Fiducial Reference Measurements for Satellite Altimetry Calibration

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Abstract

This work presents a set of recommendations that an entity interested in establishing a satellite altimetry Cal/Val site shall follow (1) To critically review the current methodology applied for calibration and validation using ground-based measurements; (2) To define requirements and establish standards and provide recommendations and best practices for altimetry calibration such that all measurements and results made are well-characterized and linked to other areas of science and technology through a world's measurement system established and maintained under the International System of Units and Metrology Standards; (3) To document procedures so that results are reliable in the long term, comparable world-wide to support an objective and unquestionable monitoring of the Sea Level and Climate Change; and (4) To establish procedures and protocols for characterizing the uncertainty budget of all FRM instruments and derived results over the entire duration of a satellite mission. The criteria to be used for the evaluation of candidate Cal/Val sites are presented. Working examples from the Permanent Facility for Altimeter Calibration in west Crete, Greece are also given for absolute bias determination of satellite altimeters.

1. What is Fiducial Reference Measurements for Altimetry

Cal/Val results
traceable to SI and Metrology standards. (light speed, time, etc.)

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

Fiducial Reference Measurements
-Establish procedures for Cal/Val uncertainty budget,
-Results well-characterized and reliable in the long-term,
-Comparable through world's measurement system;
-Impervious to instrument, setting, location, conditions, ...
-Standards, procedures, practices for FRM4ALT.

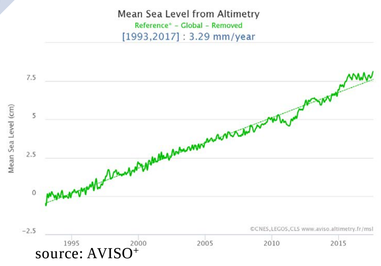
A. Site Selection,
B. Absolute Positioning,
C. Atmosphere Delays,
D. Geophysical Effects & reference surfaces,

Water Level Determination

Transponder Internal Delay

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.



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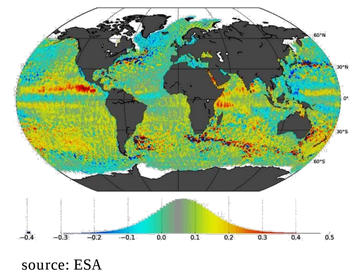
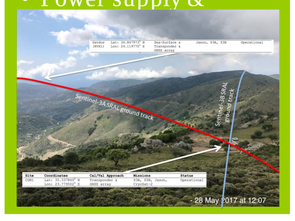


source: ESA

3. Constituents influencing Cal/Val uncertainties

Site Selection

- Repeat Cycle
- Across-track distance
- Land contamination
- Water Depth
- Directional errors
- Multi-mission
- Reference surfaces
- Accessibility
- Security
- Ground stability
- Geodetic ties
- GNSS visibility
- Power supply &

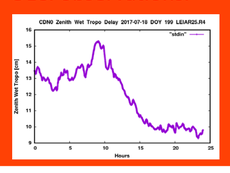


Absolute positioning

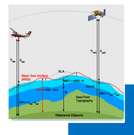
- Diverse GNSS satellites
- Diverse receivers & antennas
- Absolute GNSS antenna calibration
- 30s sampling rate
- 20 Hz high-rate ring buffer
- Reference frames
- Relative & absolute positioning
- Height diffs <2mm
- Diverse positioning systems (i.e., GNSS, DORIS, SLR, etc.)
- UTC time for GNSS observations
- At least 2-3 years of continuous operation.

Atmospheric Delays

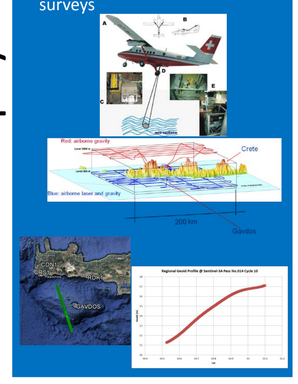
- GNSS processing to derive ionospheric and zenith tropospheric delays at the time of satellite overpass
- Operation of meteo sensors
- Validation w.r.t. global/regional modeling
- Radiosondes, photometers, radiometers measurements
- OLCI observations.



Geophysical effects



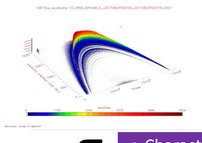
- Models for earth tides (solid earth, ocean tidal loading, pole tide) shall follow IERS conventions
- Establish reference geoid, MSS, MDT surfaces
- Validate these surface with local/regional marine/aerial/terrestrial surveys



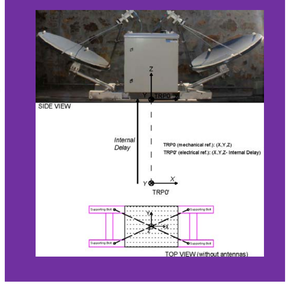
Water level determination

- Multiple (at least three) tide gauges of diverse measuring principle (radar, acoustic, pressure, floating).
- Geodetic ties between GNSS and tide gauge sensors via spirit leveling surveys with ± 1mm
- Calibration certificates from manufacturers for repeatability, reproducibility, hysteresis, drift, non-linearity, etc.
- Validation of instrument's performance, by the Cal/Val site operator, prior its permanent installation
- Field validation experiments to be conducted at least every 6 moths using a reference instrument
- Relative field calibration between operating tide gauges
- At least 1 hour of water level reading centered to the satellite overpass time of closest approach.

Transponder Calibration

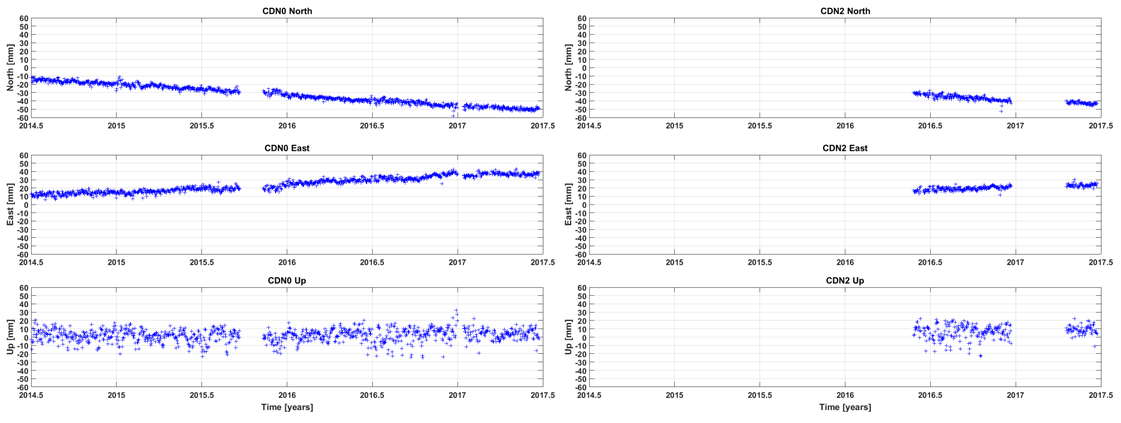


- Characterization at specialized facilities (i.e., Compact Payload Test Range @ESTEC/ESA)
- Mechanical vs electrical reference system (transponder's internal delay)
- Geodetic ties between GNSS and transponder mechanical reference
- Monitor transponder's performance w.r.t. environmental conditions (humidity, temperature, etc.)

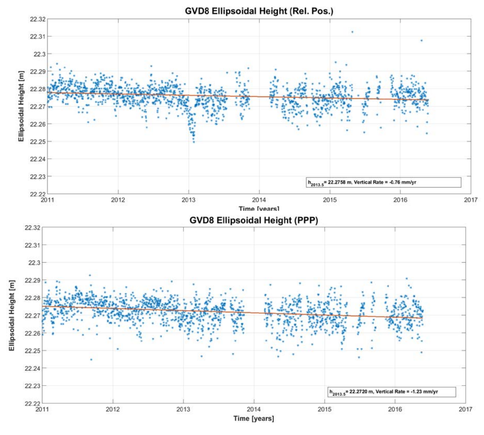


4. FRM4ALT Activities

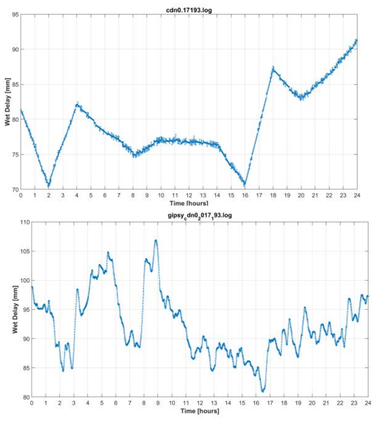
✓ **Absolute positioning results validation: (a) collocated GNSS receivers, (b) diverse processing strategies, and (c) atmospheric delays monitoring.**



(a) Time series of the CDN0 & CDN2 GNSS stations in ITRF2008. Both stations are continuously operating at the CDN1 transponder Cal/Val site, Crete, Greece.



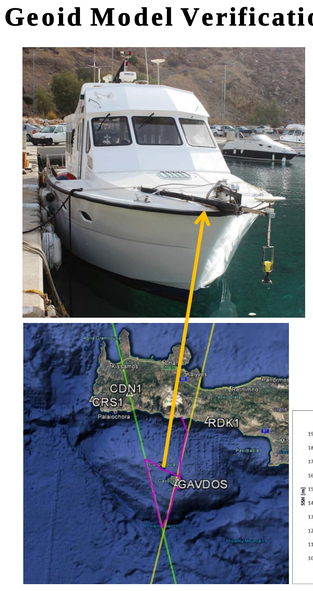
(b) Time series of GVD8 station for the ellipsoidal height at the Gavdos Cal/Val site as derived by the relative (up) and precise point positioning (down) techniques.

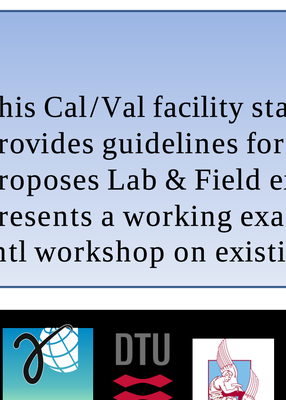


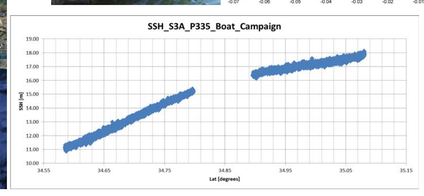
(c) Zenith wet troposphere delays for the CDN0 and CDN2 GNSS stations on 12-July-2017. Sentinel-3A overpassed at 20:00:12 UTC.

✓ **FRM4ALT Verification**

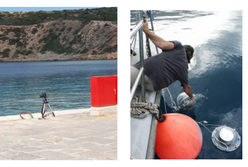
Geoid Model Verification

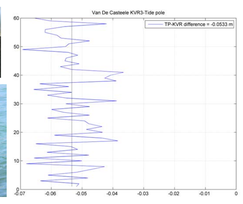






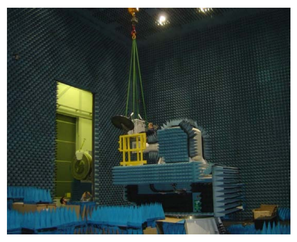
Instrument verification





Diverse Positioning (DORIS & GPS)

Absolute antenna characterized at specialized facilities



Transponder characterization at specialized facilities

✓ **Example of Uncertainty Budget Estimation (GUM BIPM)**

Uncertainty in:	Variance Estimate [mm]	Divisor	Standard Uncertainty [mm]	Sensitivity Coefficient	Uncertainty Components [mm]	Degrees of Freedom
	(a)	(b)	(c)= (a)/(b)	(d)	(e) = (c) × (d)	
Cal/Val Site Coordinates						
-Height determination	0.14	1	0.14	1	0.14	1759
-Instrument accuracy	6.00	√3	3.50	1	3.50	50
-Antenna Reference Point	2.00	1	2.00	1	2.00	∞
SSH@Cal/Val site						
-Tide gauge : Uncertainty budget	1.30	1	1.30	1	1.30	19
:reference plane	1.00	1	1.00	1	1.00	61
:vertical alignment	2.40	√3	1.40	1	1.40	50
:calibration certificate	5.50	1	5.50	1	5.50	∞
-Leveling error :repeatability	0.125	1	0.125	1	0.125	15
: monumentation stability	1.10	√3	0.60	1	0.60	50
: misalignment	1.00	√3	0.60	1	0.60	50
: observer's inexperience	1.00	√3	0.60	1	0.60	50
: instrument/method	1.00	√3	0.60	1	0.60	∞
: water level determination	1.00	√3	0.60	1	0.60	∞
MSS/MDT/Geoid						
-MSS model	33.00	1	33.00	1	33.00	200
-MDT model	85.00	1	85.00	1	85.00	200
-Geoid model	80.00	√3	46.20	1	46.20	8
-Processing						
-Coordinate transformation	0.50	√3	0.30	1	0.30	50
-Geoid slope	10.00	√3	5.80	1	5.80	50
Unaccounted						
-Unaccounted effects	10.00	√3	5.77	1	5.77	50
Combined Uncertainty					97.40 mm	
Expanded Uncertainty = k U_c (95%)					190 mm	

Concluding Remarks

- ➢ This Cal/Val facility starts delivery of procedures, protocols & results which attain FRM status;
- ➢ Provides guidelines for establishing a permanent Cal/Val site for altimetry;
- ➢ Proposes Lab & Field experiments for instrument characterization;
- ➢ Presents a working example for appraising measurement uncertainty of altimeter bias;
- ➢ Intl workshop on existing & future altimetry Cal/Val activities and Applications, Crete, 23-26 April 2018.

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