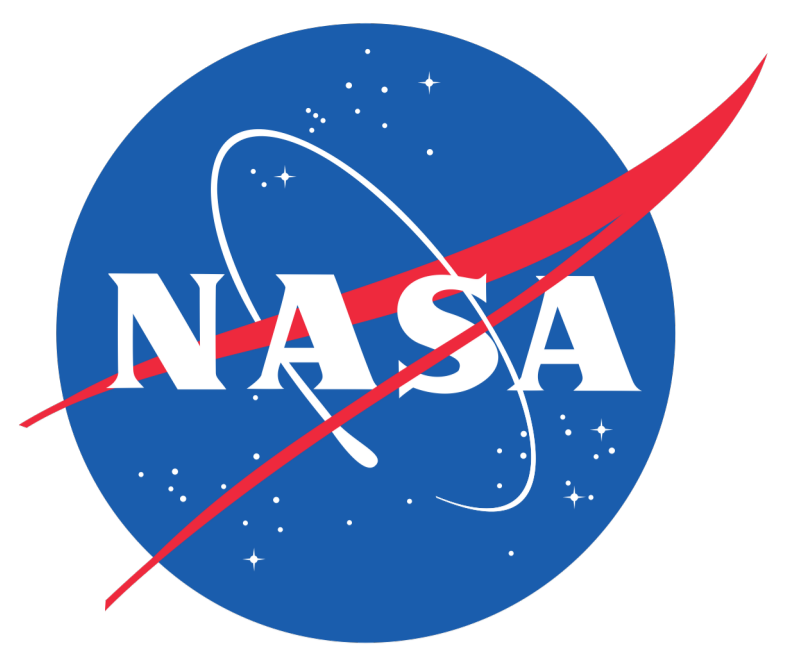# A Transponder for Calibrating Altimeters in Ku-band and C-band

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Summary

- NASA/JPL has developed a dual band transponder to calibrate radar altimeters in both Ku and C band.
- The transponder was first operated at JPL for development and test while supporting the Sentinel-6 vs Jason-3 intercalibration.
- Transponder was then installed at its permanent site on Catalina Island, California on October 27th, 2021.
- Currently routinely operated for Sentinel-6, Sentinel-3 and SWOT (nadir) missions. Also operated with Jason-3 before it moved to interleaved orbit.
- Transponder has been designed to allow calibration of range, sigma0 and time tag bias.

Transponder Operations

- For test and validation, the transponder (TRP) has been first operated at JPL with Sentinel-6 (S6) and Jason-3 (Ja3).
- Now installed on Catalina Island (around 30km off the coast, South-West of Los Angeles) and hosted by the Wrigley Institute (University of Southern California). Located 2.7km west of the Sentinel-6 reference ground track.
- Routinely operated with S6 (Since November 14th, 2021).
  - S6 using DEM mode starting cycle 50 (allowing for SAR products generation).
- Routinely operated with Sentinel-3 (Since April 14th, 2022).
- Routinely operated with SWOT (Since Oct 11th, 2023).

Transponder Location

Site	JPL	Catalina
S6 cycles	12 - 32	37 - current
Latitude	34.201676346°	33.446692629°
Longitude	-118.174087846°	- 118.479718873°
Height above Ellipsoid (WGS84)	365.6723m	35.4125m
		!!! Height updated from last year !!!

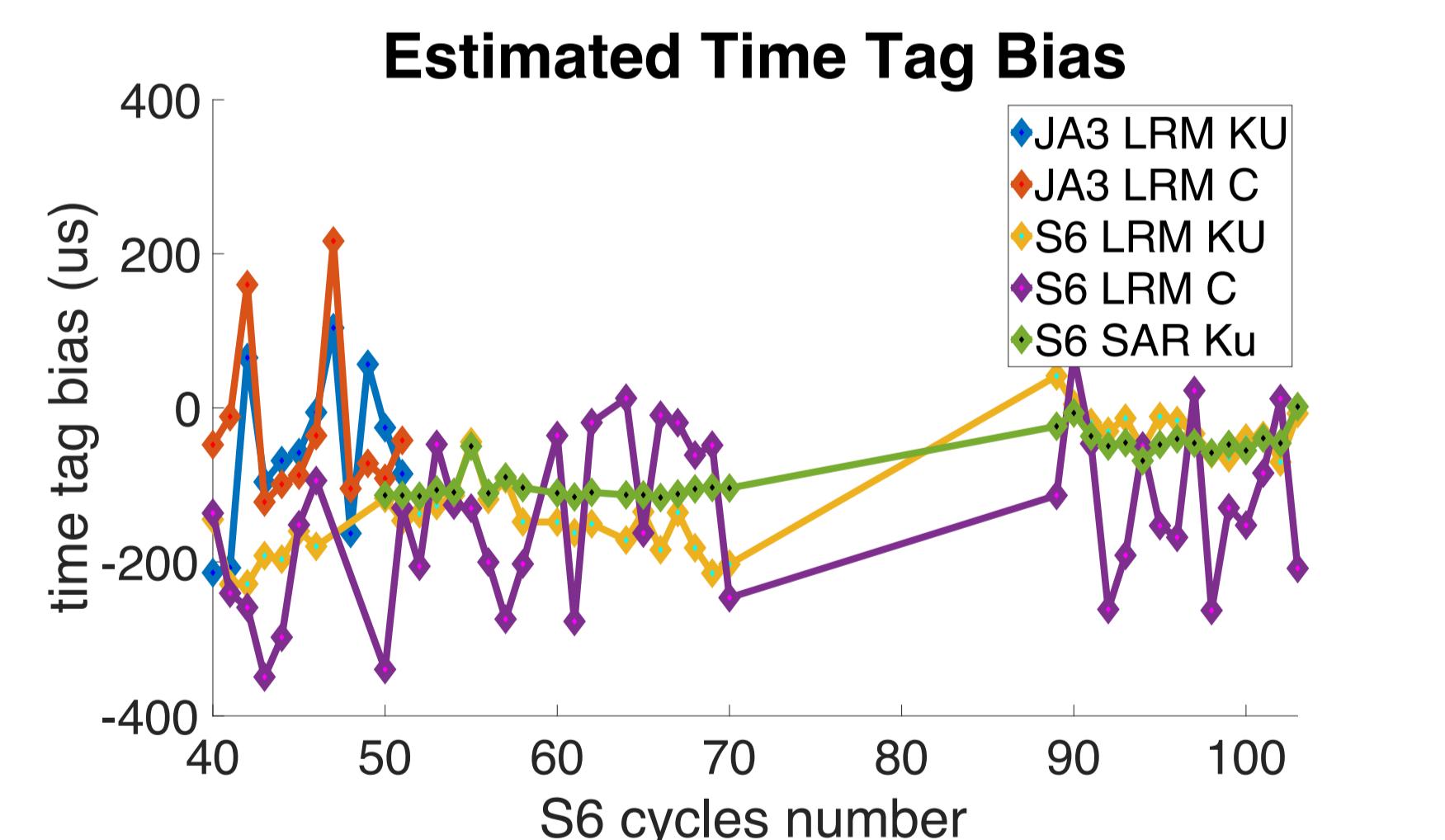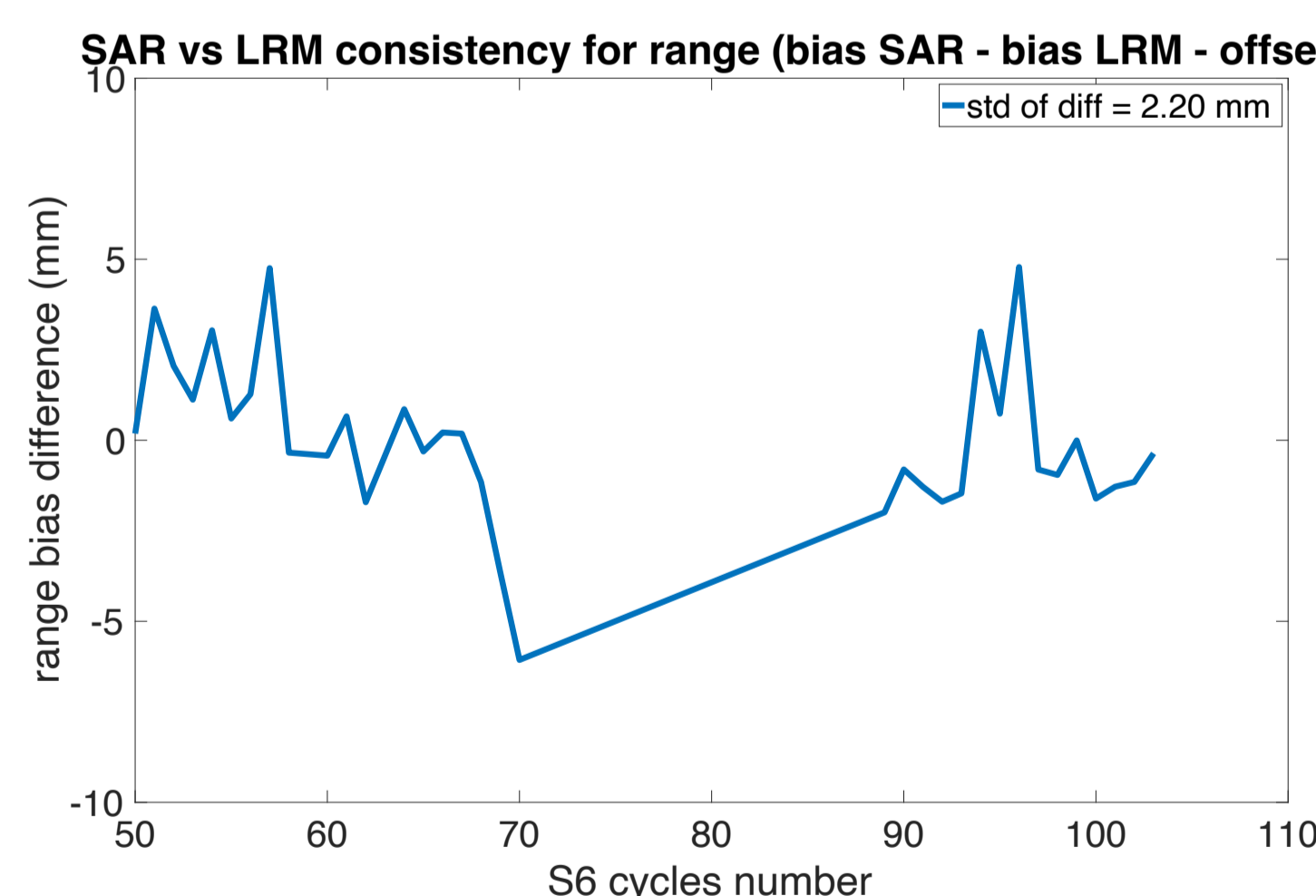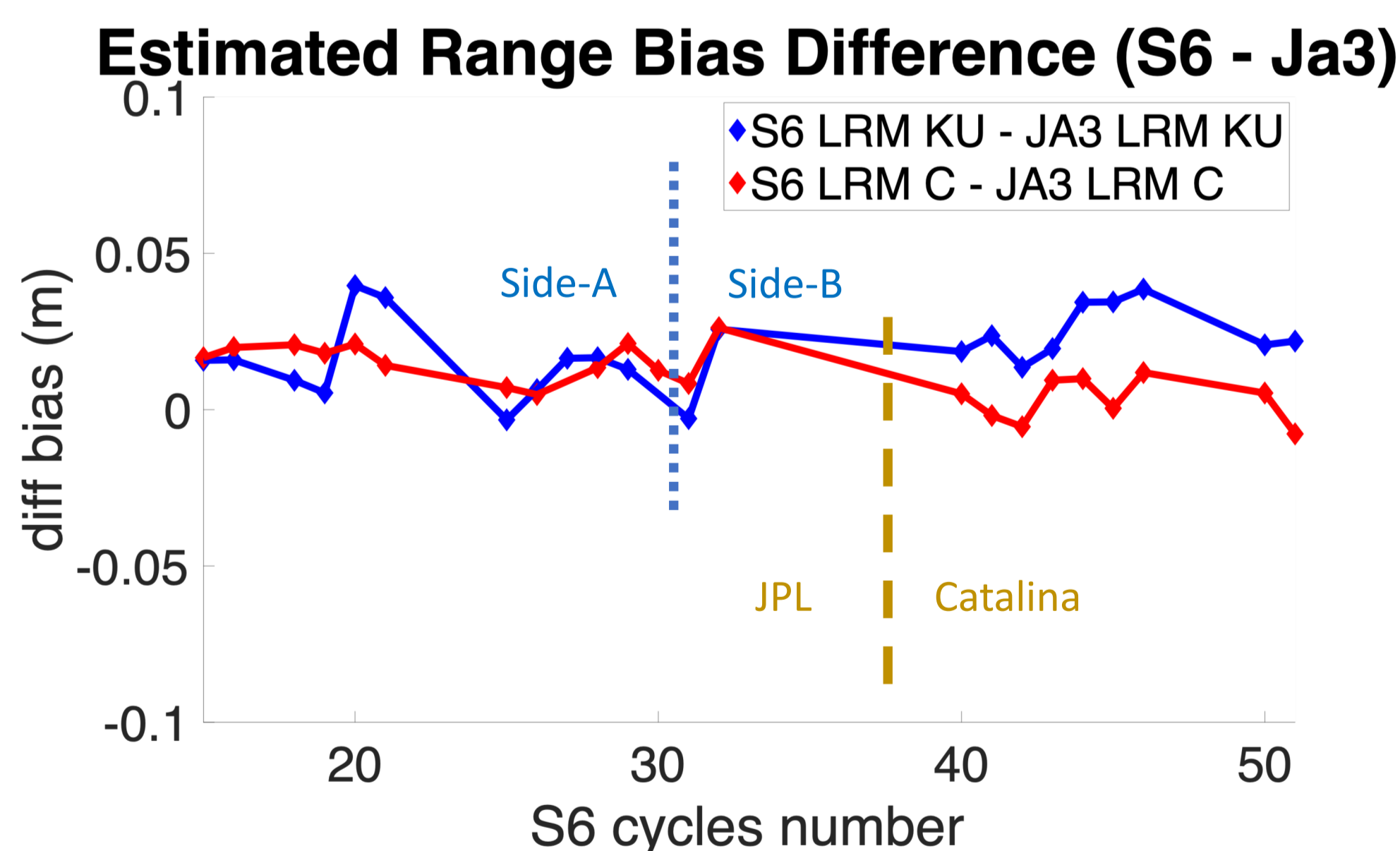| S6 cycle	Event Date	Event Description
12	March 11th, 2021	First TRP activation on JPL site (Off Track configuration and altimeter in TRP mode). Low gain for C-band (~70dB).
13	March 21st, 2021	C-Band gain increased by 9 dB (~79dB)
14	March 31st, 2021	C-Band gain increased by 3 dB to reach nominal gain (~82dB)
15	April 7th, 2021	Jason-3 DEM updated for TRP @ JPL (i.e.: beginning of Ja3 TRP acquisitions over JPL)
18	May 5th, 2021	Jason-3 DEM optimized for improved TRP signal centering
22 to 24		TRP not operational
25 to 27		Ku-Band gain reduced by 3dB for investigations
31	Sept 14th, 2021	S6 switch to altimeter side-B chain
33 to 36		TRP transfer to Catalina (not operational). Installation completed on Oct 27th, 2021
37	Nov 14th, 2021	First S6 TRP acquisition on Catalina Island (altimeter in TRP mode).
37 to 39		TRP echoes (numerical) saturation
40	Dec 09th, 2021	Ja3 DEM updated for Catalina (i.e.: beginning of Ja3 TRP acquisitions over Catalina)
40	Dec 14th, 2021	S6 Altimeter gain optimized for Catalina acquisitions.
47 to 49		S6 satellites operations suspended over Catalina (TRP remained activated)
50	March 15th, 2022	S6 OLTC update and beginning of TRP acquisitions in open loop (allowing for SAR data availability)
51	April 2nd, 2022	Last TRP acquisition with S6 and Ja3 in tandem phase before Ja3 moved to interleaved orbit
52	April 14th, 2022	First TRP calibration with Sentinel-3
55	May 11th, 2022	TRP not activated for S3 due to conflict with S6 same day flyover
63	July 30th, 2022	TRP outage
71 to 88		TRP unavailable: TRP outage and retrofit for better power management (re-installed on April 6th, 2023)
89	April 13th, 2023	Restart of TRP activations on Catalina Island
92	May 09th, 2023	S6 OLTC updated to optimize TRP acquisitions over Catalina
104	Sept 13th, 2023	First TRP activation with SWOT satellite (detection of TRP signal while altimeter tracking oceans)
107	Oct 11th, 2023	First TRP activation with SWOT satellite and altimeter in Diode/DEM Mode (beginning of TRP acquisitions)

Processing and Results

- Processor developed for SAR and LRM mode echoes to support consistent intercalibration between S6 and Ja3
- Dataset : S6: PDAP F08 NTC. Ja3 : GDR-F
- LRM Processing is based on iterative simulations of 20 Hz echoes and comparison with echoes measured by altimeter. (Allows Range and Time Tag bias evaluation. Sigma0 calibration functionality has not been implemented yet)
- Propagation corrections:
  - *Dry Troposphere Delay* is corrected for transponder altitude
  - *Wet Troposphere Delay* is derived from continuous GPS measurements
  - *Ionosphere Delay* is derived from Global Ionosphere Model (GIM) data as provided in S6 products (correction expected to be derived from GPS in the future).

Estimated Range Bias

Estimated Range Bias Iono correction comparison
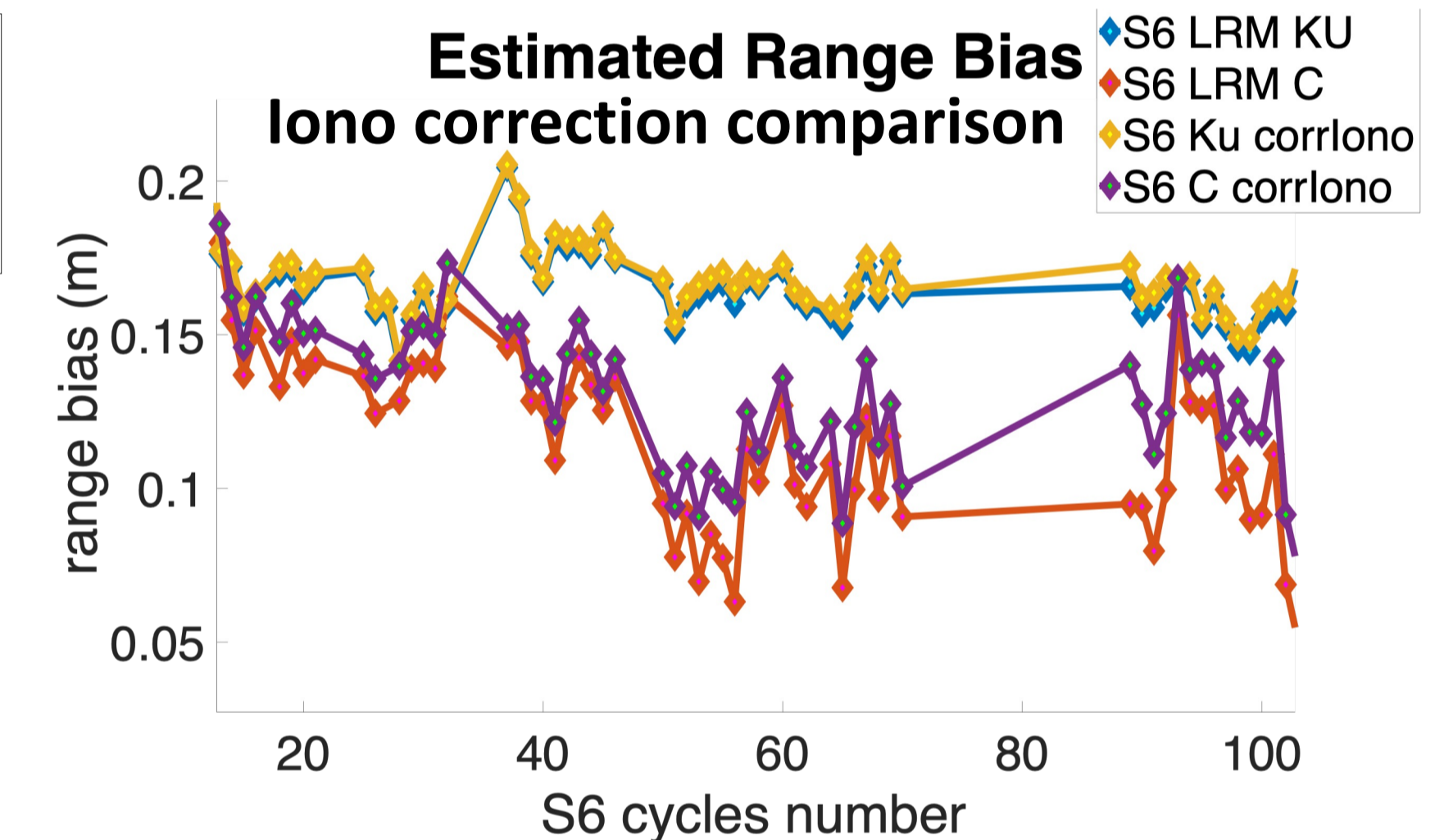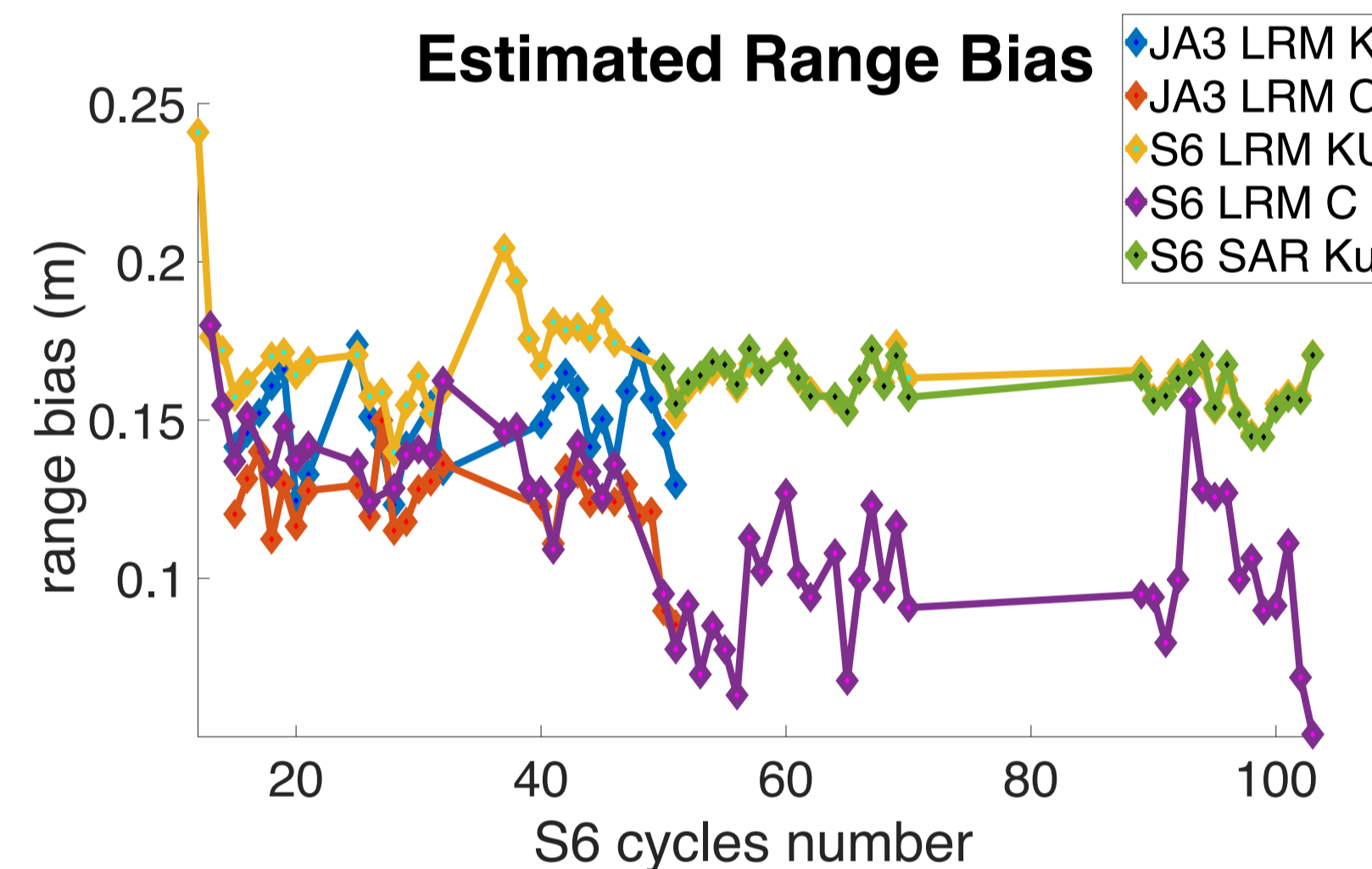
Using the latest version of the TRP position and delay correction, the agreement for Ku-Band between calibrations at JPL and on Catalina is now better than 1cm.
The agreement between LRM and SAR range bias estimations (available since cycle 50) is very good (std ~ 2mm). Note: a bias is applied on SAR to compensate for TRP main lobe distortion.

Applying an updated factor 0.881[*] (corrIono), instead of the original 0.925 (used in S6 products) to the GIM model corrections, range bias estimation stability is slightly improved for C-band.
[*]Dettmering and Schwatke [2022]

Estimated Range Bias Difference (S6 - Ja3)

SAR vs LRM consistency for range (bias SAR - bias LRM - offset)

Estimated Time Tag Bias

The time tag bias estimations for S6 are consistent with the altimeter antenna position. After retrofit the time tag bias is unexpectedly closer to 0 for Ku-band (under investigations)

Results table

Range Bias Difference (S6-Ja3)	mean (cm) Side-A / Side-B	std (cm) Side-A / Side-B
LRM Ku-band	-1.56 / -2.50[1]	1.26 / 0.87
LRM C-band	-1.54 / -0.30[1]	0.56 / 0.70
Time Tag Bias	**Mean (us)**	**Std (us)**
S6 LRM Ku-band	-154[2]	40
S6 LRM C-band	-166[2]	107
S6 SAR Ku-band	-111[2]	3.6

[1] Side-B range bias difference estimated on Catalina Island only (cycles 40 to 51)
[2] The relative position of the altimeter antenna vs satellite Centre Of Mass generates a bias of ~ -130us for S6. Data used from S6 cycles 40 to 70.

Conclusions

- **First transponder for dual band altimeter calibration**
    -> Useful for ionosphere correction validation
- **Catalina site allows for intercalibrating S6 with S3 and SWOT altimetry missions.**
- **Results demonstrate good performance in evaluating range bias both for the intermission comparison and for long term stability.**
- **Use of SAR appears promising and the excellent consistency with the LRM results confirms the simulation approach allows for good range bias estimation quality in LRM.**
- **Some investigations in progress for results after TRP retrofit**

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