Radar altimeter absolute range measurements: status and performance achieved with corner reflectors

Ferran Gibert[1], Adrià Gómez-Olivé[1], Joel Grau Bellet[2], David Gómez Rodríguez[2], Albert Garcia-Mondéjar[1], Adrián Flores de la Cruz[1], Sergi Hernández Burgos[1], Mònica Roca i Aparici[1]

1. isardSAT

2. ICGC

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Who we are

- Founded in 2006 in Barcelona, specialised in signal processing for Earth Observation.
- Focus on microwave remote sensing from space: radar altimeters, radiometers, scatterometers, SAR.
- Development of algorithms, implementation of ground segment operational processors, performance analysis & monitoring, calibration, validation, applications.
- Participation to all mission cycle (from Phase 0 to regular operation)

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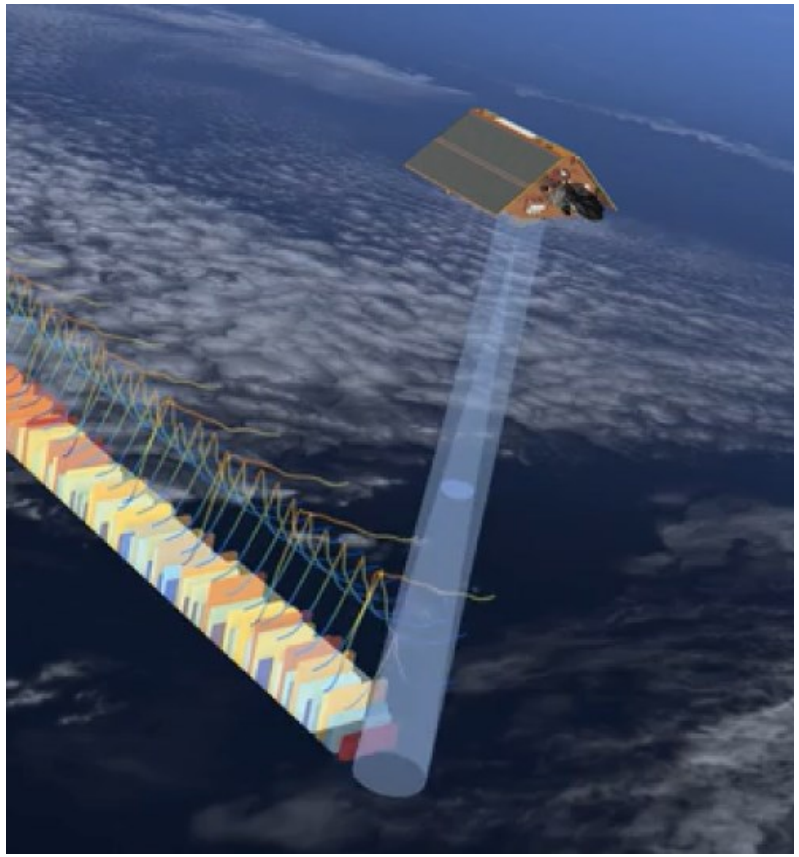
Outline

- Review of satellite radar altimetry
- Absolute range measurements with corner reflectors
- Synergy with geodesy

What is a space-borne radar altimeter?

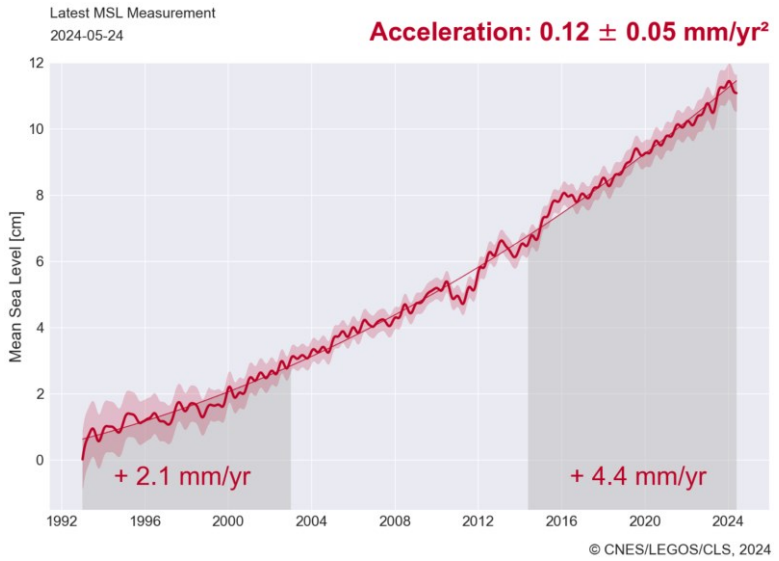
- A nadir pointing radar onboard a satellite.
- Microwave bands: Ku, Ka, C
- Altitude: 700-1300 km
- Post-processing to generate geolocated waveforms
- Geophysical corrections to path delay
- Range precision ~1cm.

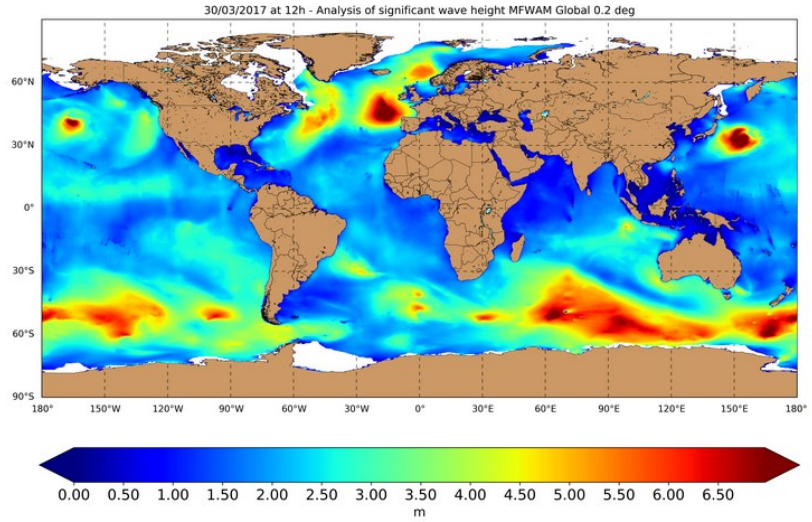
ESA altimeters: Cryosat-2, Sentinel-3 A/B, Sentinel-6, …

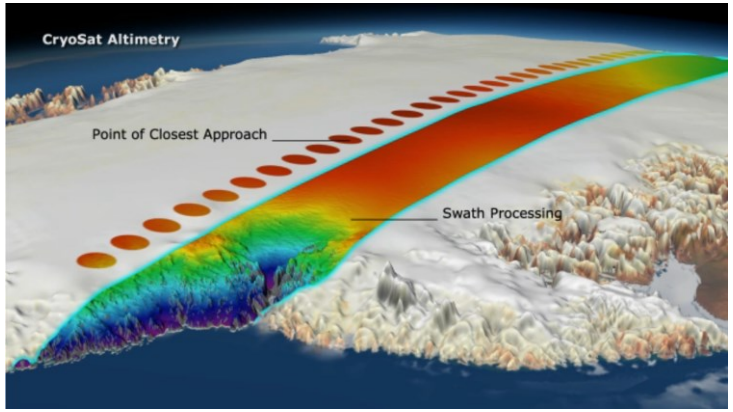


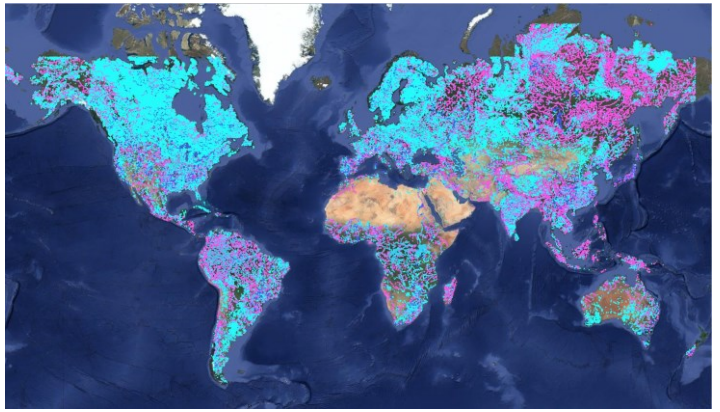
Satellite radar altimetry

- Climate
- Oceanography
- Weather forecast
- Cryosphere
- Hydrology



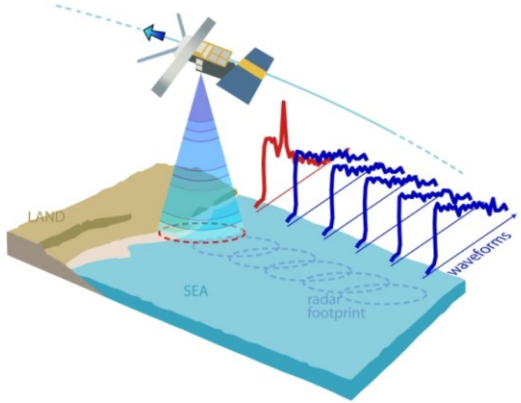


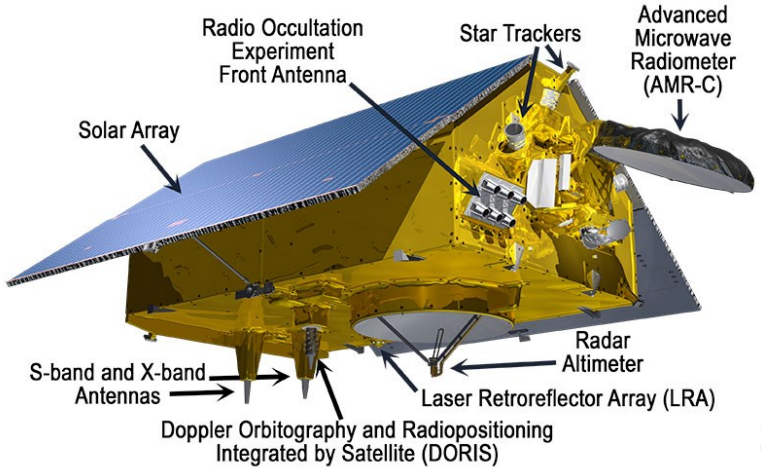




Processing

- Different processing methods allow to generate waveforms with different along-track resolution.
- Over ocean: range, wind speed and significant wave height can be retrieved.
- Need to correct range for geophysical path delay effects. Among others:
  - Ionosphere: C/Ku-band difference (only reliable over ocean)
  - Dry & wet tropo: radiometer onboard (not always).





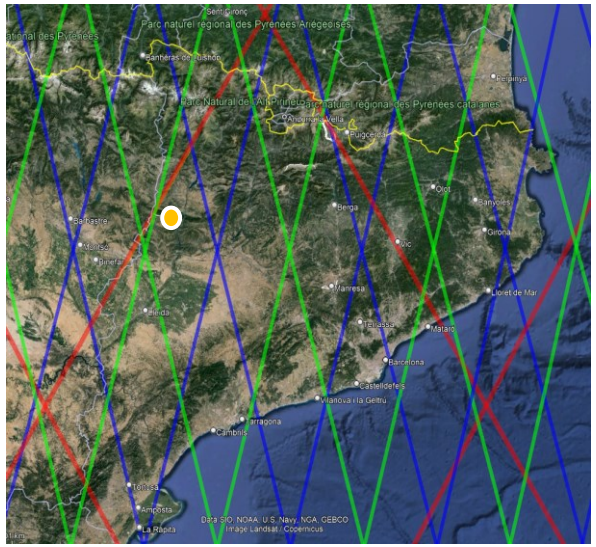
Corner reflectors for radar altimetry

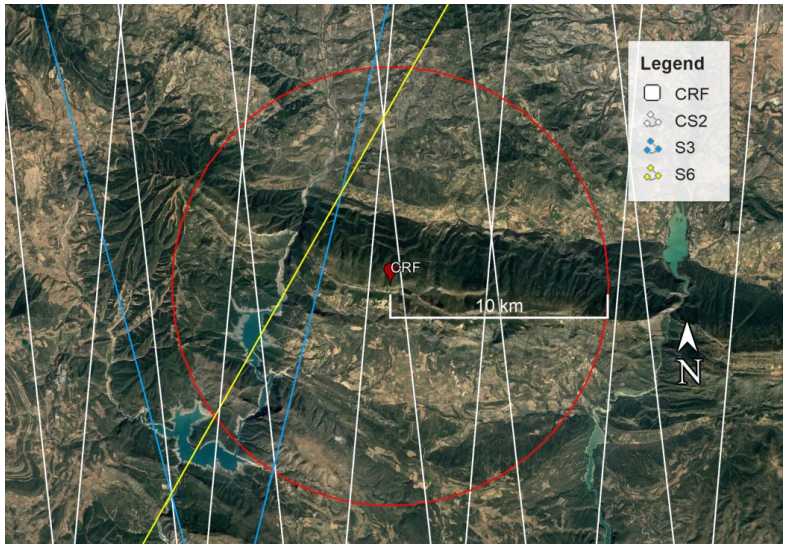
- External calibration over point targets required to ensure proper system performance.
- Corner reflectors as point target elements used in SAR since decades.
- In radar altimetry, not feasible because of too high SCR associated with classic processors (LR and HR delay-Doppler algorithms).
  - Active transponders typically used instead (Svalbard, Crete…).
- With the advent of **Fully-Focused SAR** (FFSAR, Egido & Smith 2017), such a scenario changed:
  - Now ~1m-size passive reflectors should be clearly observed!
  - First unsuccessful attempts in 2019 with CS2.
  - isardSAT starts planning one in 2020.

External calibration by means of corner reflector

Location chosen?

- Prominent site, low clutter environment,
- Site selected: Montsec Astronomical Observatory
- Close to ground tracks of Sentinel-3B, Sentinel-6, and Cryosat-2.

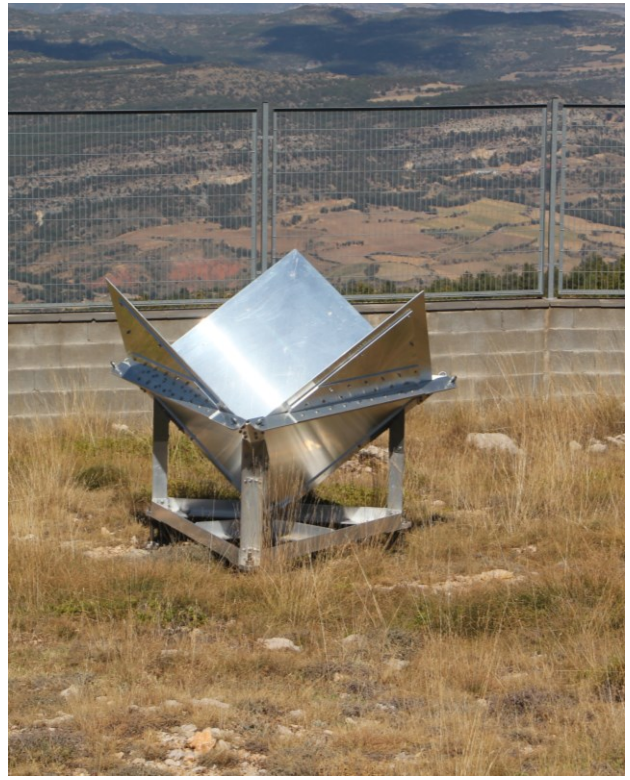




The Montsec corner reflector

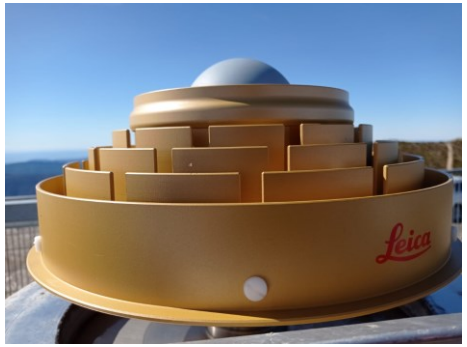
- Installed in April 2021.
- Grounded directly to mountain base rock.
- Successful measurements since September 2021.

	CR Montsec
Material	Aluminium
Weight	~ 500 kg
Length	1.4 m
Shape	Trihedral Square sides
RCS	54 dB



What about geophysical corrections?

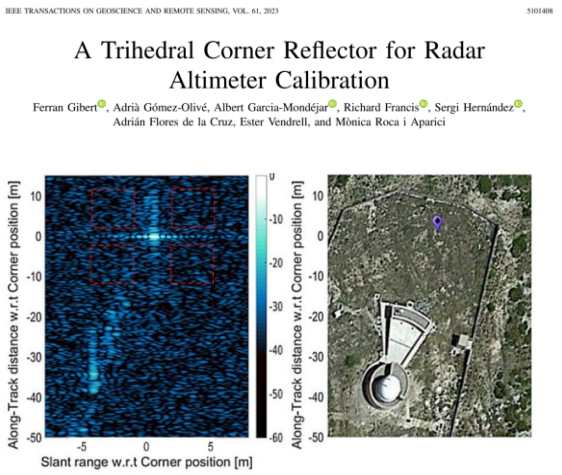
- No (good) measurements of tropo / iono path delays available as we are far from the sea.
- Need to look for alternatives
  - Ionospheric path delay: L2 products
  - Wet & Dry tropospheric: L2 products until installation of GNSS station in July 2023 (ICGC-ARES)
- Collaboration with ICGC on high rate tropospheric corrections ZTD and corner vertex determination.
- Other effects considered: solid Earth tide, ocean loading tide, pole tide (from L2 products)

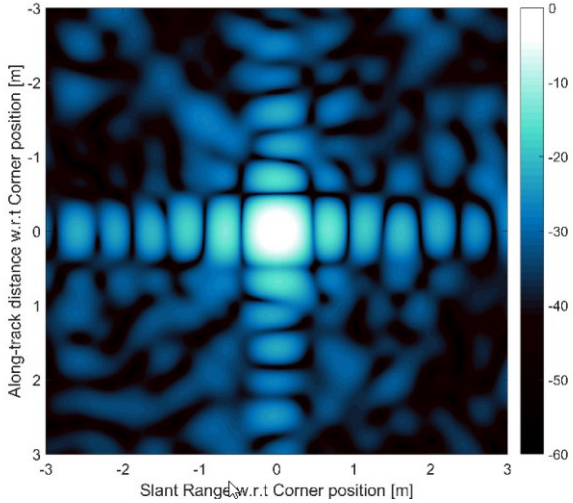


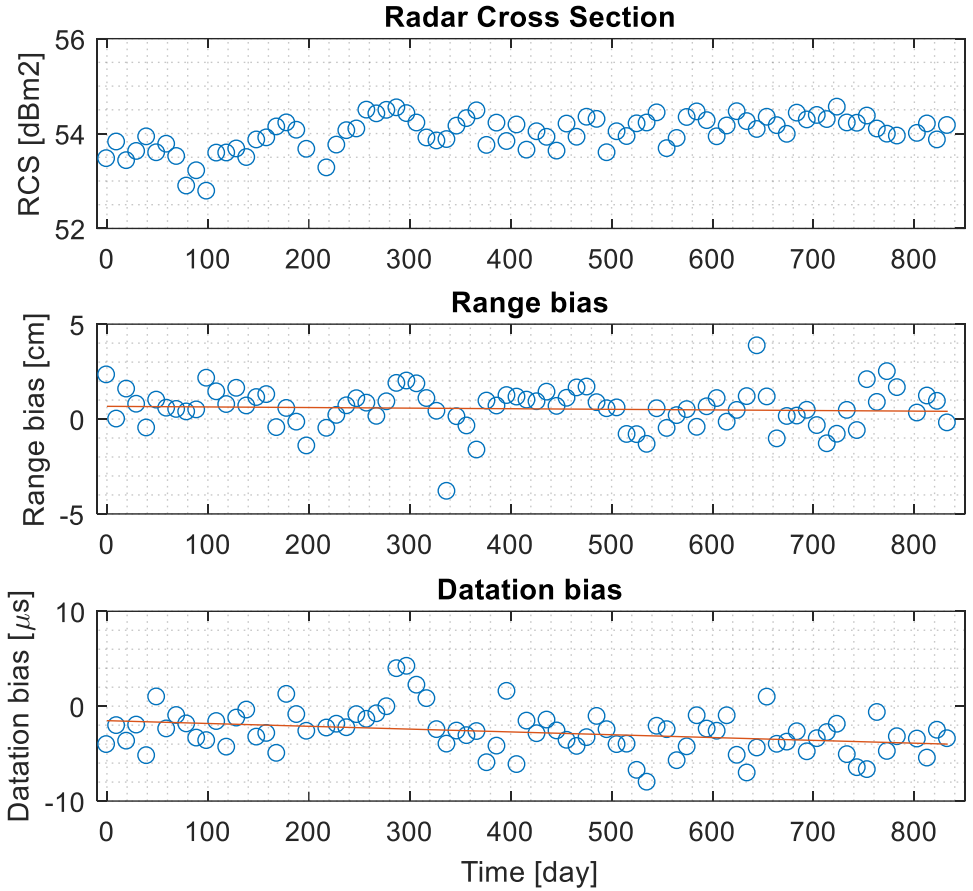
External calibration by means of corner reflector

Results

- More than 2.5 years of Sentinel-6 passes
  - 10-day repeat period
- Long term series of range, along-track displacement (datation) and reflector Radar Cross Section (RCS).







Performance

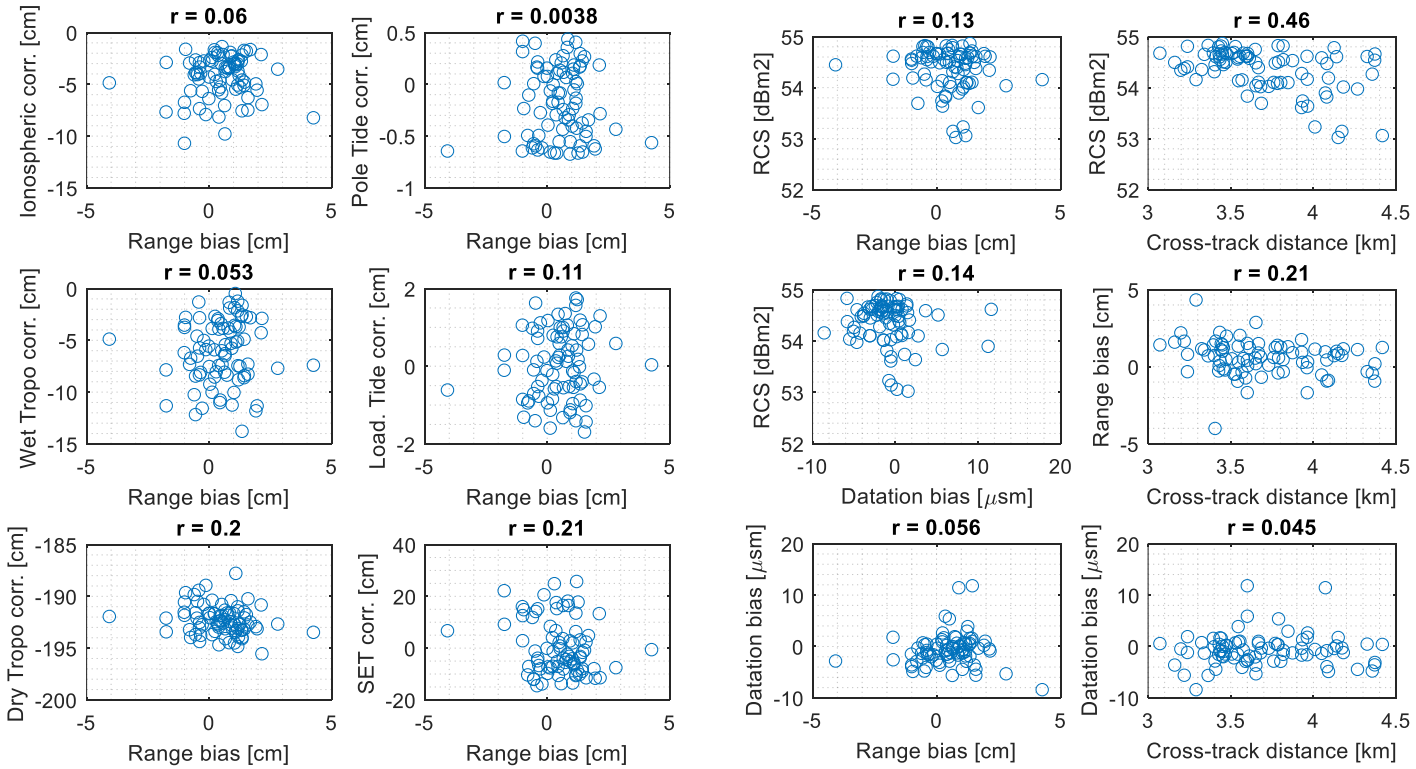
- Comparable results with respect to active transponders
  - Range bias of 3 mm with std of 9 mm.
  - Datation bias of -2.8 us with std of 2.3 us (-16 mm and 13 mm respectively)
- Corner reflectors have been validated as accurate tools for radar altimeter calibration.
- Benefits of GNSS-based tropospheric corrections demonstrated.

Sentinel-6 MF		Corr. GEO: L2		Corr. GEO: GNSS station ARES	
Period	***#Obs***	***Mean***	***STD***	***Mean***	***STD***
Sep 2021 – Apr 2024	89	5.3 mm	11 mm	--	--
Jul 2023 – Apr 2024	26	5.9 mm	12 mm	**2.9 mm**	**9 mm**

External calibration by means of corner reflector

Cross-correlation analysis

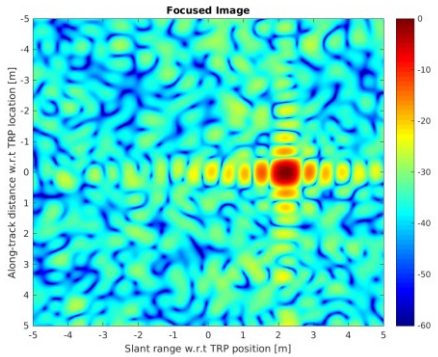
- Residual noise associated to geophysical corrections noise and residual geometry effects.



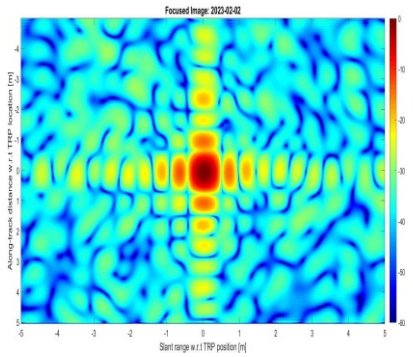
External calibration by means of corner reflector

As of today,

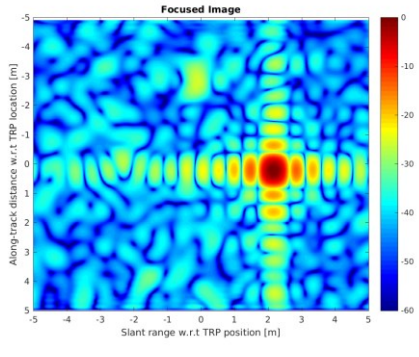
- Three altimeters under regular monitoring:



S6A - 4 km



S3B - 3 km

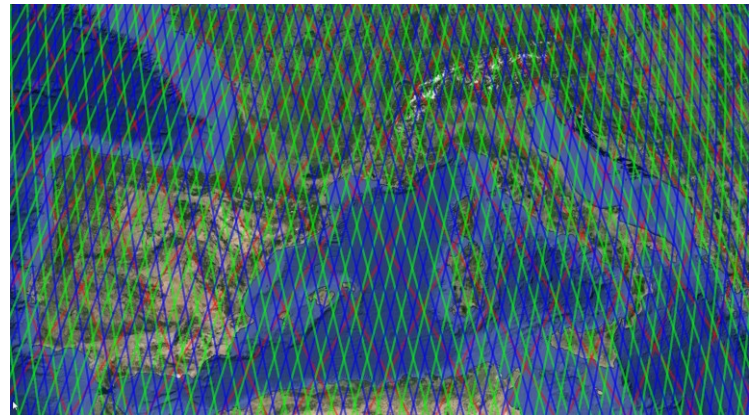


CS2 - 3.8 km

- Preliminary: S3B Asc/Desc: range std of 7-8 mm (16 passes).
- Included as one of the reference calibration facilities for the upcoming CRISTAL mission.

Summary of requirements

- CR size: 1-2 m side length.
- Site requirements:
  - Relatively far from flat areas in cross-track and vertical dimensions.
  - No further than 10-15 km from radar altimeter ground tracks.
  - Possibility to test feasibility before installation.
- Radar altimeter configured to capture the position of the reflector.
- Cheap and almost no maintenance.
- Deployable almost anywhere.



Can radar altimeters provide useful measurements for the ITRS/ETRS community?

- Radar altimeters can provide absolute range measurements to corner reflectors from platforms equipped with GNSS, SLR and DORIS.
  - Also: absolute horizontal position in along-track (eq. to datation)
  - Platforms at Low-Earth orbits (800-1300 km)
  - Range Bias < 5 mm, std < 10 mm,
  - Residual noise & bias still under investigation (margin for improvement)
  - Periodicity: ~weekly, depending on number of altimeters tracked

Complementary to facilities equipped with SLR/GNSS?

What target precision should be achieved?

Thank you for your attention!

isardSAT®

C/ Doctor Trueta, 113, 1r
08005 Barcelona

Surrey Research Park
40 Occam Road
Guilford, Surrey GU2 7YG, UK

+ 34 93 350 55 08
info@isardSAT.cat
https://www.isardsat.cat/

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