# On-ground processing and performance of the Poseidon-4 altimeter internal calibration: chirp replica and attenuator

Michele Scagliola[1], Lisa Recchia[1], Alessio Izzo[1], Andrea Recchia[1], Marco Fornari[2], Robert Cullen[3], Luisella Giulicchi[3]

(1) Aresys, Via FLUMENDOSA, 16, 20132 Milano, Italy (Contact: andrea.recchia@aresys.it)
(2) RHEA for ESA, Noordwijk, the Netherlands
(3) European Space Agency ESA/ESTEC, Keplerlaan 1, 2201, AZ, Noordwijk, the Netherlands

## Abstract

The main payload of Sentinel-6 Michael Freilich is a dual-band (Ku and C) pulse-width limited radar altimeter, called Poseidon-4, that transmits pulses at a high pulse repetition frequency thus making the received echoes phase coherent and suitable for azimuth processing. Among the different unique characteristic of Poseidon-4, it is worth recalling that digital pulse range compression is performed on-board to transform the received chirp using a matched filter. Thus, a proper calibration approach has been developed, including both an internal and external calibration. In particular, this abstract presents the long-term monitoring of the internal calibration data for chirp replica and for attenuator that are processed on ground by ad-hoc tools provisioned by Aresys to ESA:

- CAL1 INSTR: This mode measures the internal instrument transfer function in Ku band and in C band. The results of these measures can be taken into account at Digital compression level in the chirp replica (f) to optimize the impulse response of the instrument.
- CAL ATT: Since amplification gain control knowledge directly impacts the σ0 measurements, an attenuation calibration is included in the design. This measures the top of the range impulse response within the full attenuation dynamic range that is then matched to a corresponding value on ground.

The performance of Poseidon-4 altimeter is here presented by analysis of the long-term monitoring of the on-ground processed data from CAL1 INSTR and CAL ATT calibration sequences commanded on board. The analysis of such calibration data allows to verify that the instrument has reached the requirements and that it is maintaining the key performance over its life. Moreover, in-depth analysis of the calibration data revealed how the instrument depends on its temperature and on the orbit of the satellite.

## Chirp Calibration Tool

The Chirp Calibration Tool is aimed at analysing the internal instrument transfer function for the Radar Altimeter Chirp using the CAL1 INSTR mode measurements and at providing accordingly a compensated chirp replica. The principle of the CAL1 internal calibration is to perform measurements by looping back the Tx chain directly to the Rx chain through a dedicated path in the duplexer of the RFU. The CAL1 INSTR signal includes the Tx and Rx chains distortions in amplitude and phase and it can be used to take into account (or compensate for) these distortions into the replica, in order to have the best matched filtering.

- The Chirp Calibration Tool takes as input a CAL-1 INSTR level 0 file and computes the corresponding Instrument Transfer Function. The chirp replica contained in the Radar Data Base (RDB) is then used to compute the Range Impulse Response (RIR), including all the Tx and Rx chains distortions in amplitude and phase, and a complete set of quality parameters is computed in order to allow for RIR monitoring over time. Finally, by making use of the ideal instrument chirp, a compensated chirp replica is computed and annotated in the output file.

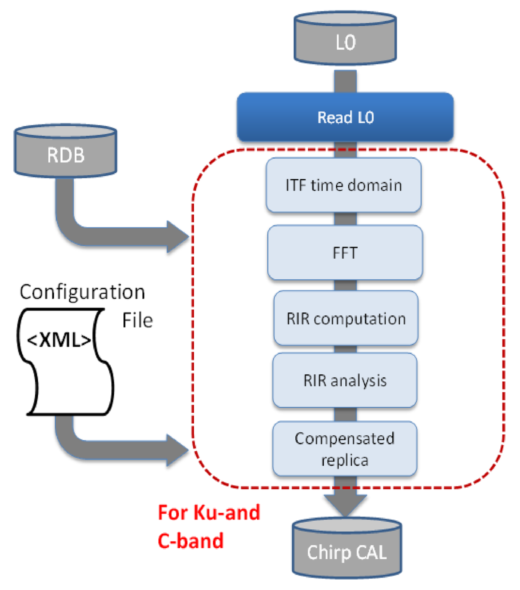
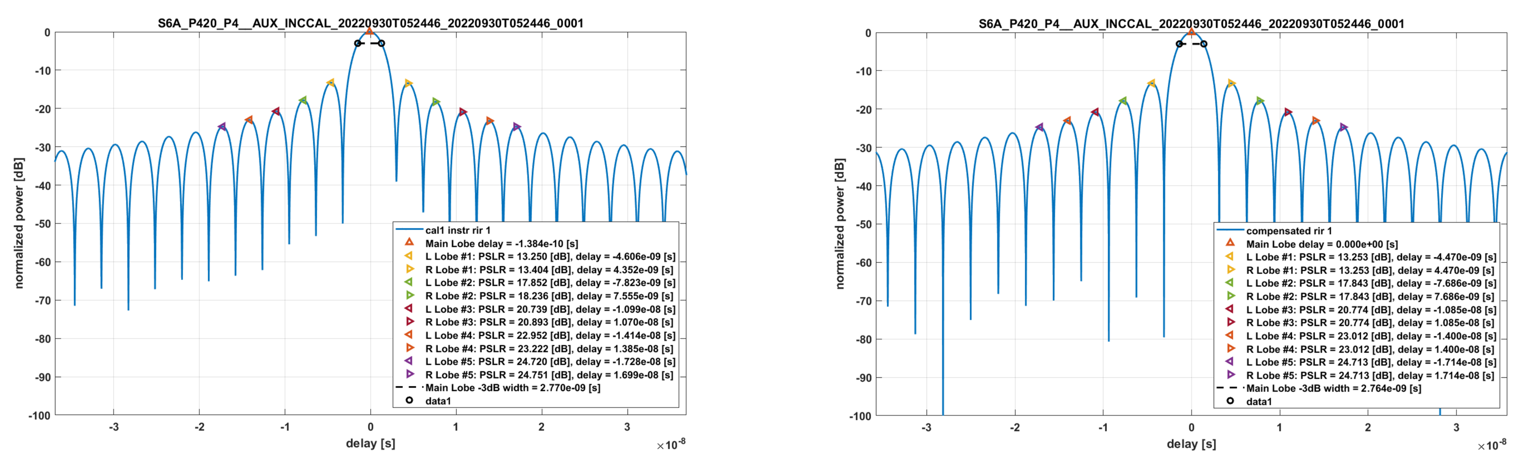



**Fig.1** Chirp Calibration Tool: block scheme.




(a) (b)

**Fig.2** (a) Computed RIR. (b) Compensated RIR.

## AGC Calibration Tool

The AGC Calibration tool is aimed at processing on-ground CAL-1 Automatic Gain Control (AGC) level 0 products to extract gain and delay settings for each attenuator step. The objective of this tool is to perform:

- relative calibration of each AGC command, i.e. estimating the effective attenuation applied for each command;
- calibration of the delay variation depending on the applied AGC command.

- The AGC Calibration tool is in charge of processing the set of CAL1 calibration contained in the CAL-1 Automatic Gain Control (AGC) level 0 products in order to obtain an estimate of the ATT1 and ATT2 Gain and Delay by measuring the delay and gain of the peak of the reconstructed RIR obtained from range compression. The estimates of the attenuators gain and delay values, for both Ku and C band, and of the tracking attenuation and delay tables are obtained by system inversion.

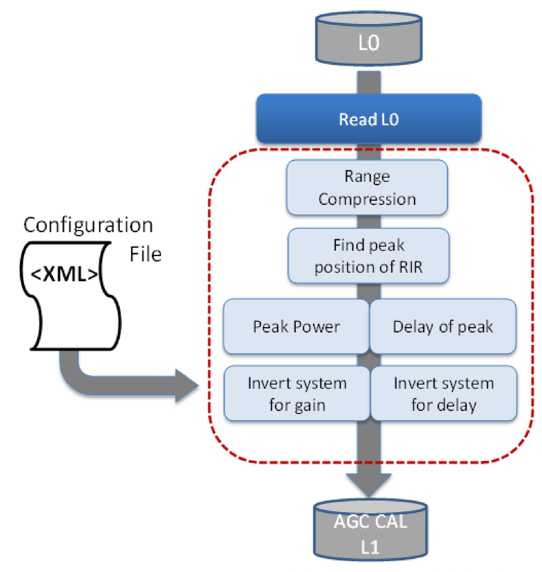
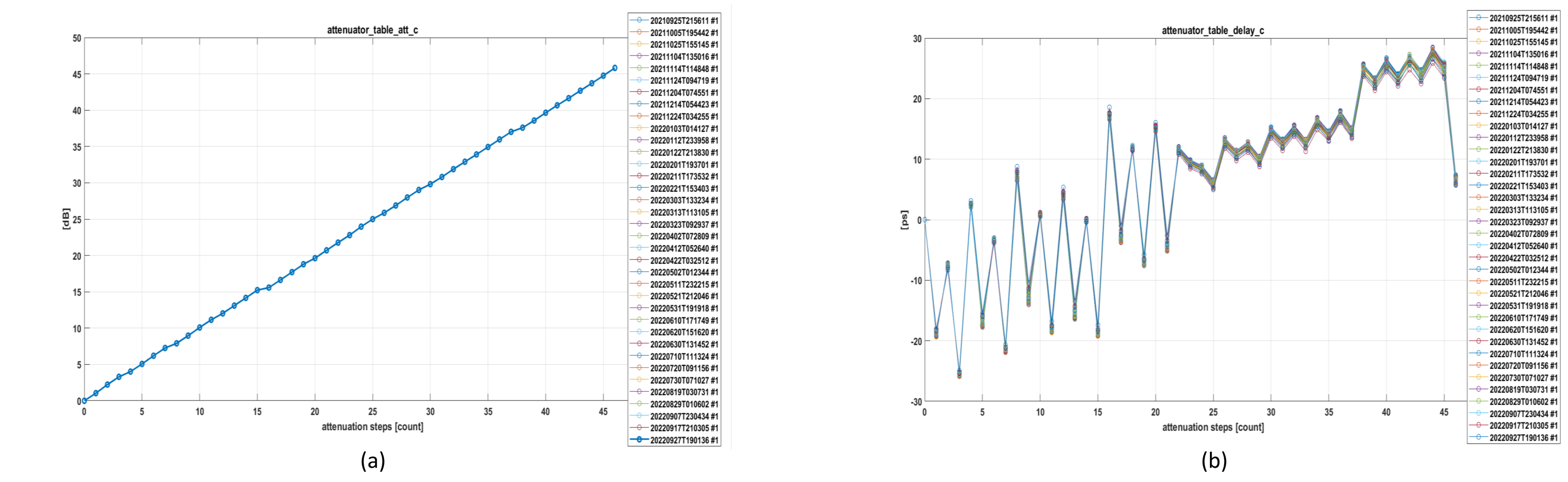



**Fig.3** AGC Calibration Tool: block scheme.




(a) (b)

**Fig.4** (a) Attenuation estimates for each attenuation step. (b) Delay estimates for each attenuation step.

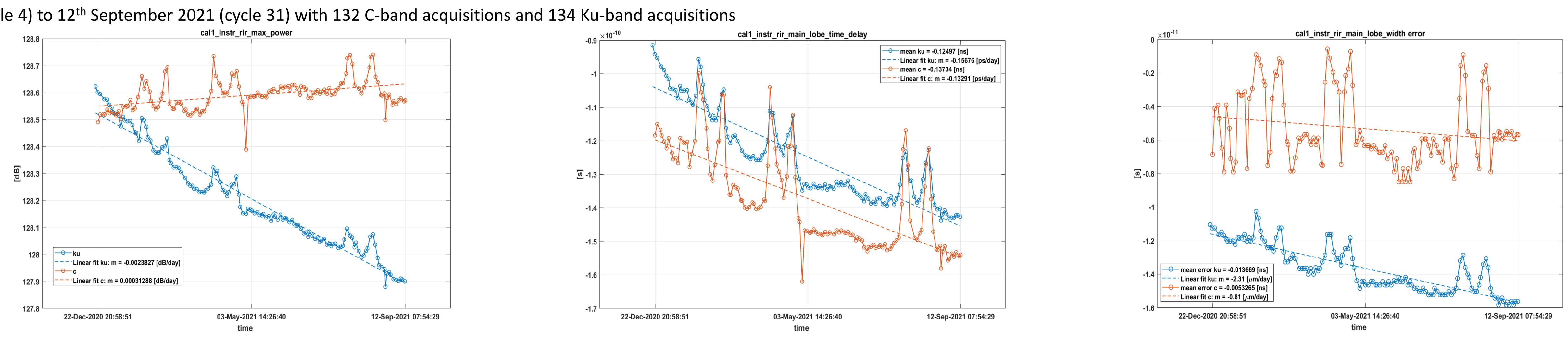
## Long-Term monitoring – RIR analysis

**RIR Analysis** is conducted looking at the time evolution of the RIR for both Poseidon-4A and Poseidon-4B

- **Poseidon-4A:** analysis of CAL1 INSTR data from 20th December 2020 (cycle 4) to 12th September 2021 (cycle 31) with 132 C-band acquisitions and 134 Ku-band acquisitions

| Parameter | C-band | Ku-band |
|---|---|---|
| Max power variation | 0.114 dB/year | -0.87 dB/year |
| Main lobe delay (linear trend) | -7.3 mm/year | -8.6 mm/year |
| Main lobe width error (linear trend) | -0.3 mm/year | -0.84 mm/year |
| Secondary lobes delay error | < 0.21 ns | < 0.16 ns |
| Secondary lobes relative power error | < 0.6 dB | < 0.25 dB |

**Tab.1** RIR analysis of Poseidon-4A from 20th December 2020 (cycle 4) to 12th September 2021 (cycle 31).



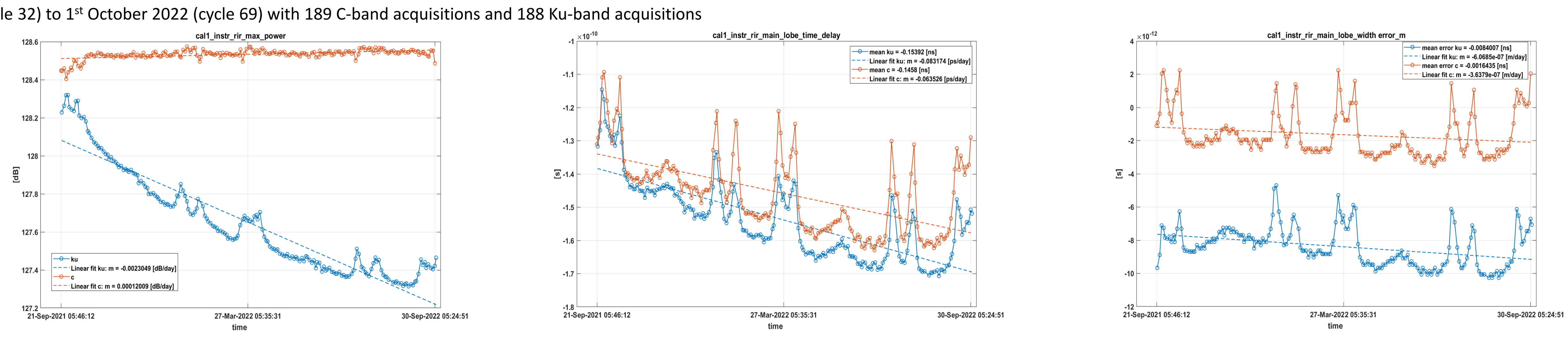

(a) (b) (c)

**Fig.5** Evolution over time of: (a) Peak power, (b) main lobe delay and (c) main lobe width error.

- **Poseidon-4B:** analysis of CAL1 INSTR data from 21st September 2021 (cycle 32) to 1st October 2022 (cycle 69) with 189 C-band acquisitions and 188 Ku-band acquisitions

| Parameter | C-band | Ku-band |
|---|---|---|
| Max power variation | 0.044 dB/year | -0.84 dB/year |
| Main lobe delay (linear trend) | -3.5 mm/year | -4.6 mm/year |
| Main lobe width error (linear trend) | -0.13 mm/year | -0.22 mm/year |
| Secondary lobes delay error | < 0.185 ns | < 0.18 ns |
| Secondary lobes relative power error | < 0.41 dB | < 0.25 dB |

**Tab.2** RIR analysis of Poseidon-4B from 21st September 2021 (cycle 32) to 1st October 2022 (cycle 69).




(a) (b) (c)

**Fig.6** Evolution over time of: (a) Peak power, (b) main lobe delay and (c) main lobe width error.

## Long-Term monitoring – ATT analysis

**Attenuator Commands Analysis** is conducted looking at the time evolution of the attenuation and delay, with focus on Science and Calibration mode, for both Poseidon-4A and Poseidon-4B.

To ensure a nominal signal level at ADC input, Poseidon-4 receiver chain includes two variable attenuators. On each attenuator, the attenuation level can be adjusted inside a scale of 23 dB in one dB step, so that the overall receiver chain gain has a total dynamic of 46 dB.

- **Poseidon-4A:** analysis of CAL1 ATT data from 30th November 2020 (cycle 4) to 6th September 2021 (cycle 30) with 25 dataset available.

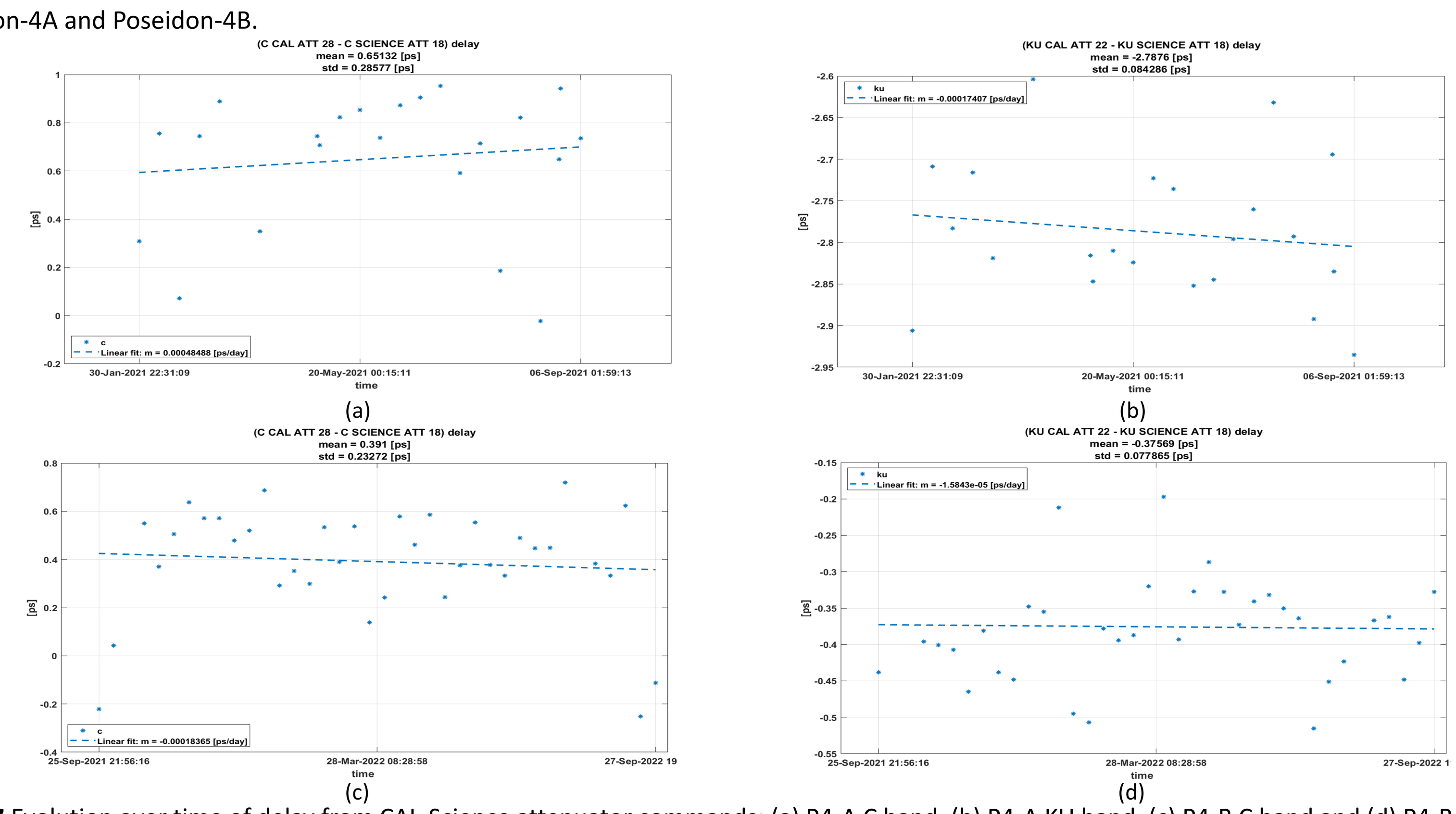
| | Science attenuator commands* | | CAL attenuator commands* | | CAL-Science attenuator commands** | |
|---|---|---|---|---|---|---|
| | C band | KU band | C band | KU band | C band | KU band |
| Delay | 0.0106 mm/year | -0.067 mm/year | -0.0071 mm/year | 0.056 mm/year | 0.0265 mm/year | -0.0095 mm/year |
| Attenuation | 0.0276 dB/year | -0.0261 dB/year | -0.0045 dB/year | 0.0537 dB/year | 0.0022 dB/year | 0.0033 dB/year |

**Tab.3** Time evolution of Science, CAL and CAL minus Science attenuator commands of Poseidon-4A. (*) Data from 30th November 2020 (cycle 4) to 6th September 2021 (cycle 30). (**) Data from 30th January 2021 (cycle 8) to 6th September 2021 (cycle 30).

- **Poseidon-4B:** analysis of CAL1 ATT data from 25th September 2021 (cycle 32) to 27th September 2022 (cycle 69) with 36 dataset available.

| | Science attenuator commands* | | CAL attenuator commands* | | CAL-Science attenuator commands* | |
|---|---|---|---|---|---|---|
| | C band | KU band | C band | KU band | C band | KU band |
| Delay | -0.045 mm/year | -0.065 mm/year | -0.055 mm/year | -0.066 mm/year | -0.01 mm/year | -0.0009 mm/year |
| Attenuation | -0.0025 dB/year | -0.0125 dB/year | -0.0034 dB/year | -0.0071 dB/year | -0.00087 dB/year | 0.0054 dB/year |

**Tab.4** Time evolution of Science, CAL and CAL minus Science attenuator commands of Poseidon-4B. (*) Data from 25th September 2021 (cycle 32) to 27th September 2022 (cycle 69).



(a) (b) (c) (d)

**Fig.7** Evolution over time of delay from CAL-Science attenuator commands: (a) P4-A C band, (b) P4-A KU band, (c) P4-B C band and (d) P4-B KU band.

## Conclusion

Analysis of CAL1 INSTR showed similar results between Poseidon-4A and Poseidon-4B:

- Observed Power Loss for Ku-band RIR while slight power increase for C-band RIR.
- A drift of the main lobe location is observed for both KU and C band.
- A dependence of the RIR quality parameters on the instrument temperatures is observed in correspondence of temperature spikes.
- Results obtained from CAL1 INSTR confirm same trends obtained with CAL1-SAR in terms of main lobe delay, main lobe width error and max power variation, while it introduces more information about the secondary lobes delay and power error.

P4 use constant but different attenuator settings for Science and CAL mode. On ground, science data are calibrated with CAL1 (CAL attenuator setting), and the difference in delay and attenuation between science and CAL attenuators is corrected as a constant (drift not compensated). The analysis of the CAL1 ATT showed:

- Small drift in delay and attenuation for the Science and CAL attenuator settings.
- Very small drift in the difference of delay and attenuation between Science and CAL attenuators (not calibrated on ground).
- The change of attenuation values during the mission life suggests that the use of different ATT command on ground will not introduce drift.