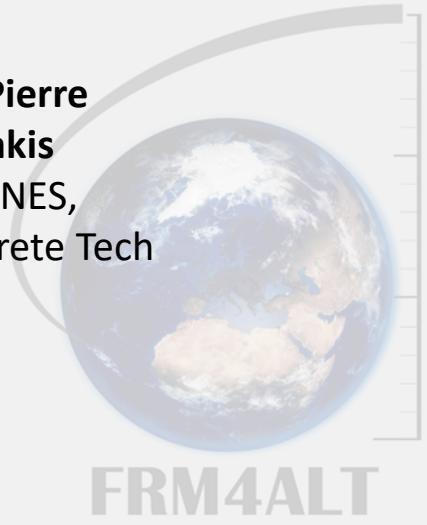
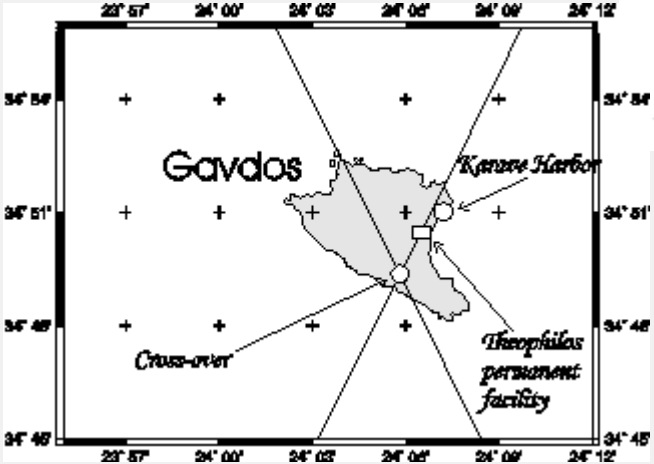
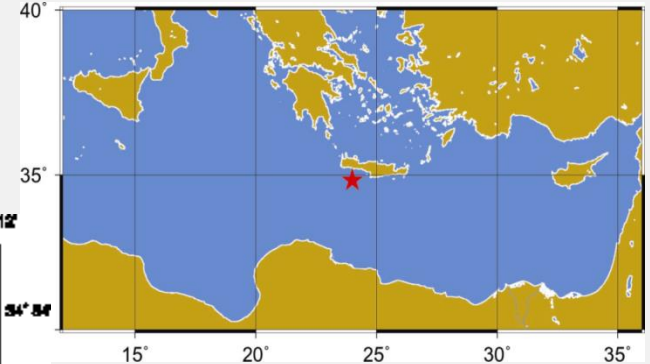
Absolute calibration of the Sentinel-3 altimeter with sea-surface and transponder at FRM Standards in West Crete, Greece

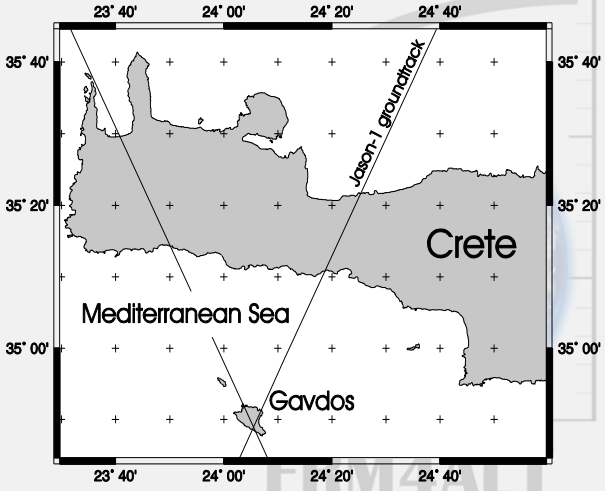
Mertikas S. P. (Crete Tech University), **Craig Donlon** (ESA/ESTEC), **Pierre Féménias** (ESA/ESRIN), **C. Mavrocordatos** (ESA/ESTEC), **D. Galanakis** (Space Geomatica P.C., Greece), **T. Guinle** (CNES, France), **F. Boy** (CNES, France), **A. Tripolitsiotis** (Space Geomatica, Greece), **X. Frantzis** (Crete Tech University, Greece).



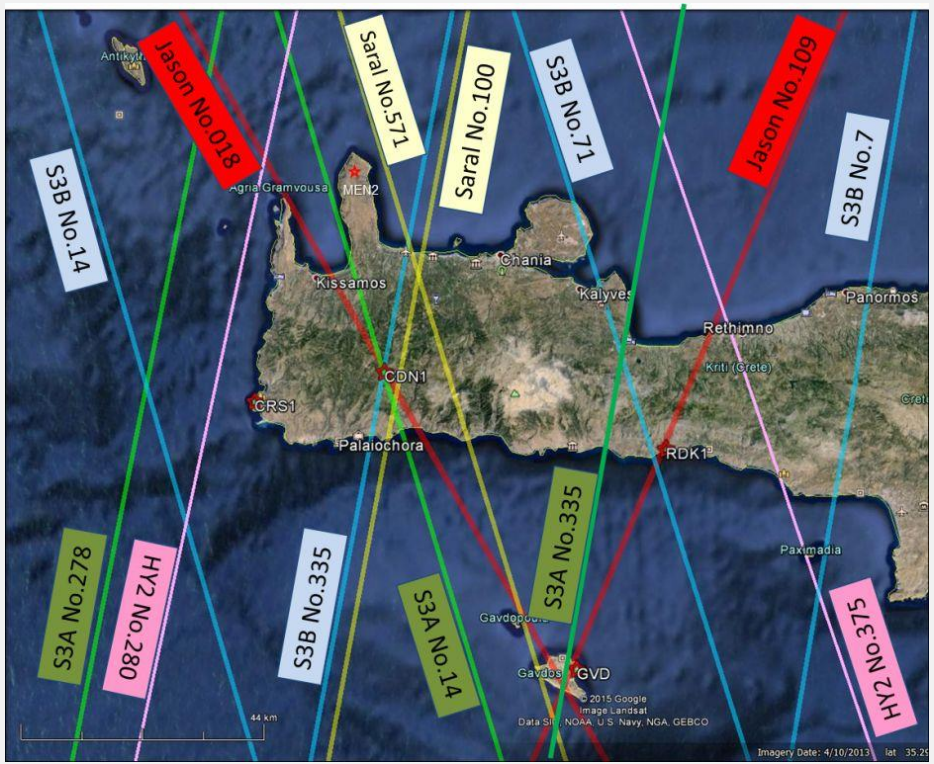
Gavdos Permanent Cal/Val Facility



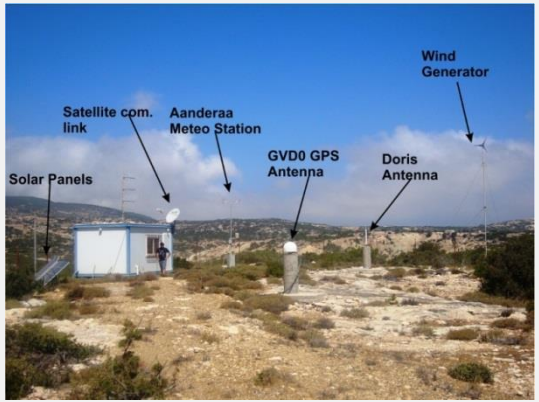


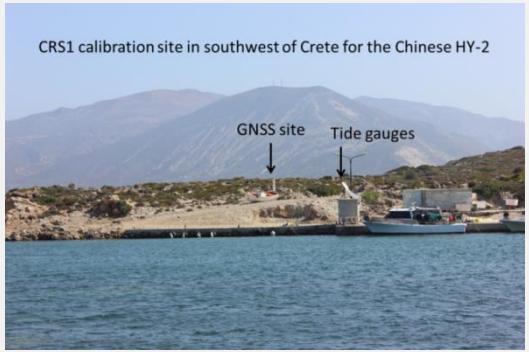


Tracks around Gavdos & Crete

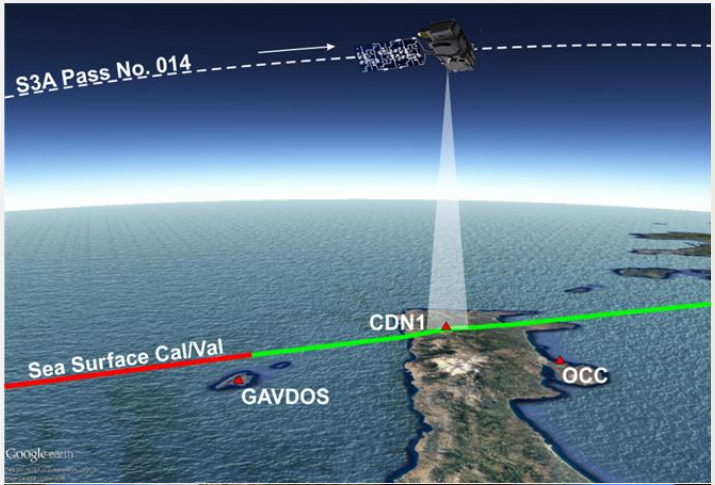


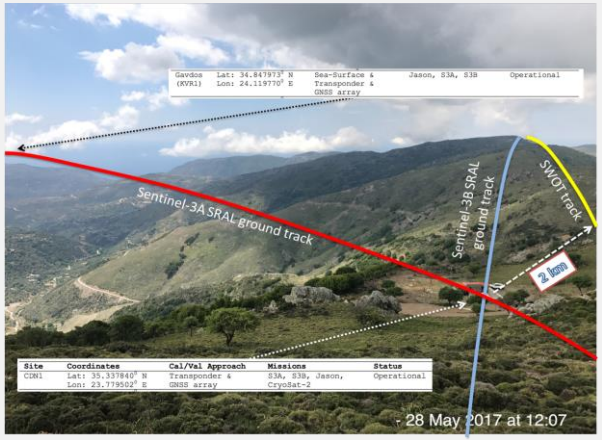
Gavdos and West Crete Facilities

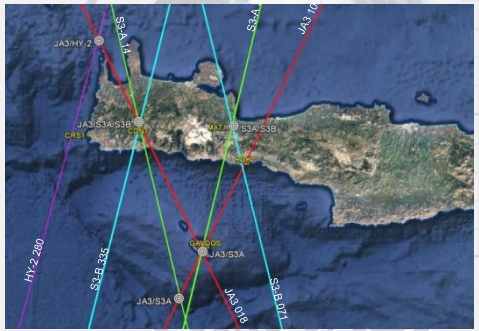




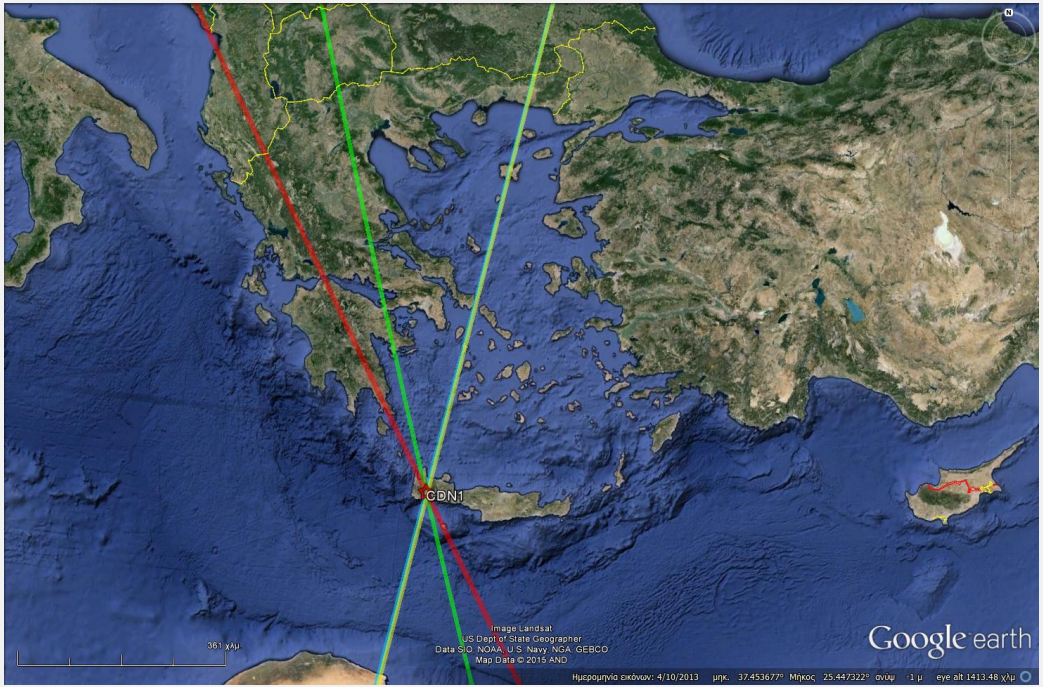
Transponder & Sea-Surface Cal/Val

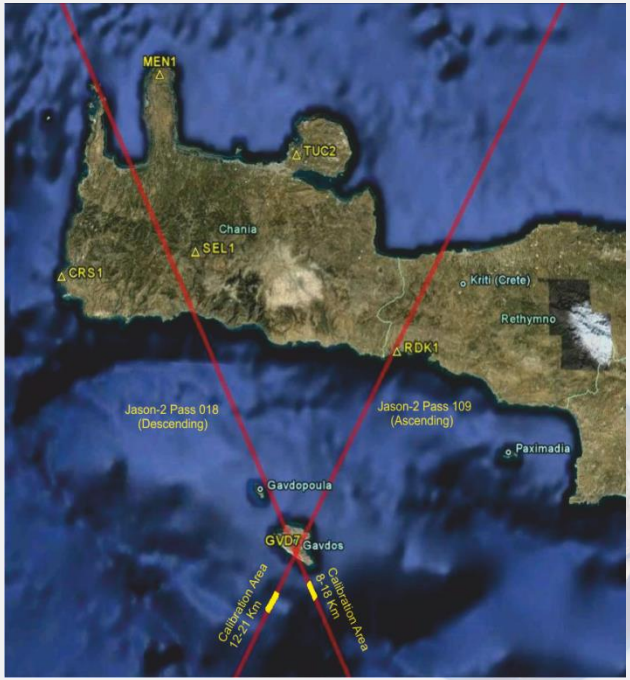






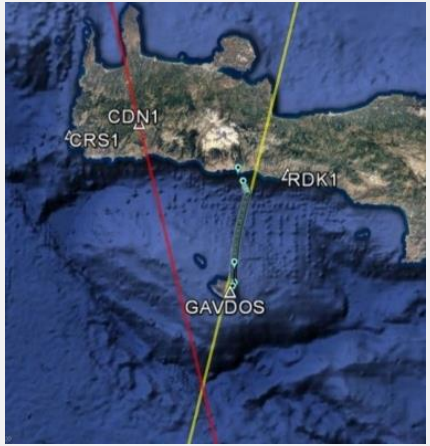
Land and Sea Calibrating regions

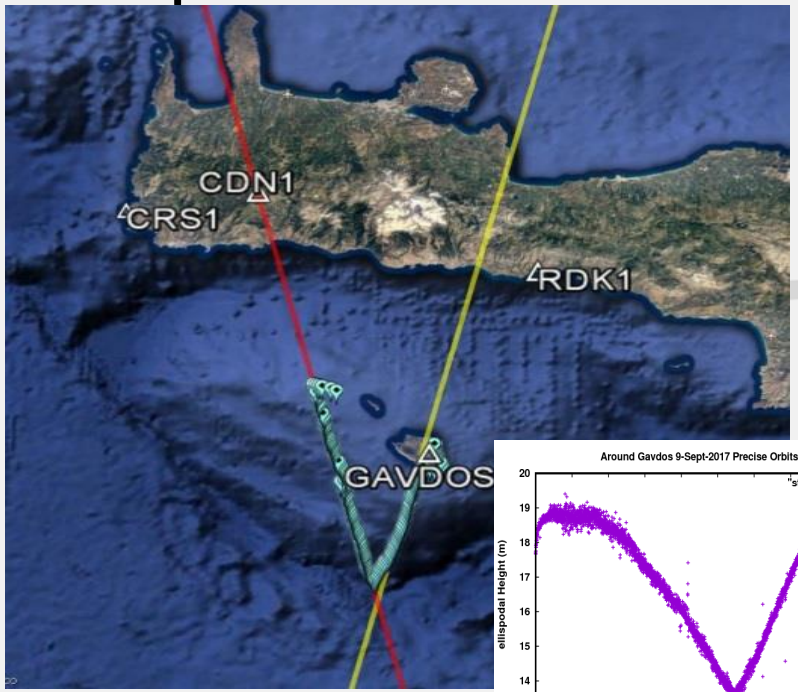




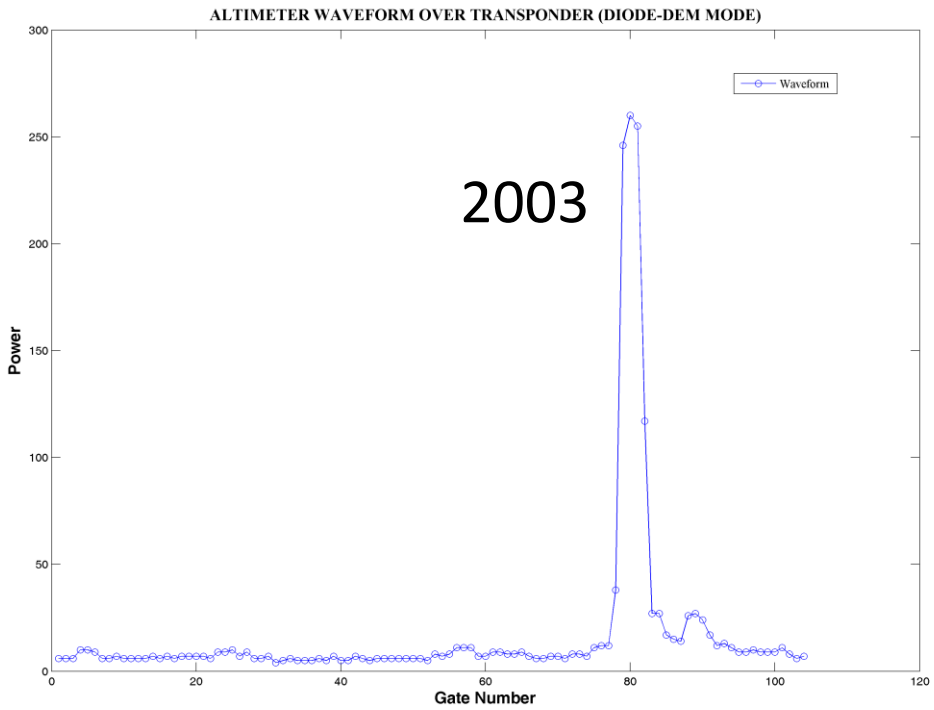
FRM4ALT

Boat Campaigns in Sept 2017

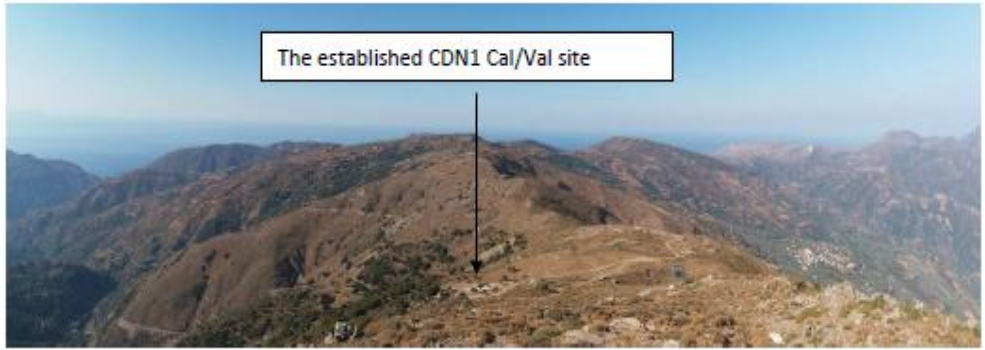


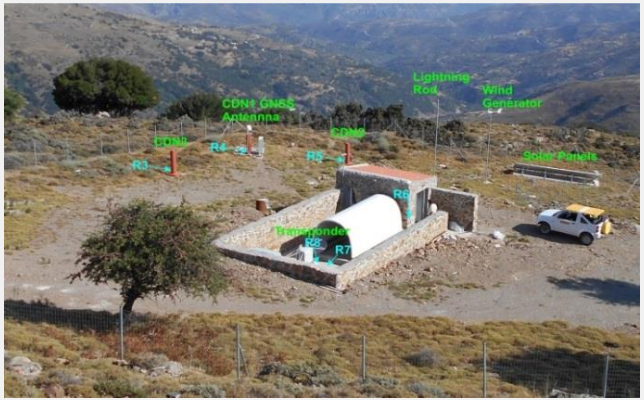


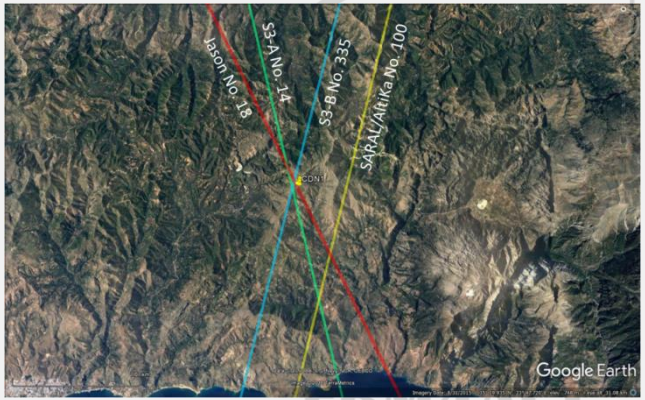
GVD3: Transponder Calibrations in Gavdos



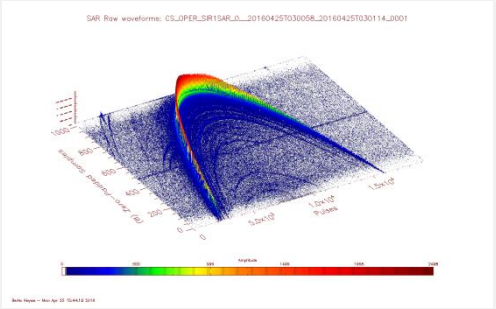
CDN1: ESA Sentinel-3 Altimeter Calibration



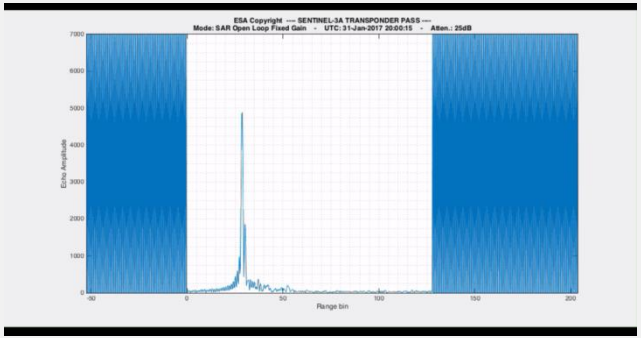




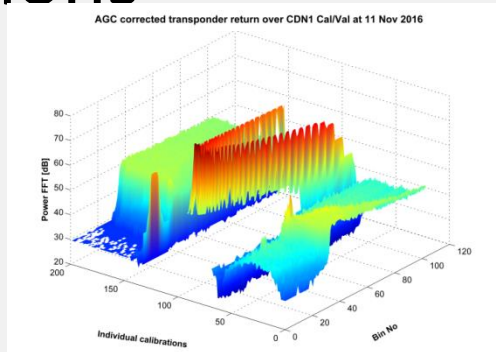
CDN1 Transponder Calibrations



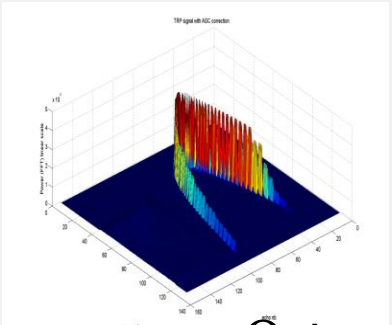
Cryosat-2, 25-Apr-2016



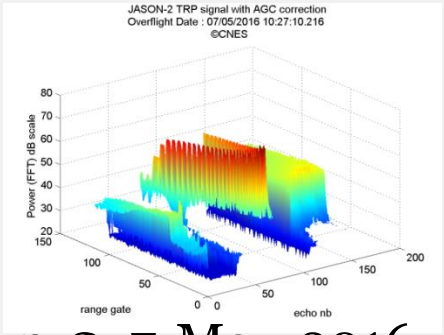
Sentinel-3, 31-Jan-2017



Jason-3, 11-Nov-2016

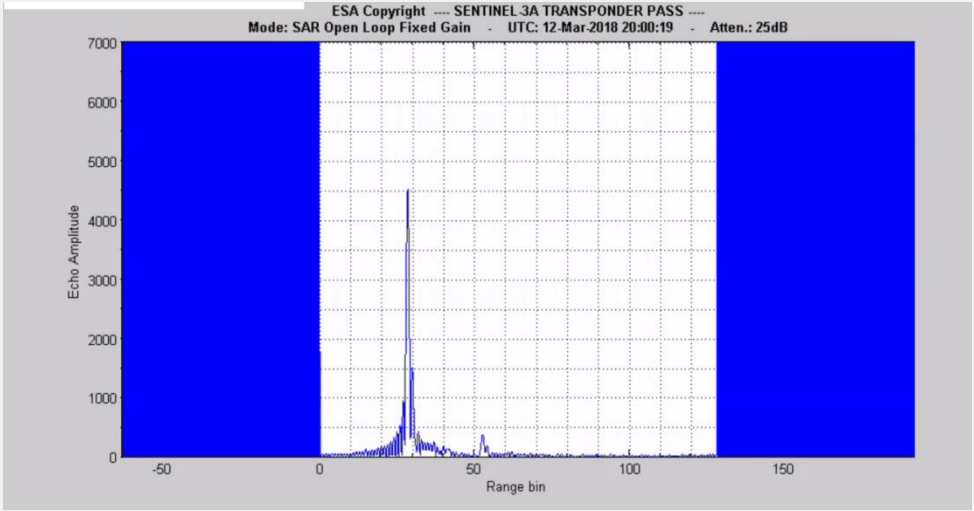


Jason-2, 2-Oct-2015

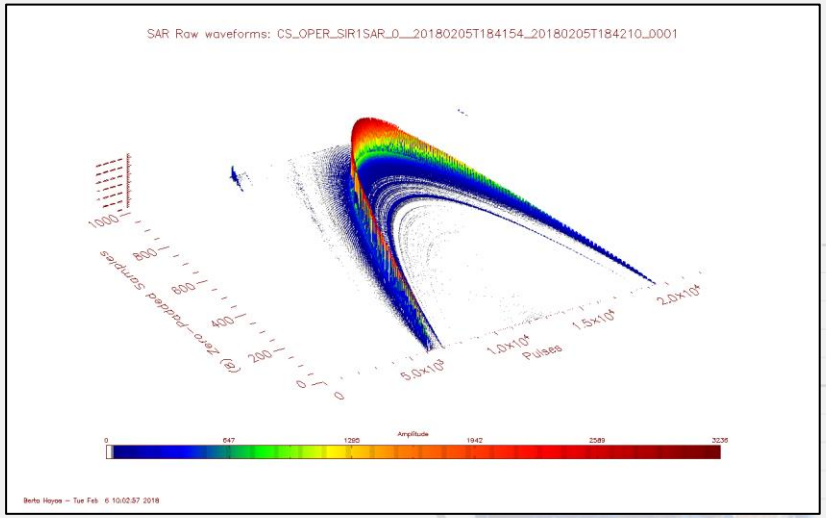


Jason-2, 7-May-2016

Recent Transponder Responses

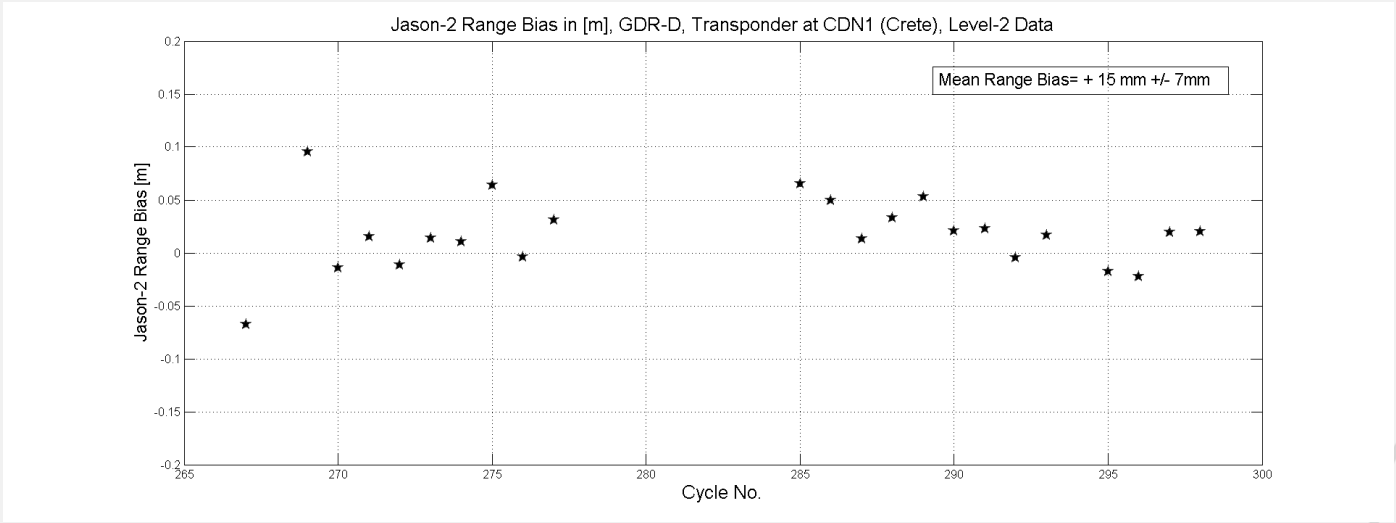


Sentinel-3, 12-Feb-2018



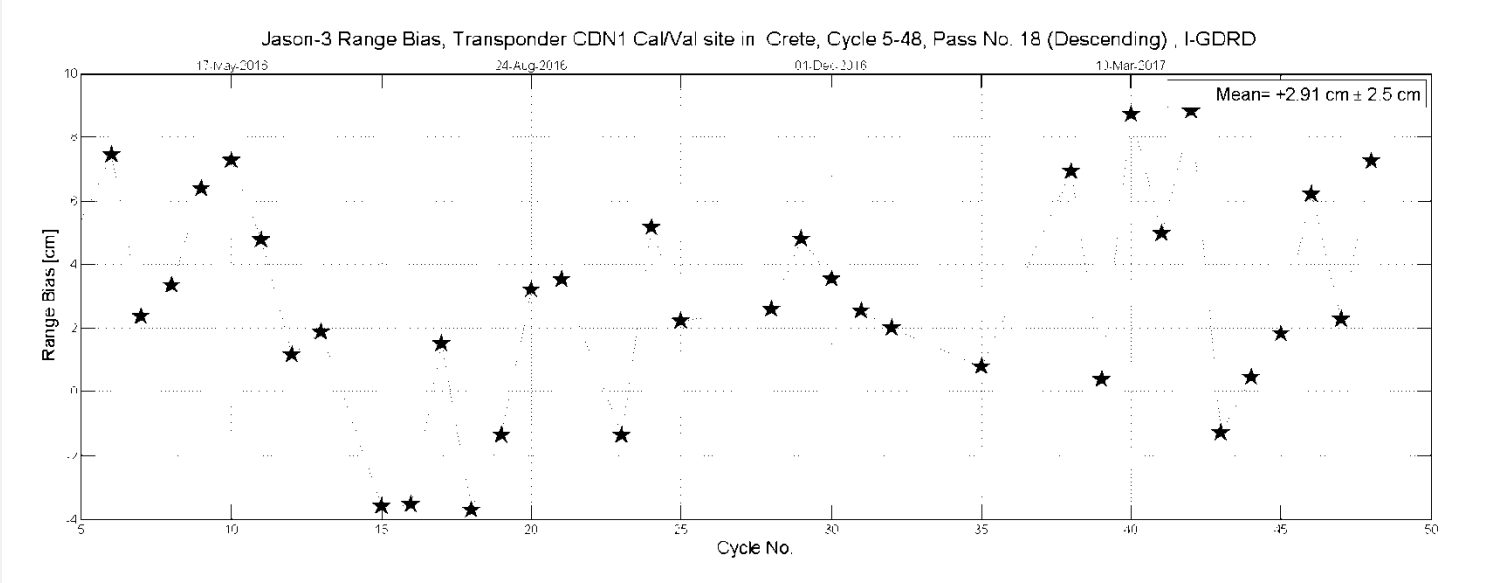
CryoSat-2, 5-Feb-2018

Jason-2 Transponder Calibrations



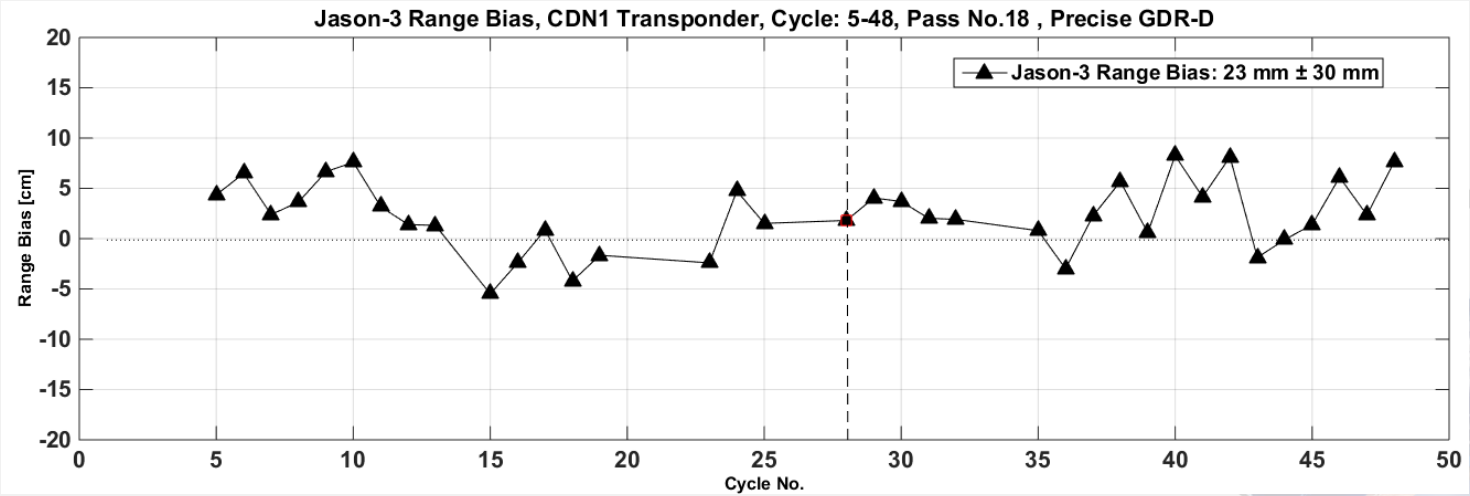
- Descending Pass No. 18, in 2015 and in 2016 (in Tandem with Jason-3),
- Precise Orbit [POE], Sensor-GDR-D,
- Range Bias B= **+15 mm ± 7 mm**,
- Variations may be due to **yaw steering** applied in Jason-2 & Jason-3.

Jason-3 Transponder at CDN1 Cal/Val



- Sensor-I-GDR-D, Cycles 5-24, MOE Orbit,
- Jason-3 **Range Bias= +29 mm ± 3 mm**.

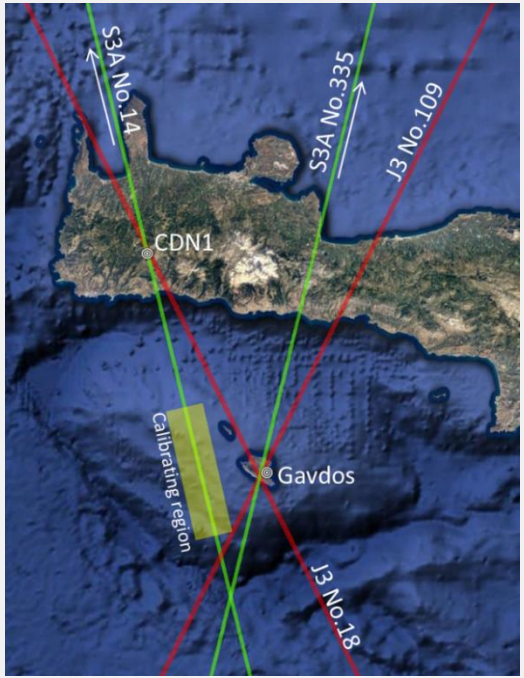
Jason-3 Transponder, No.18 Descending CDN1 Cal/Val West Crete

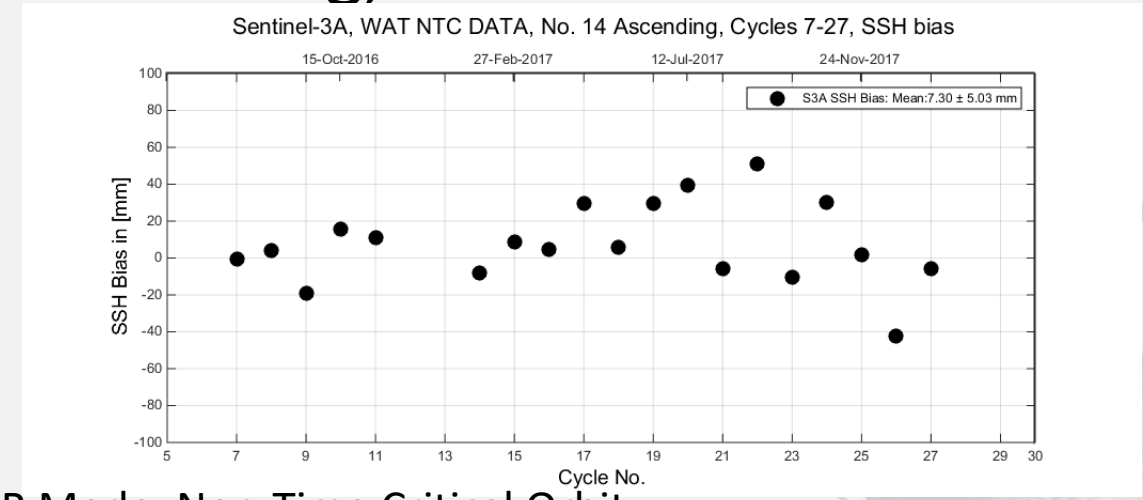


- GDR-D, Cycles 5-48, Precise Orbit,
- Jason-3 **Range Bias= +23 mm ± 30 mm (median= +21 mm).**

CDN1: 2017 worst winter over 50 years

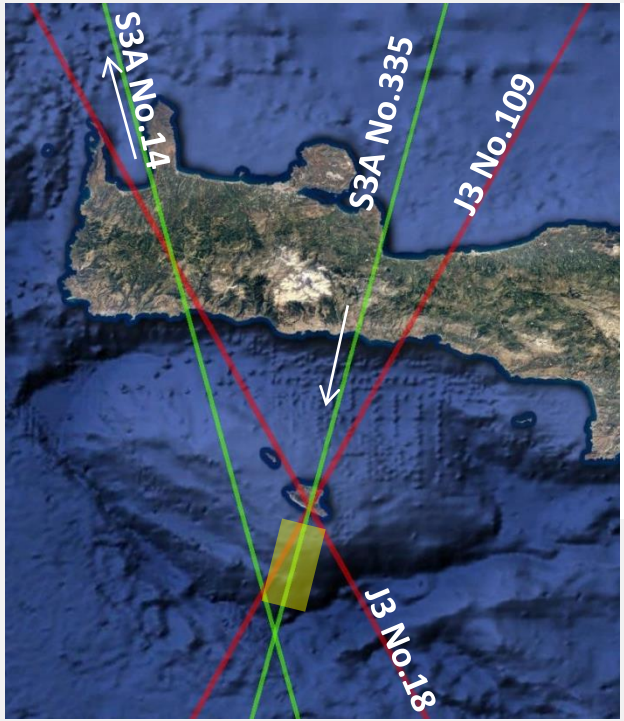
Sentinel-3A SSH Cal/Val, No. 14 Ascending, West Gavdos

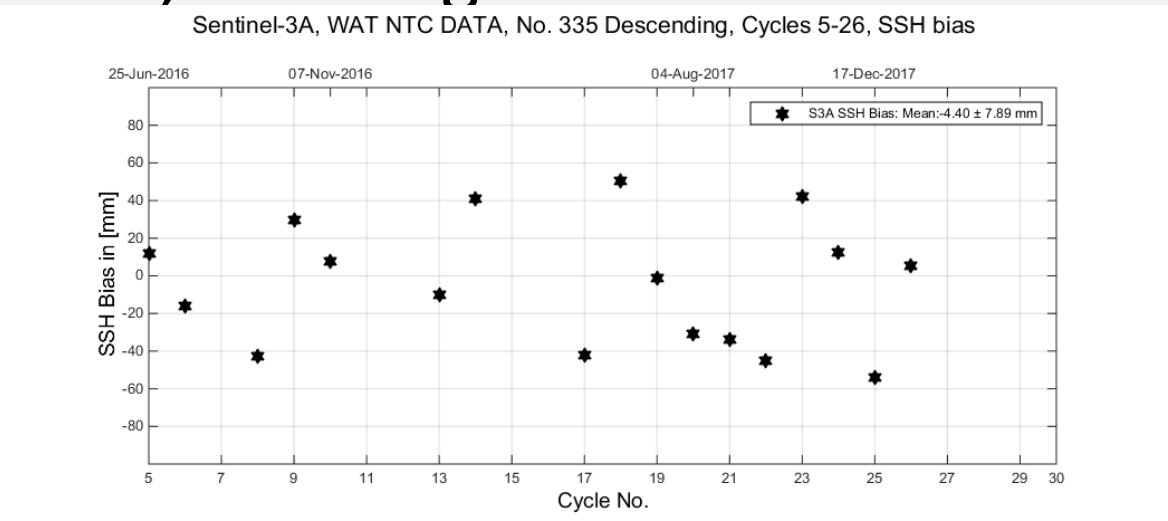




SAR Mode, Non-Time Critical Orbit,
Same orbit as the transponder orbit at CDN1 Cal/Val in Crete,
SSH Bias **= +7 mm ± 5 mm (Ascending)**
Pass No. 14 next to and west of Gavdos

Sentinel-3A, Sea-Surface Calibration Descending No. 335, Crossing Gavdos

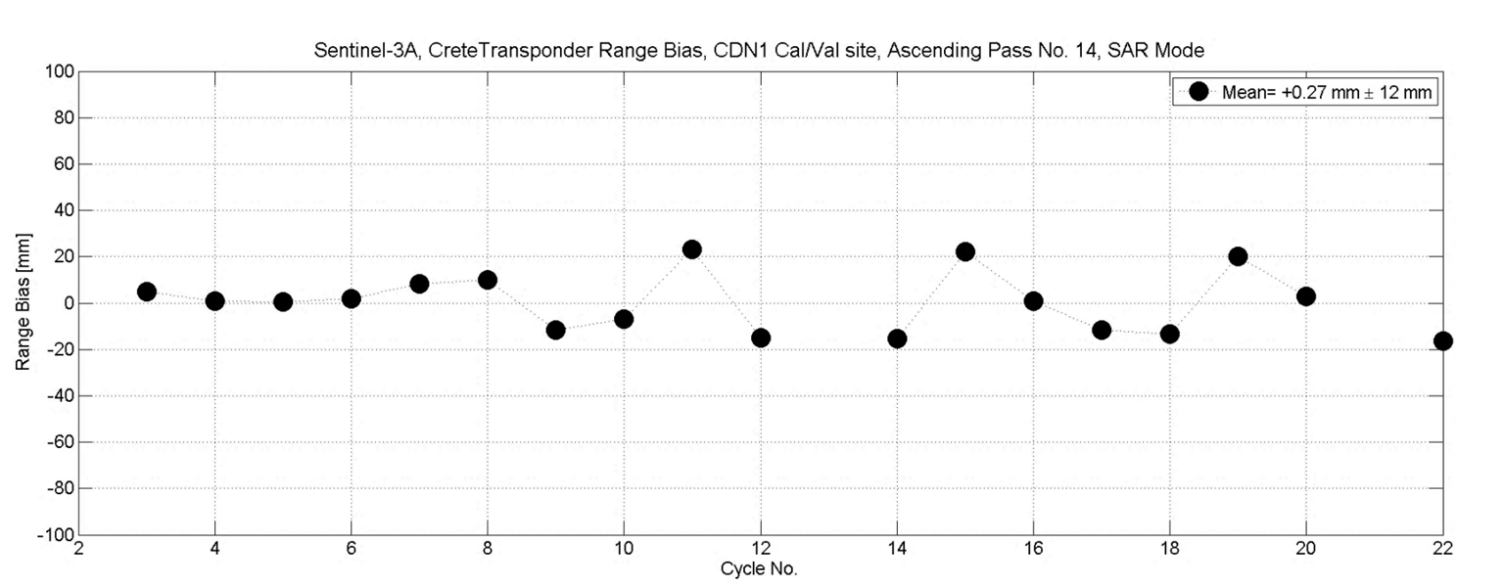




Pass No. 335 (Descending), Similar to Jason No.109 orbits

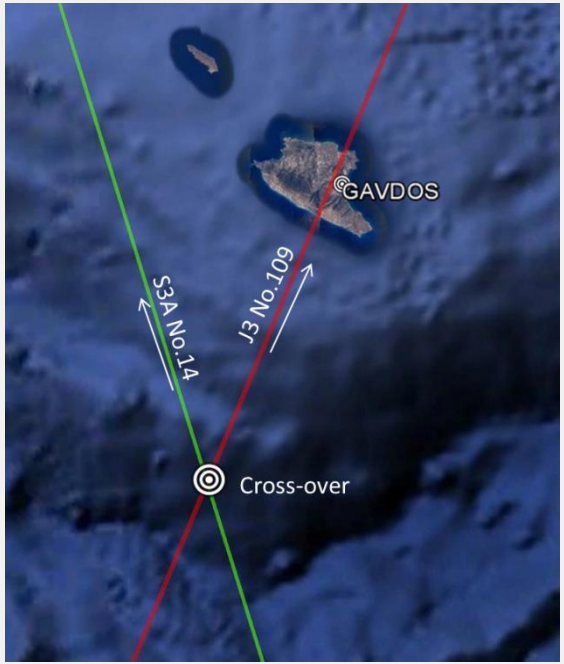
Mean Range Bias **= -4 mm ± 8 mm (Descending)**.

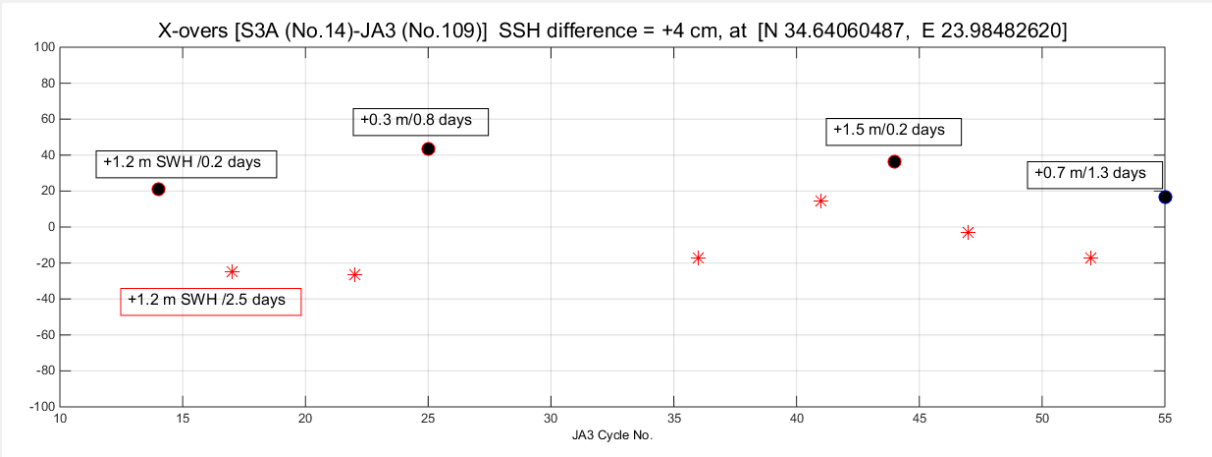
Sentinel-3 over transponder at CDN1



Sentinel-3A, SAR, Pass No. 14 (Ascending),
Passing over CDN1 Transponder,
Mean Range Bias **= +3 mm ± 12 mm**.

Cross-Overs [S3A (No.14)-JA3 (No.109)] south of Gavdos, both ascending orbits

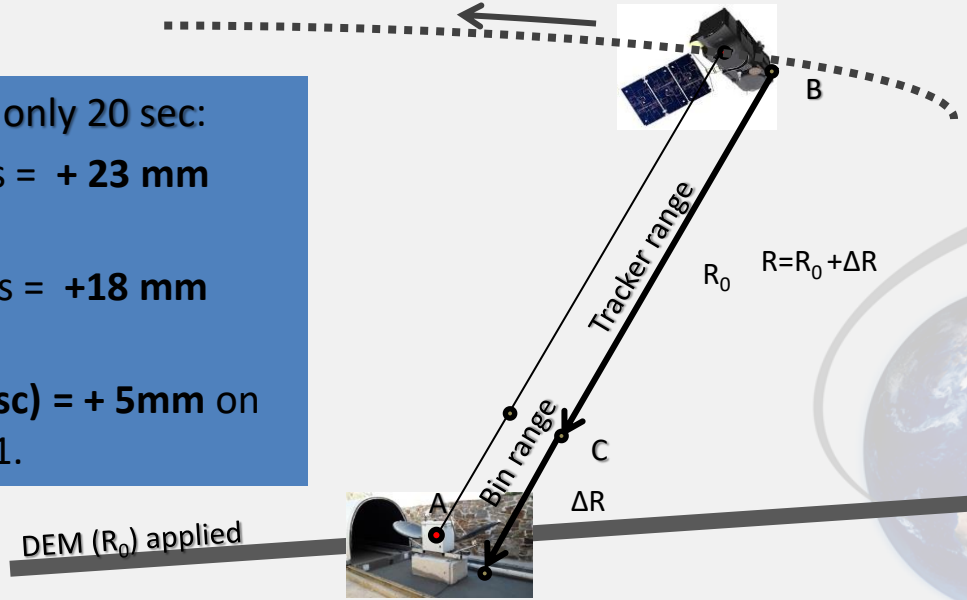




Black circles: Cross-over almost the same day,
Red star: Cross –over more than 2 days
Sentinel-3A measures SSH higher than Jason-3 by **+4 cm about**.

Simultaneous Sentinel-3A and Jason-3 over CDN1 Transponder

- On 11-Nov-2016 , separated only 20 sec:
  - Sentinel-3A : Range Bias = **+ 23 mm** (Ascending No. 14)
  - Jason-3 : Range Bias = **+18 mm** (Descending No. 18)
- Difference **S3A (Asc)-JA3(Desc) = + 5mm** on "simultaneous" pass @ CDN1.



Summary of Cal/Val

Sea-Surface Calibrations

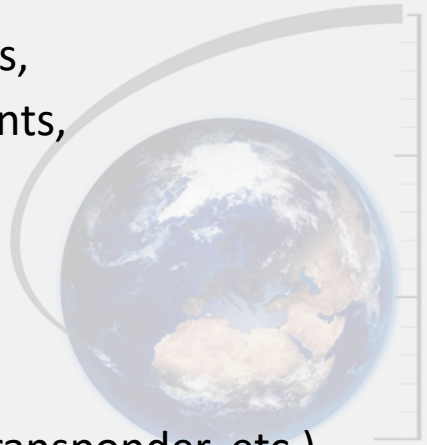
Satellite	Ascending	Descending	Average	Cycles
Jason-1	+28 mm	+50 mm	**+ 39 mm**	70-100
Jason-2	+7 mm	–23 mm	**-8.0 mm**	2-298
Jason-3	-30 mm	-32 mm	**– 33.5 mm**	1-24- Processing
Sentinel-3	+7 mm (No.14)	-4 mm (No.335)	**+1.5 mm**	5-26
Cross-Over	S3A and JA3		**+ 40 mm**	10 cycles

Transponder Range Calibrations

Satellite	Data	Descending	Year
JA-3(CDN1, Crete)	I-GDR, MOE	+ 29.0 mm	2016-2017
JA-3(CDN1, Crete)	GDR-D, POE	+ 23.0 mm	2016-2017
S3A (CDN1, Crete)	SAR, NTC	**+ 3 mm**	2016-2017
S3A versus JA3	20 sec apart	**+5 mm**	11-Nov-2016

Fiducial Reference Measurements 4ALT

- Gavdos/Crete: Permanent Altimeter Calibration Facility: Long-term : (1) Bias & drifts; (2) Biases among missions; (3) Connect different missions.
- To attain Fiducial Reference Standard:
  - Documented SI (Système international d'unités) traceability,
  - Independence from the satellite geophysical retrieval process,
  - Uncertainty budget for all FRM instruments and measurements,
  - FRM measurement protocols.
  - Specification of uncertainty budgets for:
    - Instrument measurements;
    - Cal/Val Methodology employed;
    - Algorithms, Models (geoid, MSS, dynamic topography, transponder, etc.).

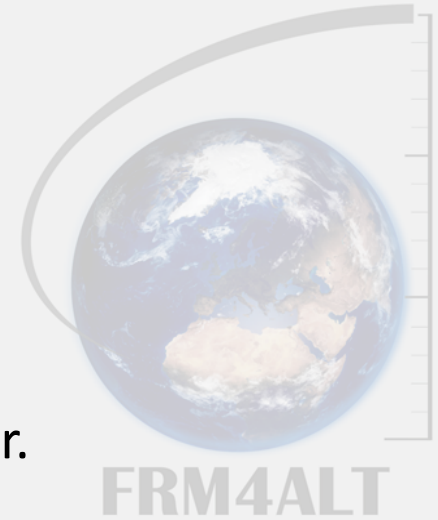


FRM4ALT Best Practices (1)

- Cal/Val Site Selection:
  - Protected harbor,
  - away from runoffs,
  - ground subsidence (harbor, buildings,…),
  - Deep sea (>200m),
  - Geoid, MDT, absolute gravity, circulation available,..
- Procedures:
  - Observations for 6 months before set up,
  - Equipment housing, protection, power, comms,..
  - Multiple pillars (3 GNSS, 3 TG, 2 meteo,..)
  - Unobstructed tie control and stability.

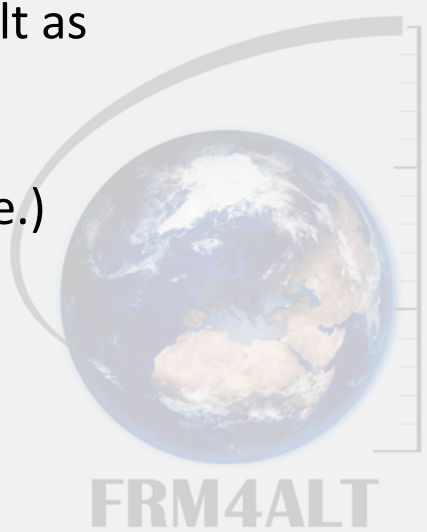
FRM4ALT Practices (2)

- GNSS Instrumentation:
  - At least two diverse type receivers and antennas,
  - Different positioning to produce final coordinates,
  - Characterize antennas every 2-3 yrs,
  - Sampling rates 30 sec,
  - Ring buffer for 2-3 days,
  - Backup instrumentation available.
- Ground Stability:
  - Monitor continuously,
  - 2-3 yrs before altimetry Cal/Val,..
  - Establish heights with uncertainty <± 0.5 mm/yr.



FRM4ALT Practices (3)

- Reference Frames:
  - Transform all coords into altimetry system,
  - Be in agreement with altimetry products (ITRF2014, ITRF2008, …),
  - Relation of Cal/Val site wrt MDT, Geoid, MSS, ... Difficult as absolute geoid height ±35cm ellipsoid.
- GNSS Processing:
  - Apply various techniques, strategies (DD, PPP, Iono free.)
  - Determine ellipsoid height with uncertainty,
  - Any differences more than ±2 mm, reconsider,
  - Final Cal/Val site coords in tide-free wrt satellite orbit,
  - Reprocess GNNS data every 6 months.



Uncertainties on FRM Standards

Standard Uncertainty	Uncertainty Estimates (a)	Divisor (b)	Standard Uncertainty (c)=(a)/(b)	Sensitivity coefficient (d)	Uncertainty components (e) = (c) x (d)	Degrees of freedom
GPS Height Processing [A]	0.14 mm	1	0.14mm	1	0.14 mm	1759
GPS Receiver Manufacturer	6.0 mm	√3	3.5 mm	1	3.5 mm	50
GPS Antenna Reference Point – Lab Calibration	2.0 mm	1	2.0 mm	1	2.0 mm	∞
Water Level Observations	1.3 mm	1	1.3 mm	1	1.3 mm	19
Tide Gauge Zero Offset	5.0 mm	√3	2.9 mm	1	2.9 mm	2
Tide Gauge Vertical Misalignment	2.4mm	√3	1.4mm	1	1.4mm	50
Tide Gauge Calibration Certificate	5.5 mm	1	5.5mm	1	5.5 mm	∞
Spirit Levelling [Type-A]	0.13 mm	1	0.13 mm	1	0.13 mm	15
GPS & Tide Gauge Thermal Expansion (Monument)	1.1mm	√3	0.6 mm	1	0.6 mm	50
Spirit Levelling Target Misalignment [Type-B]	1.0 mm	√3	0.6 mm	1	0.6 mm	50
Observers' Experience	1.0 mm	√3	0.6 mm	1	0.6 mm	50
Spirit Levelling Instrument	1.0 mm	√3	0.6 mm	1	0.6 mm	∞
Water Level at Tide Pole	1.0 mm	√3	0.6 mm	1	0.6 mm	∞
MSS/GEIOD Models	5.8 mm	1	5.8 mm	1	5.8 mm	8
Cal/Val Processing & Transformations	0.5 mm	√3	0.3 mm	1	0.3 mm	50
Geoid Slope	10.0 mm	√3	5.8 mm	1	5.8mm	50
Unaccounted Uncertainty (Geoid ,N, MDT,..)	50.0 mm	√3	5.8 mm	1	5.8mm	50
Root of Sum of Squares [RSS]	52.0 mm	√3	28.8 mm	1	28.8mm	50

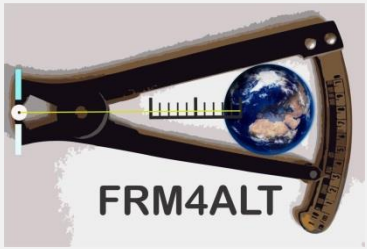
Acknowledgements

Support provided by:

- ESA/ESTEC [Craig Donlon],
- ESA/ESRIN [Pierre Féménias],
- EU-Copernicus,
- CNES [T. Guinle, F. Boy].

Next Month in Crete

- **International Cal/Val Altimetry Review & Applications Workshop,**
  - **23-26 April 2018 in Chania, Crete, Greece.**



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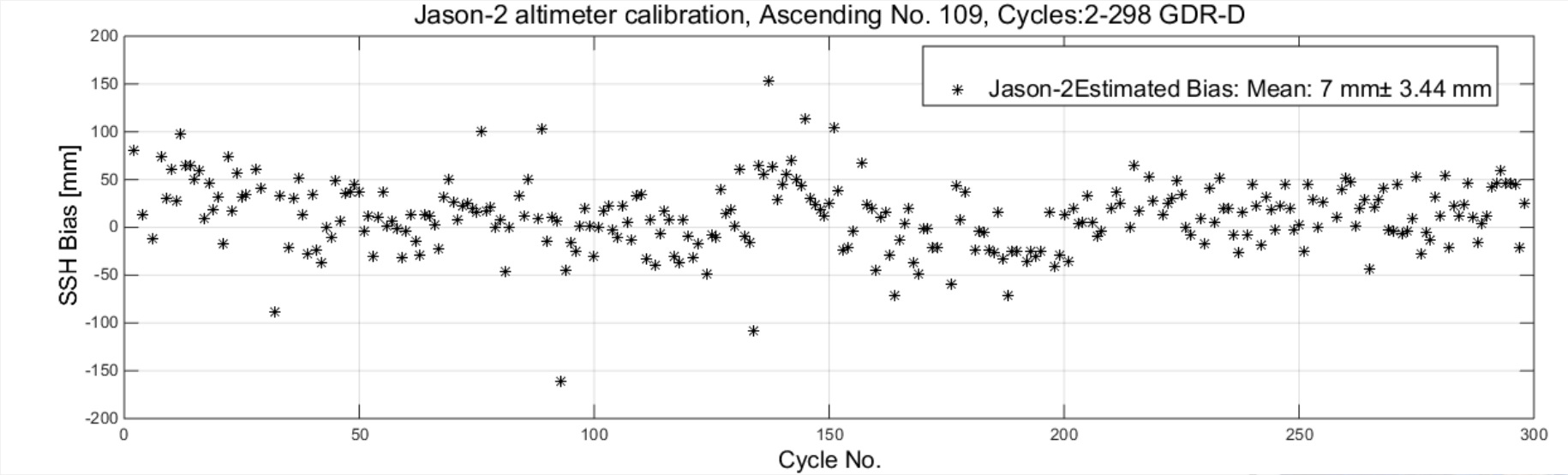
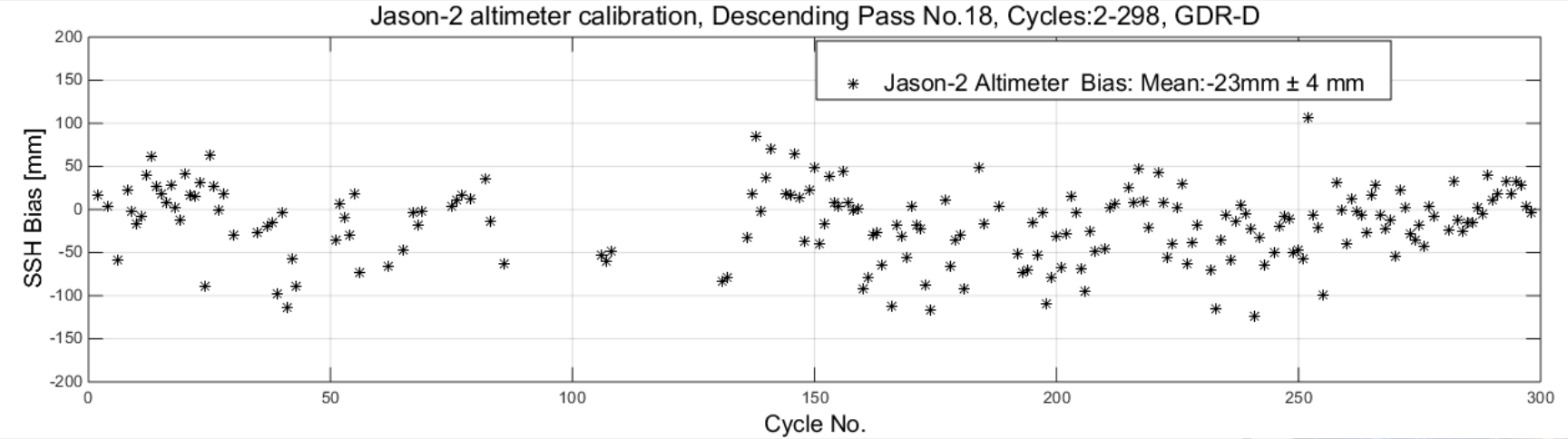
Back-Up slides

Jason-2 Ascending Pass No. 109



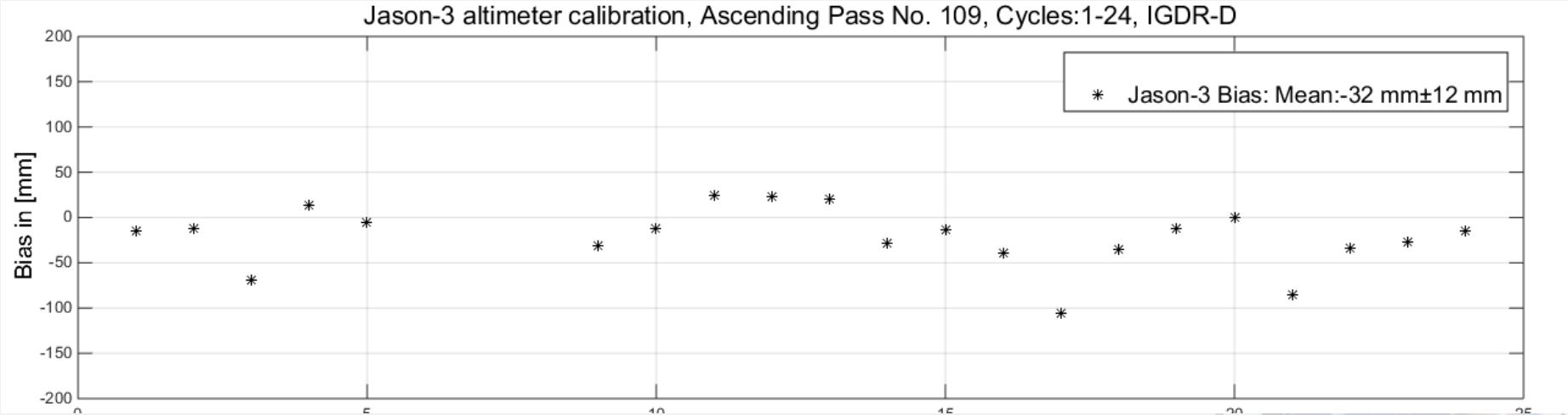
- Ascending Pass No.109, GDR-D , Cycles: 2-298;
- Calibration region **14.5km-24 km;**
- **Bias= +7 mm** ±3 mm, using local gravimetric geoid model;

Jason-2 Descending Pass No. 18



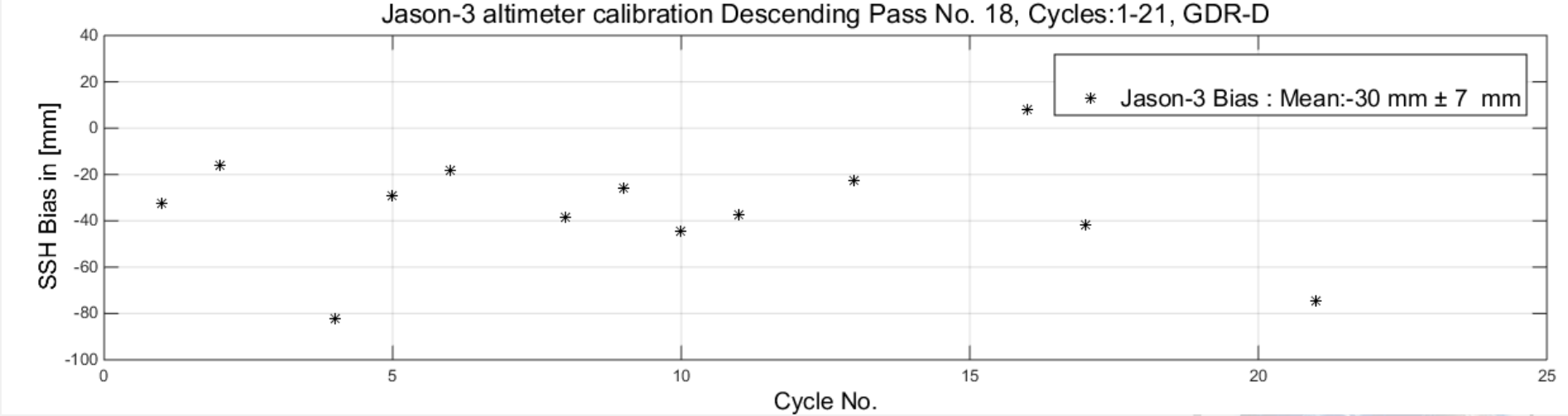
- Descending Pass No. 18, GDR-D , Cycles: 2-298;
- GOCE dynamic topography; Cal region **9km-20 km**;
- Bias= **– 23 mm** ± 4 mm

Jason-3 Ascending Pass No. 109



- Ascending Pass No.109, IGDR-D , Cycles: 1-24;
- Calibration region **14.5km-24 km;**
- **Bias= -32 mm** ± 12 mm, using local gravimetric geoid model;

Jason-3 Ascending Pass No. 18



- Descending Pass No.18, IGDR-D
- **Bias= -30 mm** ±7 mm, using local gravimetric geoid model;

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