Derivation of an alternative GRACE Follow-On LRI1B data product

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GRACE Follow On

- The LRI measures distance variations between the reference and transponder spacecraft (S/C).

  Please refer to the talk:
  Malte Misfeldt (EGU22-6448, today 13:20)

- From these distance variations one can observe the structure of the Earth's gravity field and it temporal variations.

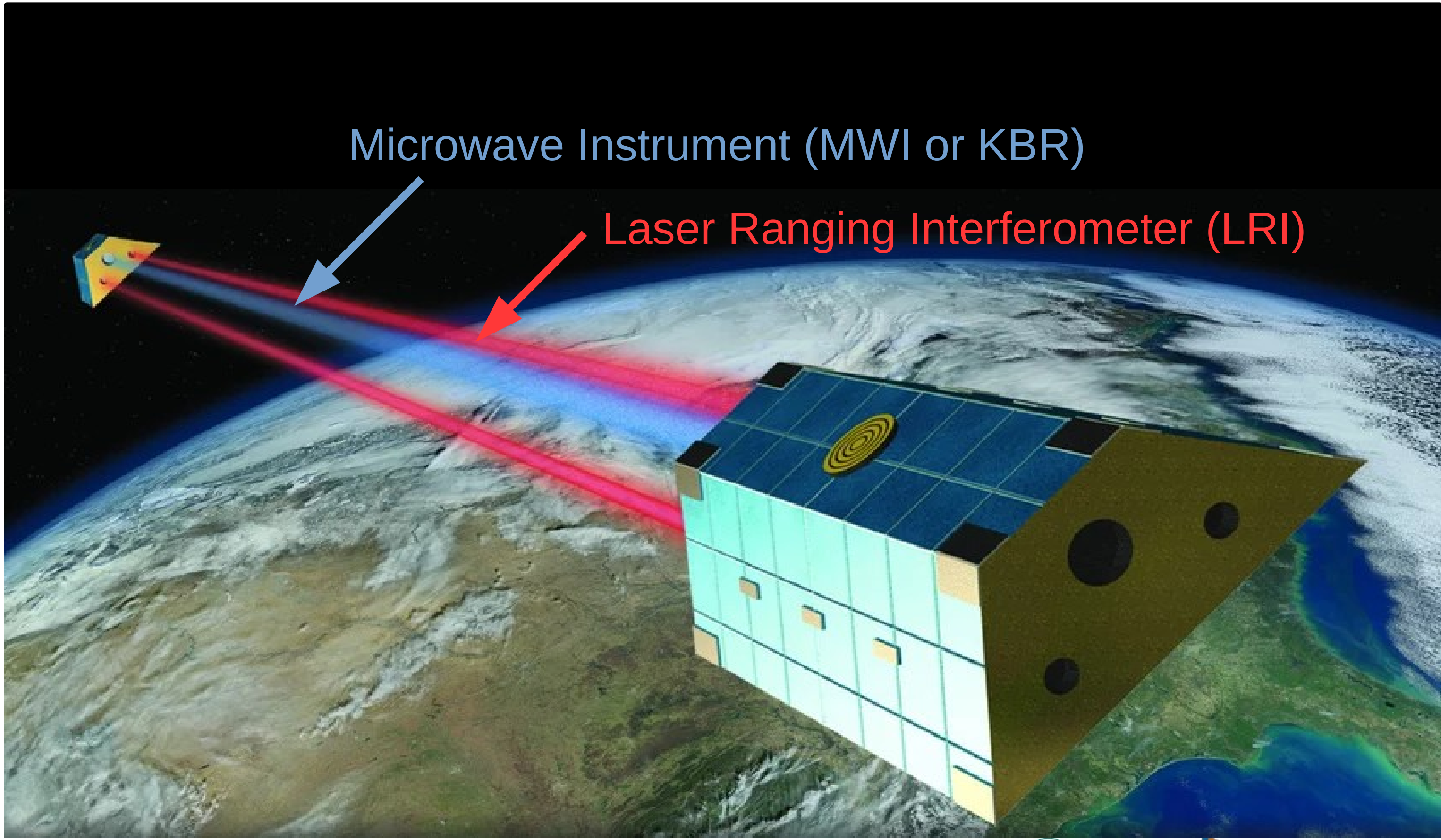
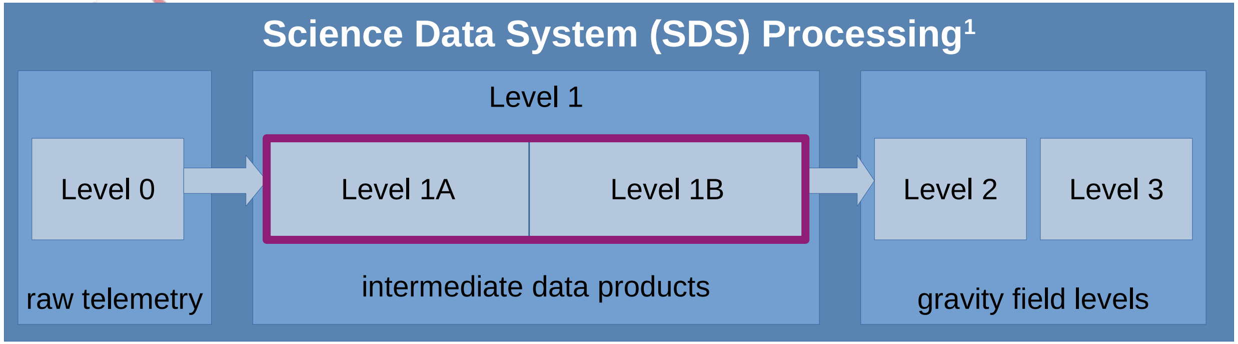
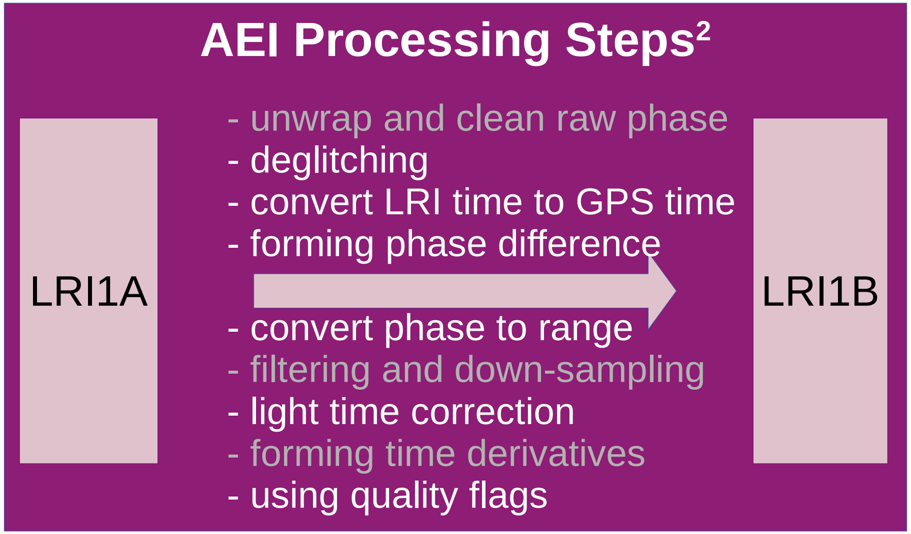


Figure from Max Planck Institute of Gravitational Physics, https://www.aei.mpg.de/408756/grace-follow-on

Overview of GRACE-FO Data Products





- Data processing for all instruments is done by SDS.
- The AEI team derives an alternative Level1B data product for the LRI data, which can also be used for gravity field recovery.
- Data available at https://wolke7.aei.mpg.de/s/fDbWiMDKzEH56JK

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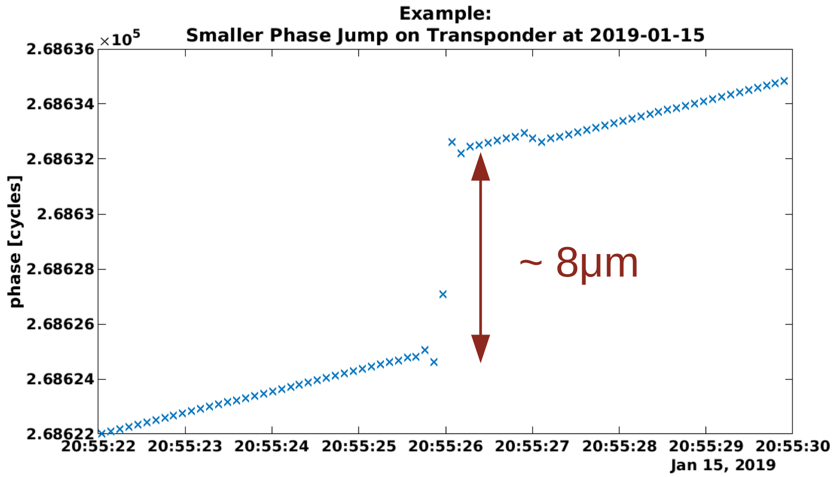
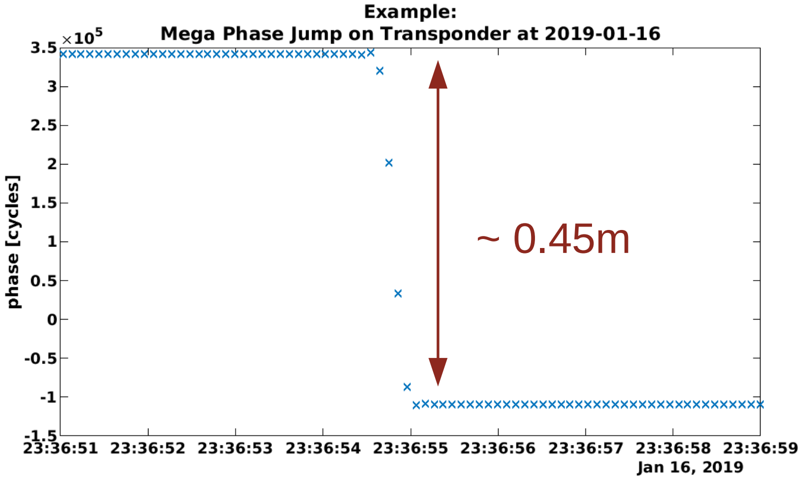
[1] Hui Ying Wen et al, JPL/NASA, Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) Level-1 Data Product User Handbook, Sep 2019
[2] L. Mueller, Generation of Level 1 Data Products and Validating the Correctness of Currently Available Release 04 Data for the GRACE Follow-On Laser Ranging Interferometer, 2021, DOI: http://doi.org/10.15488

Deglitching

- phase jump events in LRI phase are mainly produced by mechanical vibration at thruster activation [3]
- Deglitching detects and removes phase jumps from reference and transponder phase by fitting models to these glitches and subtracting them from the raw data





[3] Klaus Abich et al. 2019, In-Orbit Performance of the GRACE Follow-on Laser Ranging Interferometer, Phys. Rev. Lett. 123,031101

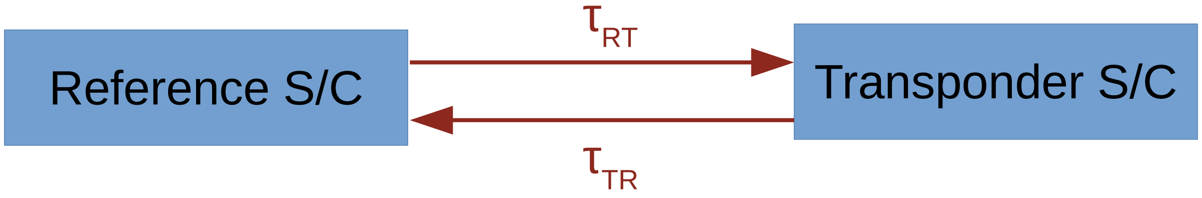
Forming Phase Difference

For computing the phase difference of reference (R) and transponder (T) we need to

- convert time-tags[1] from LRI time into GPS time for each spacecraft

$$GPS_{\text{time tag}} = LRI_{\text{time tag}} + \text{smooth}(\text{ datation bias} + \text{TIM1B} + \text{CLK1B}_{\text{eps time}})$$

- interpolate T data onto R GPS time-tags by considering the light travel time τ_{TR} between T and R spacecraft



[1] Hui Ying Wen et al, JPL/NASA, Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) Level-1 Data Product User Handbook, Sep 2019

Convert LRI Phase to Biased Range

$$\rho_{LRI} \approx \varphi_{LRI} \cdot \frac{c_0}{2\,\nu_R}$$

Simplified formula for converting phase [cycles] to a biased range [m].

We estimate a time-dependent absolute laser frequency ν(t) with

- Method 1:
  - cross-correlation of KBR and LRI measurements for each day in a month
  - resulting scales and time shifts between instruments is interpolated to a 10 Hz time-series.[2]

- Method 2:
  - uses other LRI telemetry like temperature values or laser set-points.
    (Paper in preparation, by Malte Misfeldt et al.)

Next AEI version of LRI1B considers frequency variations in KBR and LRI measurements, which couple via the absolute satellite distance as [4]

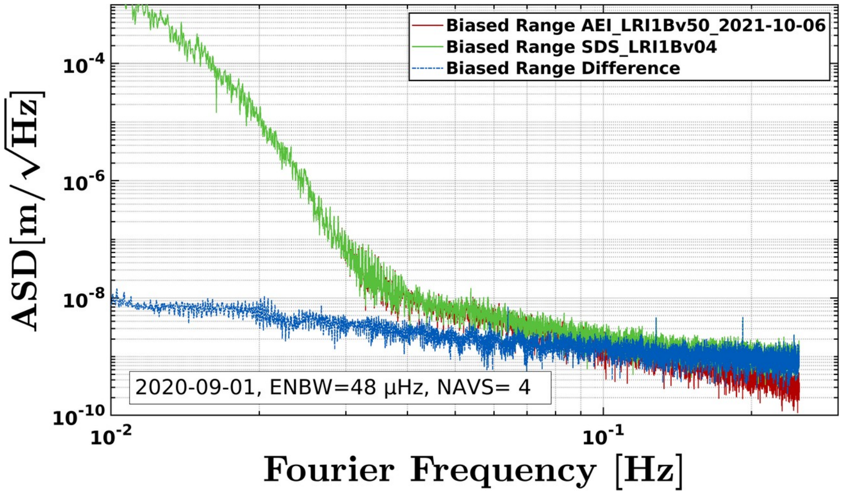
$$\rho_{\mathrm{TWR,2exact}}(t) := \frac{c_0}{2}\int_0^t \frac{\mathrm{d}\varphi_{\mathrm{TWR}}(t')/\mathrm{d}t'}{\nu_{\mathrm{R}}(t'-\Delta t_{\mathrm{RTR}}(t'))} - \left(\frac{\nu_{\mathrm{R}}(t')}{\nu_{\mathrm{R}}(t'-\Delta t_{\mathrm{RTR}}(t'))} - 1\right)\mathrm{d}t' = \frac{c_0 \Delta t_{\mathrm{RTR}}(t)}{2} - \frac{c_0 \Delta t_{\mathrm{RTR}}(0)}{2}.$$

[2] Laura Müller, 2021, DOI: http://doi.org/10.15488

[4] Vitali Müller et al., Comparing GRACE-FO KBR and LRI ranging data with focus on carrier frequency variations, 2022, https://arxiv.org/abs/2205.08862

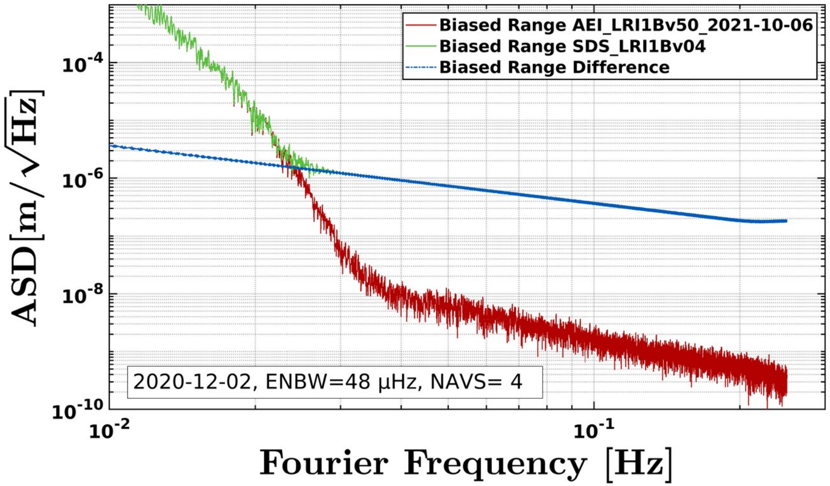
Biased Range LRI1B SDS and AEI

Typical Amplitude Spectral Densities for SDS (LRI1B v04), AEI (LRI1B v50) and their difference (AEI – SDS) since July 2020.



Sometimes ASD level of LRI1B v04 is increased due to jumps in the range. Possible reasons:

- IPU reboots might couple via the time-tag correction or from cross-calibration with KBR data
- unusual phase jump events which are not removed as good as usual

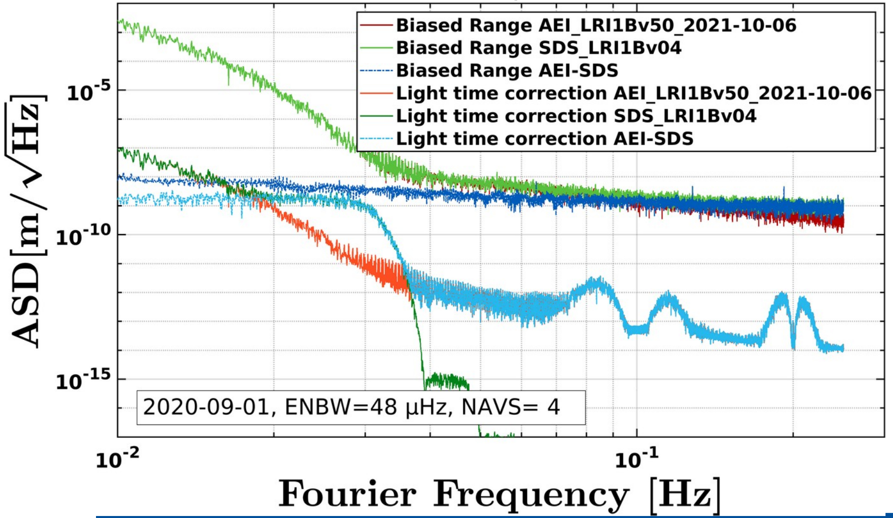


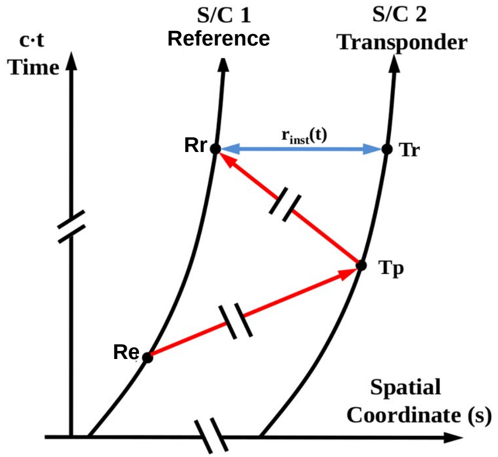
Light Time Correction

- The biased range differs from the instantaneous range due to the finite speed of light (non-zero light travel time).

  - Light time correction is derived from the GNI1B orbit data product.
- An alternative method to compute LTC is given by Yan et al. 2020.[5]

  - key feature is the lower (numerical) noise (well below 1 nm/rtHz).
- LRI1B v04 achieved lower noise for f > 30 mHz by different CRN filter since July 2020.[5]



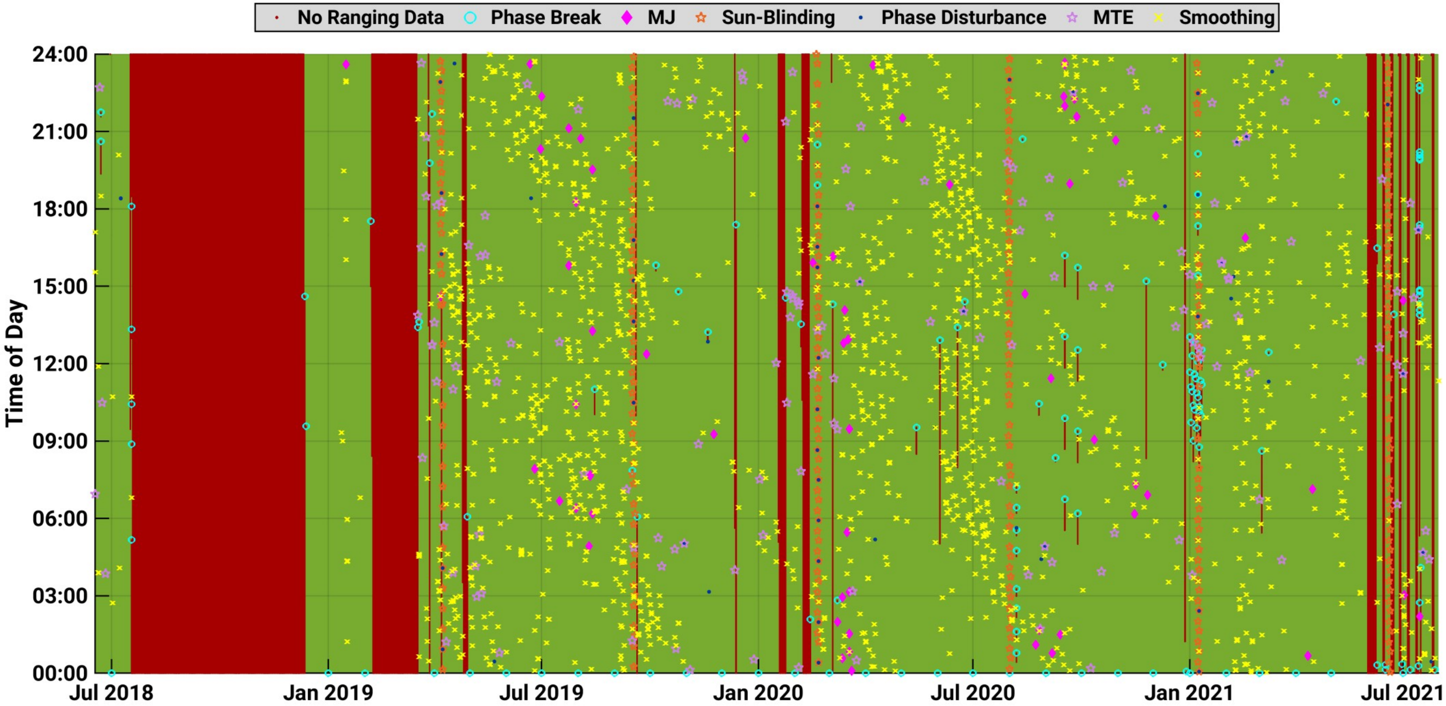


Sketch from Yihao Yan et al.[5]

[5] Yihao Yan et al, Revisiting the Light Time Correction in Gravimetric Missions Like GRACE and GRACE Follow-On, 2020 https://arxiv.org/abs/2005.13614
[6] GRACE_FO_JPL_L1_Release_Notes, section from Gene Fahnestock, 2020-06-30, ftp://isdcftp.gfz-potsdam.de/grace-fo/DOCUMENTS/RELEASE_NOTES/

Quality Flag

AEI uses a quality flag for marking special events
- which might affect the quality of the ranging data
- where data correction was applied



[2] L. Mueller, Generation of Level 1 Data Products and Validating the Correctness of Currently Available Release 04 Data for the GRACE Follow-On Laser Ranging Interferometer, 2021, DOI: http://doi.org/10.15488

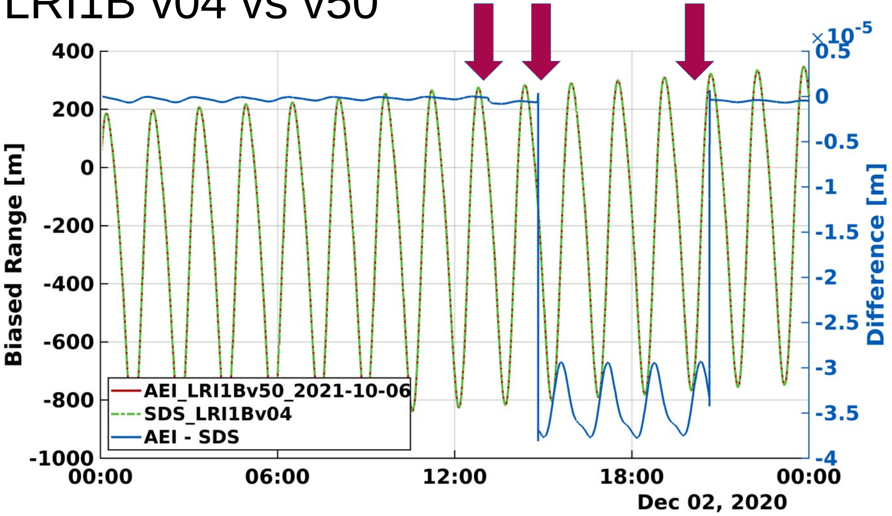
Thank you for your attention!

LRI1B v50 available at: https://wolke7.aei.mpg.de/s/fDbWiMDKzEH56JK
If you want to use our data we are happy to help!
(laura.mueller@aei.mpg.de)

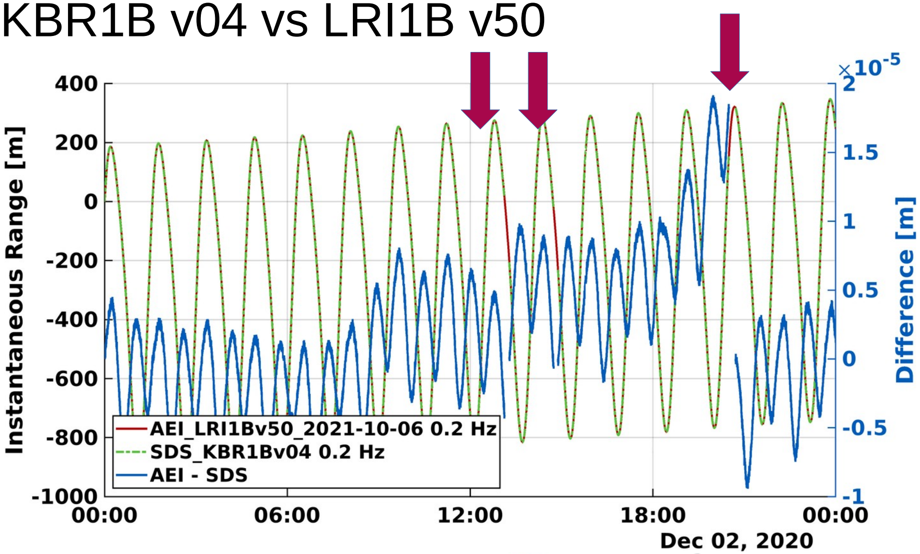
Time domain for biased range 2nd Dec 2020

- Instrument Processing Unit (IPU) reboots can be seen from gaps in KBR-LRI comparison (right plot).
- IPU reboots affect SDS LRI1B (see again slide 7). The difference of AEI and SDS LRI biased range show steps at the time of IPU reboot (left plot).

LRI1B v04 vs v50



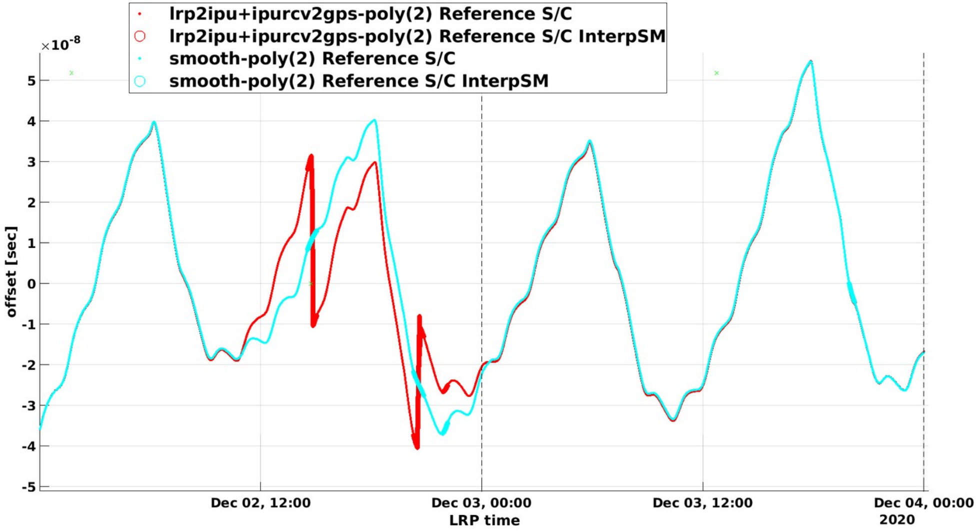
KBR1B v04 vs LRI1B v50



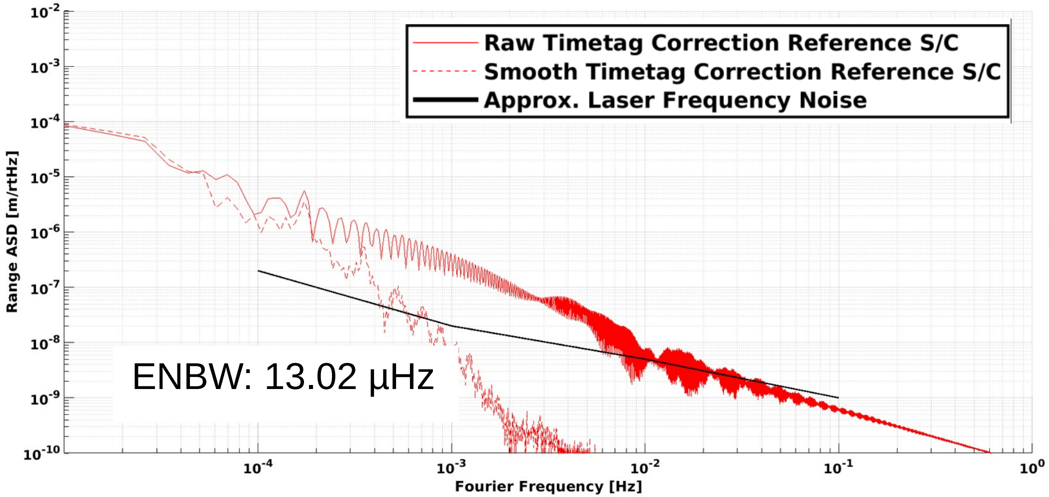
Example time-tag correction for 2nd and 3rd Dec 2020

- Gaps in the time correction are filled using interpolation.
- Outliers or jumps are removed, filled with interpolated values and are smoothed.
- The smoothed values are used in the AEI processing for deriving LRI measurements in GPS time.

Time Offsets between LRI and GPS time minus a polynomial of degree 2. Example for reference spacecraft.



Spectrum of time-tag correction values has been re-scaled to range domain using 10 m/s (10MHz) value.



Summary of AEI LRI1B data

- AEI uses an advanced deglitching algorithm for removing phase jumps
- we compute a smooth time correction for converting LRI time-tags to GPS time
- The biased range is derived with a time-depended absolute laser frequency and time-shift on a monthly basis. This yields a biased range without offsets at every day-bound.
- ASD level of biased range ends usually at approx. 400 pm/rtHz at ~0.25 Hz
- the light time correction is well below 1nm/rtHz for Fourier Frequencies > 20mHz
- a quality flag shows different events, where the data quality might be reduced

Literature

[1] Hui Ying Wen et al, JPL/NASA, Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) Level-1 Data Product User Handbook, Sep 2019
ftp://isdcftp.gfz-potsdam.de/grace-fo/DOCUMENTS/Level-1/

[2] Laura Müller, Generation of Level 1 Data Products and Validating the Correctness of Currently Available Release 04 Data for the GRACE Follow-On Laser Ranging Interferometer, 2021,
DOI:http://doi.org/10.15488

[3] Klaus Abich et al. 2019, In-Orbit Performance of the GRACE Follow-on Laser Ranging Interferometer, Phys. Rev. Lett. 123,031101
https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.123.031101

[4] Vitali Müller et al, Comparing GRACE-FO KBR and LRI ranging data with focus on carrier frequency variations, 2022
https://arxiv.org/abs/2205.08862

[5] Yihao Yan et al, Revisiting the Light Time Correction in Gravimetric Missions Like GRACE and GRACE Follow-On, 2020
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[6] GRACE_FO_JPL_L1_Release_Notes, section from Gene Fahnestock, 2020-06-30,
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