Mesures (BIPM) for determining measurement uncertainty. Integration of Cal/Val results at this facility obtained from diverse instruments, locations, setting, techniques will be also presented. Finally, practical guidelines for achieving FRM-quality ground reference data will be provided, along with plans for expanding the ESA-PFAC Cal/Val services to other, non-altimetry EO missions

1. What is Fiducial Reference Measurements for Altimetry

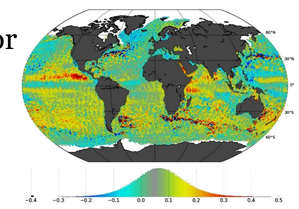
Satellite Altimetry Cal/Val results
traceable to SI & Metrology
(i.e., light speed, time)

Measurement Uncertainty
-Critically review current Cal/Val techniques;
-Identify each constituent to uncertainty ;
-Documented & unbroken chain of calibrations;
-Connect uncertainty to SI-traceble measurements.

Fiducial Reference Measurements for Altimetry
-Establish procedures for Altimetry Cal/Val uncertainty budget,
-Report results well-characterized & reliable in the long-term,
-Make Cal/Val results comparable worldwide,
-Impervious to reference instrument, setting, location, conditions,
-Organize standards, procedures, best practices for FRM4ALT.

2. Why FRM for altimetry now?

- ✓ Build up **objective** and **reliable** record for Earth observation;
- ✓ **Traceable** in the long term;
- ✓ **Comparable** world-wide;
- ✓ Connected to undisputed reference and measurement systems.

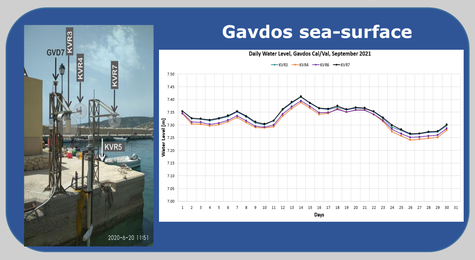


source: ESA

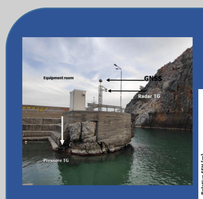
3. Ground FRM Infrastructure for Altimetric measurements/products.

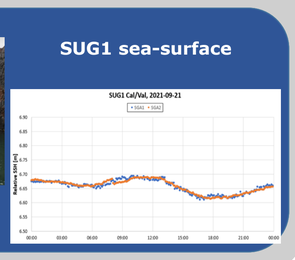
Sea-Surface Height

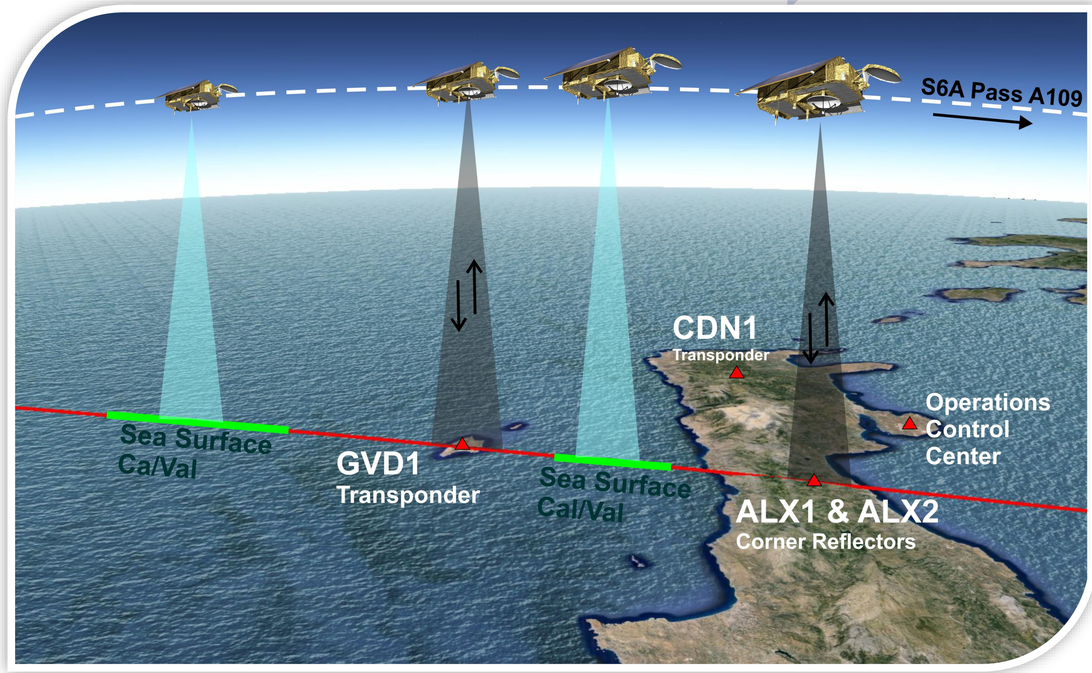
Gavdos sea-surface



SUG1 sea-surface



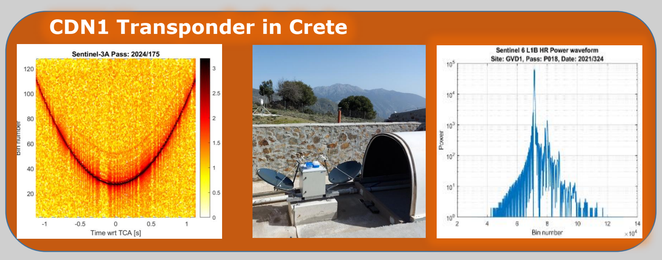




Range & sigma-naught Ground Reference

GVD1 Transponder in Gavdos

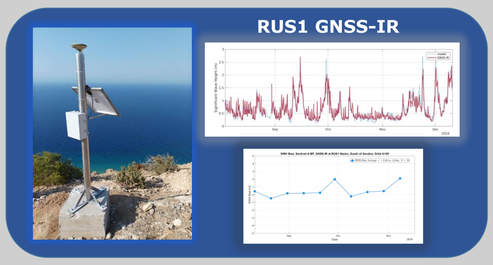
CDN1 Transponder in Crete

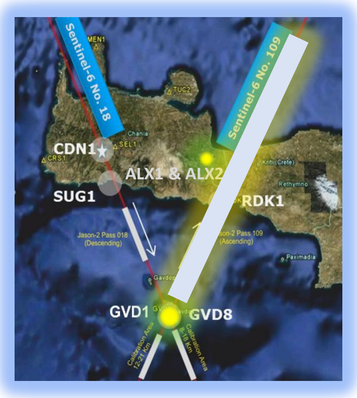


Sea state, SWH and wind Ground Reference

Sea-State Optical Infrastructure

RUS1 GNSS-IR





ALX1 & ALX2 Corner Reflectors in Crete

4. Practical steps towards FRM realization

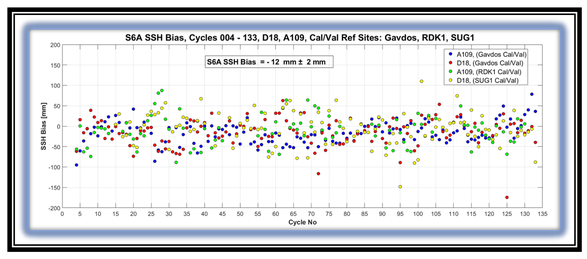
1. Choose Reference Measurements
   - •Time & Coordinate Reference System,
   - •Tracing measurements & Sources of Uncertainty,
   - • Instrumentation characterization (pre- and post deployment).
2. Operational Practice
   - •Long-term stability of Ground Reference,
   - • Homogeneity,
   - • Consistency,
   - • SI-traceability.
3. Quality Control
   - • Define Uncertainty Constituents,
   - • Document procedures to report FRM uncertainty budgets,
   - • Maintain standards, protocols and characterization procedures,
   - •Consolidate data formatting, archiving and distribution.
4. External Review
   - •Ask for External Review of the FRM infrastructure,
   - •Use independent data sets to satellite,
   - •Inspect of FRM documents.

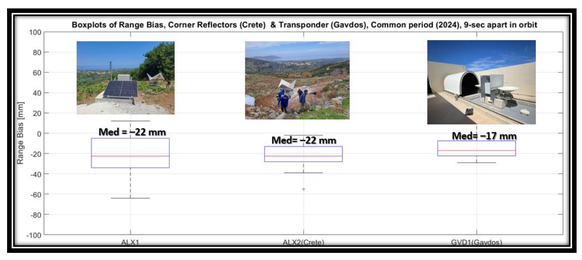
Transponders & Corner Reflectors

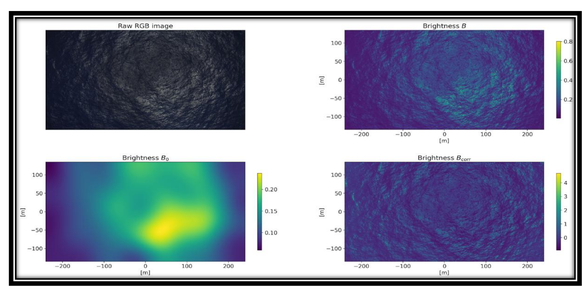
	CDN1 TRP		GVD1 TRP		ALX1 CR
	Standard Uncertainty		Standard Uncertainty		Standard Uncertainty
GNSS Site	CDN1	CDN2	GVD0	GVD2	ALX0
Abs. Positioning	0.1	0.2	0.1	0.1	1.1
GNSS Antenna ARP	5.0	10.0	10.0	10.0	10.0
Tidal Corrections	2.0	2.0	2.0	2.0	2.0
Non-tidal	2.0	2.0	2.0	2.0	2.0
TRP Internal Delay	15.0	15.0	10.0	10.0	-
Levelling	0.1	0.1	0.1	0.2	0.4
Ell. Heights per station	16.1	18.2	14.4	14.4	11.6
Final Ell. Heights	24.3		20.4		11.6
Ionosphere Delays	2.9		2.9		2.9
Troposphere Delays	5.8		5.8		5.8
Satellite Orbit	20.0		20.0		20.0
Satellite Attitude	2.0		2.0		2.0
Instrument Noise	7.0		7.0		7.0
Bin Range	5.0		5.0		5.0
Orbit Interpolation	0.5		0.5		0.5
Singal Processing	4.5		4.2		4.5
Unaccounted	10		10		30
FRM Uncertainty Budget	± 35.10 mm		± 32.5 mm		± 39.6 mm

Sea-Surface Cal/Val

	Gavdos SSH		SUG1 SSH	RDK1 SSH
	Standard Uncertainty		Standard Uncertainty	Standard Uncertainty
GNSS Site	GVD7	GVD8	SUG1	RDK1
Abs. Positioning	0.1	0.1	0.2	0.1
GNSS Antenna ARP	10	5	10	10
Tidal Corrections	2	2	2	2
Non-tidal	2	2	2	2
Tide Gauge Zero Point	8	8	10	10
Levelling	0.1	0.1	0.2	0.1
Ell. Heights per station	11.1	7.0		
Final Ell. Heights	13.2		14.4	14.4
Ionosphere Delays	2.9		2.9	2.9
Troposphere Delays	5.8		5.8	5.8
Reference Surfaces (MSS)	50.0		50.0	50.0
Unaccounted	15.0		15.0	15.0
FRM Uncertainty Budget	± 54.5 mm			







Concluding Remarks

- ➢ This Cal/Val facility attains FRM standards with diverse instrumentation, techniques, locations, settings;
- ➢ Provides FRM results for range, sigma-0, time-tagging, sea state, Significant Wave Height;
- ➢ Implements multi-mission, multi-mode (LRM, SAR) & frequencies (Ka-, Ku-band) altimetry Cal/Val;
- ➢ Controls quality following GUM and QA4EO guidelines and best practices;
- ➢ Extends methods and infrastructure to validate non-altimetry missions, e.g., Sentinel-1 (imaging radar) and Sentinel-5P (atmospheric monitoring).

Acknowledgments:
Part of this work has been produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union and/or European Space Agency.