Status of the DORIS satellite data processing at DGFI-TUM

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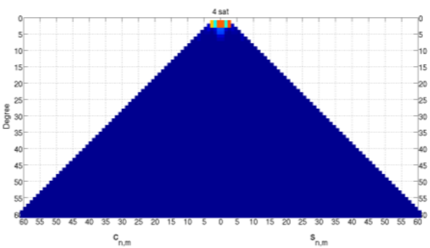
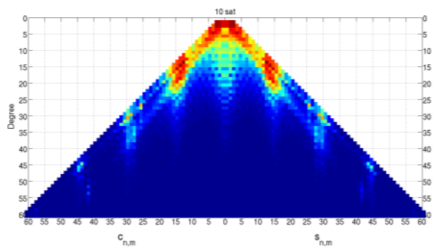
History of DORIS implementation at DGFI-TUM

➢ Initial implementation of Jason-2 macromodel and nominal yaw steering model for SLR data analysis in 2013/2014

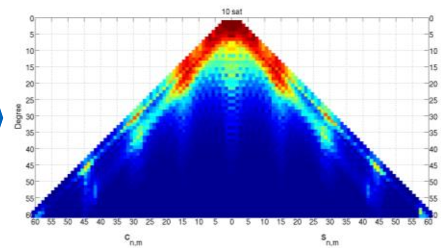
- Software: **DGFI Orbit and Geodetic parameter estimation Software (DOGS)**
- Motivation: improved gravity field determination using an SLR multi-satellite constellation
- In addition to all available spherical satellites, most-tracked satellite Jason-2 was logical



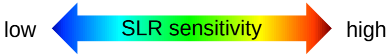
LA-1/-2 + ET-1/2



10 spherical satellites



10 sph. sat. + Jason-2



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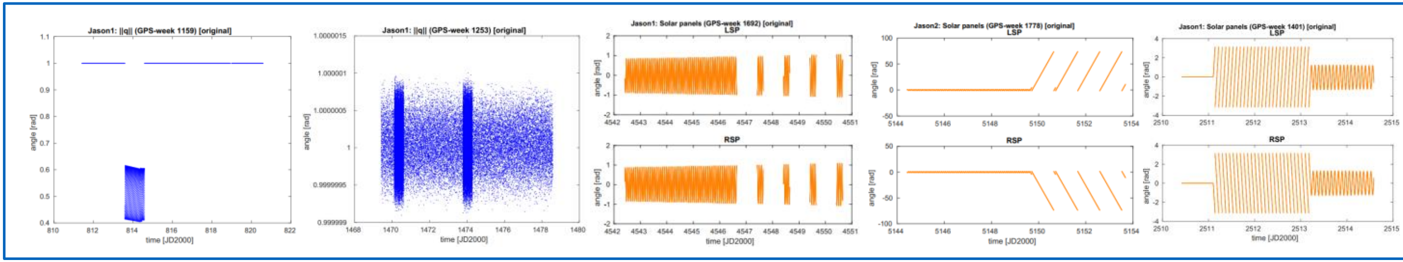
  - Software: **DGFI Orbit and Geodetic parameter estimation Software (DOGS)**
  - Motivation: improved gravity field determination using an SLR multi-satellite constellation
  - In addition to all available spherical satellites, most-tracked satellite Jason-2 was logical
- Initial work on DORIS analysis during a research stay at NASA GSFC in early 2018
  - **Many thanks to F. Lemoine, N. Zelensky and the GSFC team for their great help!!**
- After a major software revision in 2018, focus on DORIS implementation again in 2019
  - Especially work of J. Zeitlhoefler and S. Rudenko led to an error-free and refined satellite attitude handling

Implemented satellites/models in DOGS-OC

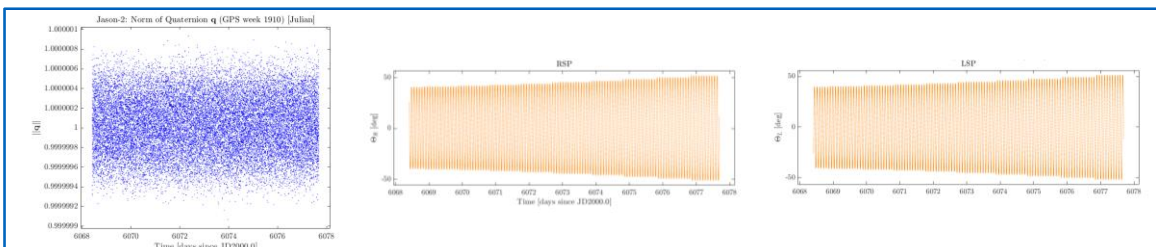
- Jason-1/-2/-3 for full mission period (until Jan. 2019)
  - Geometric model and optical properties for accurate Gas-Surface-Interaction (GSI) modelling
  - Mass history files
  - Maneuver handling files (arcs splitted at maneuver epochs)
  - Satellite attitude event files (used for nominal yaw steering model)
- Reprocessing (3.5 day arcs)
  - Iterative processing of SLR observations (elimination of outliers)
  - Estimated parameters: initial state vector, atmospheric scaling factor polygon (12-hourly), OPR empirical accelerations, SRP/Albedo scaling factors, (no range-/time biases)

Refined attitude handling of Jason satellites

- Extensive pre-processing for attitude observations was necessary

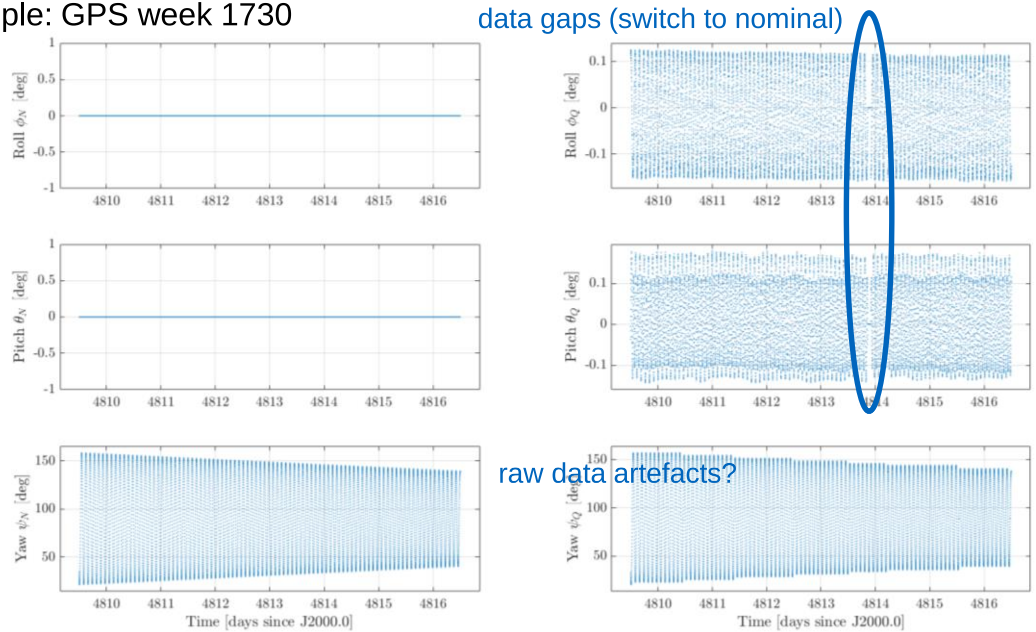


- Now, a filtered, interpolated and plausibility-checked attitude observation time series is available for the full mission periods of all Jason satellites



Refined attitude handling of Jason satellites

- Jason-2 **nominal yaw steering vs. attitude observations** in local orbital frame [RPY]
  - example: GPS week 1730



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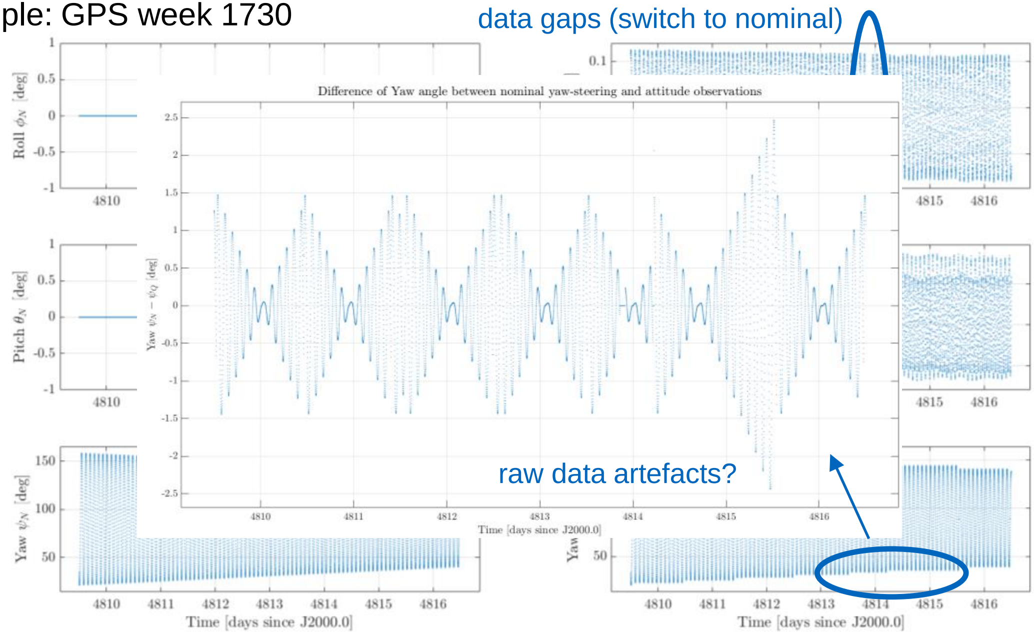
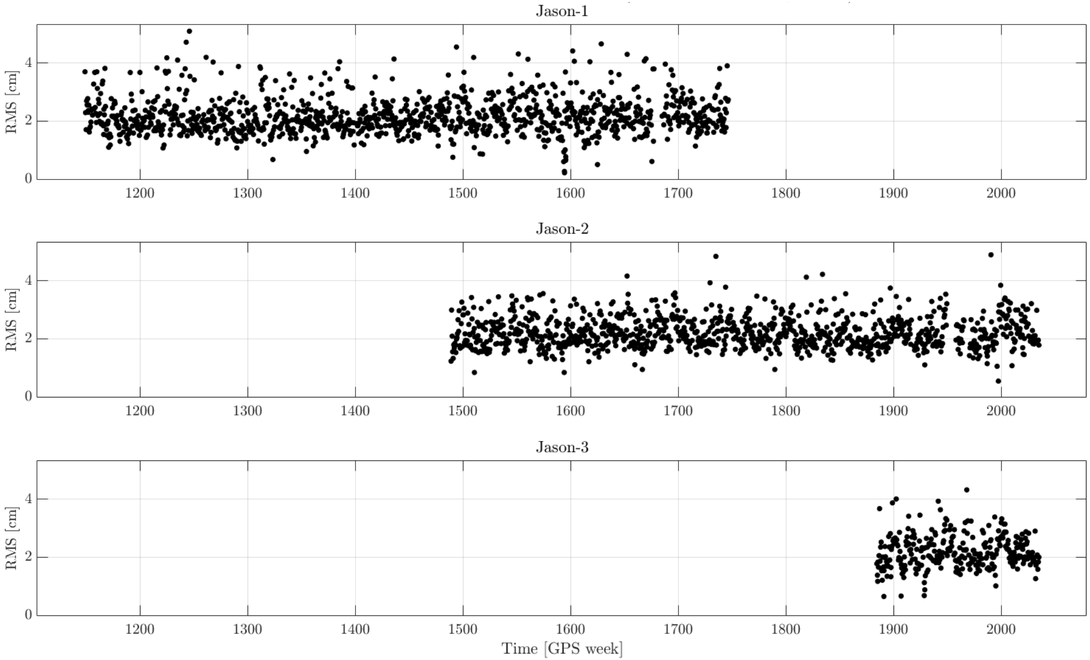


Jason-1/-2/-3 SLR-only orbit fits (nominal yaw steering)

➢ **SLR-only orbits are of good quality** over the full mission periods



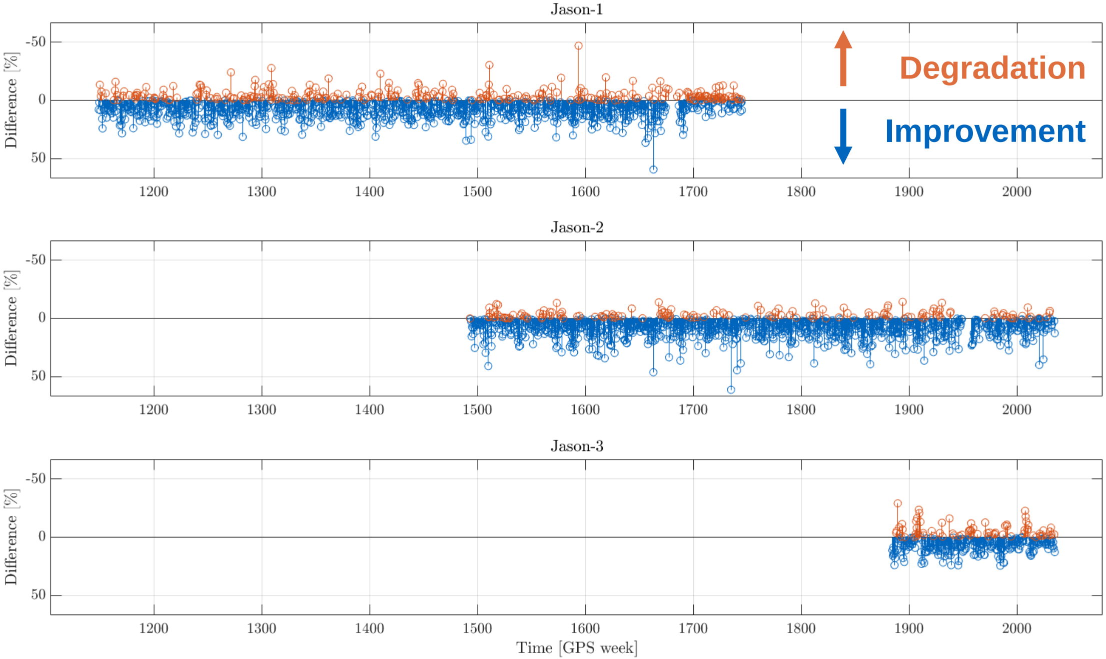
mean RMS ~ 2.2 cm

mean RMS ~ 2.1 cm

mean RMS ~ 2.0 cm

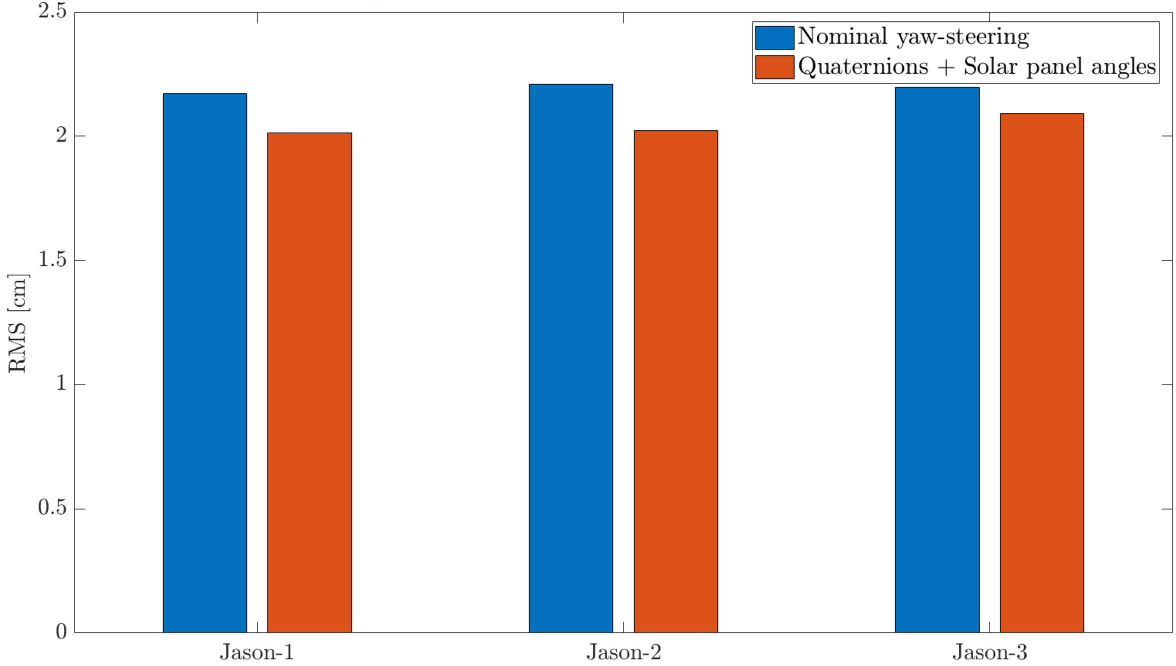
Jason-1/-2/-3 SLR-only orbit fits (nominal vs. attitude obs.)

- Percentage of improved arcs: **74.14 %** (Jason-1), **84.91 %** (Jason-2), **76.87 %** (Jason-3)



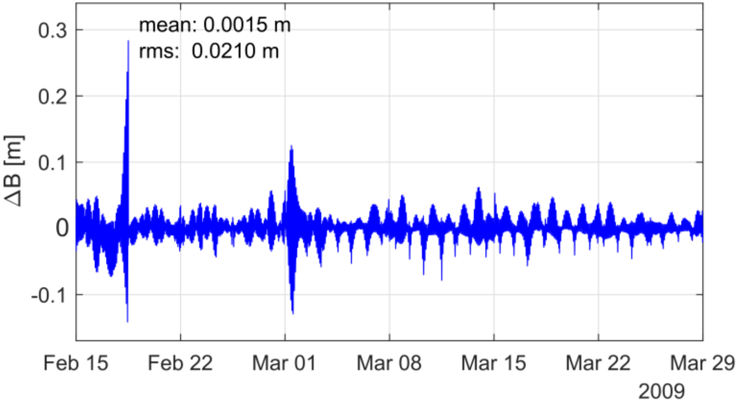
Jason-1/-2/-3 SLR-only orbit fits (nominal vs. attitude obs.)

- Mean improvements: **7.29 %** (Jason-1), **8.38 %** (Jason-2), **4.77 %** (Jason-3)



SLR-only orbit comparison (nominal vs. attitude obs.)

- Orbit differences in latitude, longitude and height (radial) components
  - Small mean in latitude and longitude direction
  - Scatter around **21 mm** in latitude and **16 mm** in longitude direction



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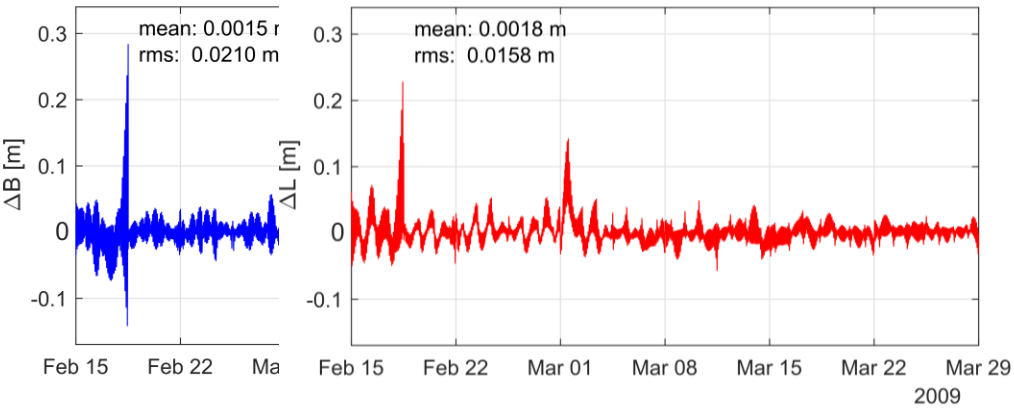
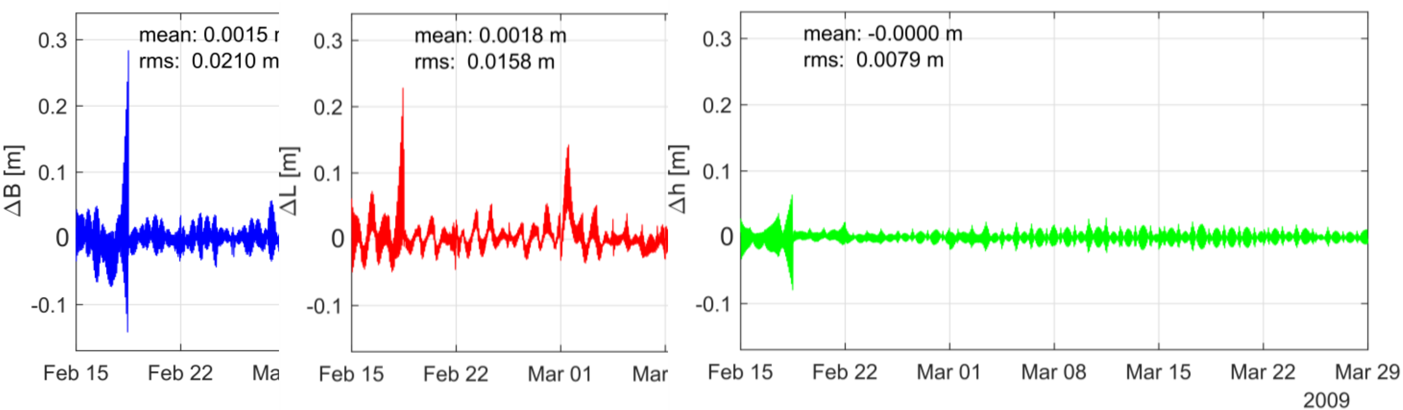


SLR-only orbit comparison (nominal vs. attitude obs.)

- Orbit differences in latitude, longitude and height (radial) components
  - Small mean in latitude and longitude direction
  - Scatter around **21 mm** in latitude and **16 mm** in longitude direction
  - Marginal mean offset in radial direction but scatter of around **8 mm**



Status of DORIS implementation at DGFI-TUM

- Import of DORIS data in **IDS 2.2 format**
- **Jason-1/-2/-3** macro-models according to IDS recommendations implemented
- Attitude handling via **nominal yaw steering model** and **quaternions/solar panel angles**
- Station-dependent phase center offsets in the measurement direction (**IDS phase law**)
- DPOD2014, IERS 14 C04, EIGEN-6S (d/o 120), EOT-11a, (no NT-L currently)
- (Estimation of the correction to the wet part of the tropospheric zenith delay)

- Estimated parameters (comparable to SLR setup):
  - Initial state vector, atmospheric scaling factor polygon (12-hourly), OPR empirical accelerations, SRP/Albedo scaling factors,
  - Station- and pass-wise frequency biases

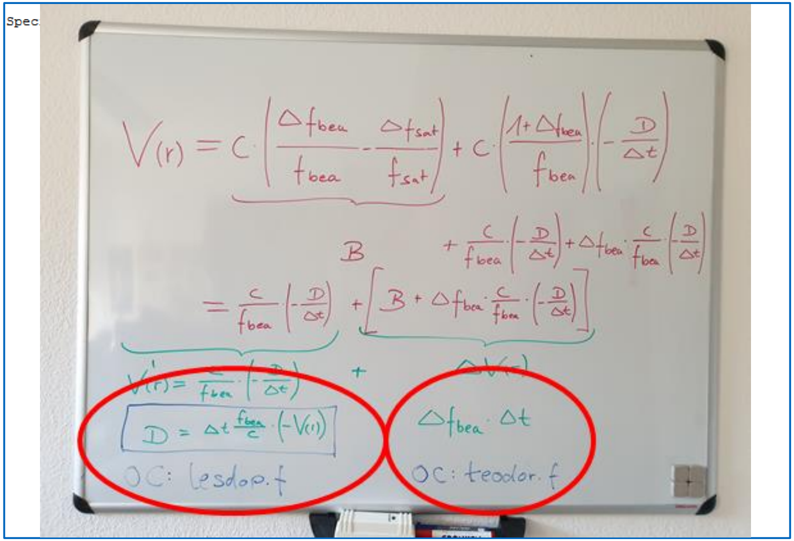
Issue with IDS 2.2 format description

➢ Conversion **from range-rate to Doppler counts** somehow not clear (units do not agree)!

```
Specifications on the DORIS data format:

     Time for DORIS = beginning of count interval

     Range rate has been commputed using the following equation:

        V(r) = c/f(bea)[(f(bea)-f(sat))-D/dt]

             = [c/f(bea)][f(bea)-f(sat)] + [c/f(bea)][-D/dt]              (1)

        with  Vr = range rate (m/s)
              dt = count interval (s)
              D  = cycle count
              c  = 299792458 (m/s)
              f(bea)= nominal beacon frequency (change from Version 1)
                      no relativity correction has been applied
              f(sat)= best estimate of the actual satellite frequency
                      long term on-board frequency drift taken into account
                      relativity correction applied

     Because the true frequency offset between f(bea) and f(sat) will be
        slightly different from the nominal value, a bias is typically
        estimated for each station pass.

     The corresponding processing equation for Version 2.1 and 2.2 data is

      V(r) = c(df(bea)/fbea - df(sat)/fsat) + c[{1 + df(bea)}/f(bea)][-D/dt]   (2)

           = bias + [c/f(bea)][-D/dt] + df(bea)[c/f(bea)][-D/dt]

        where df(bea)= difference between actual beacon frequency and the
                       nominal value used to generate the data
              df(sat)= difference between actual satellite frequency and
                       the best available estimate used to generate the data
```

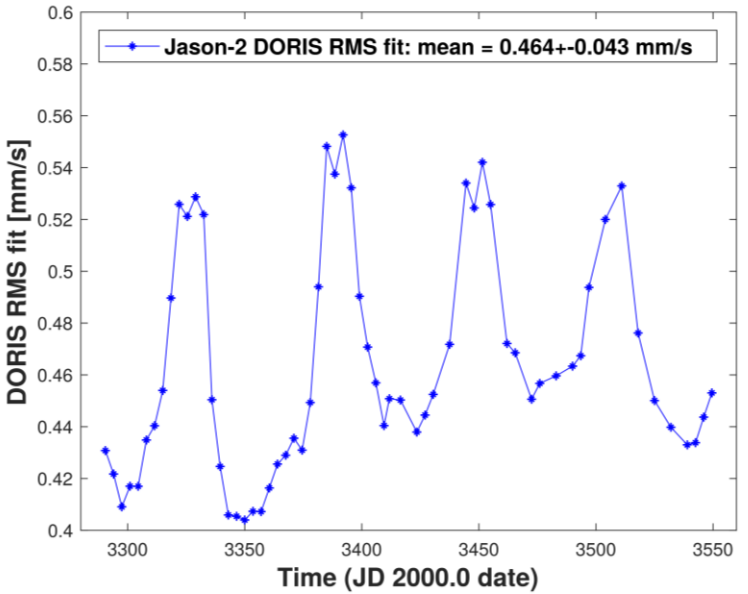
Issue with IDS 2.2 format description

- Conversion **from range-rate to Doppler counts** somehow not clear (units do not agree)!
  - Nominal frequency used to convert range-rate into Doppler counts
  - Everything else is shifted to the estimated frequency bias!!



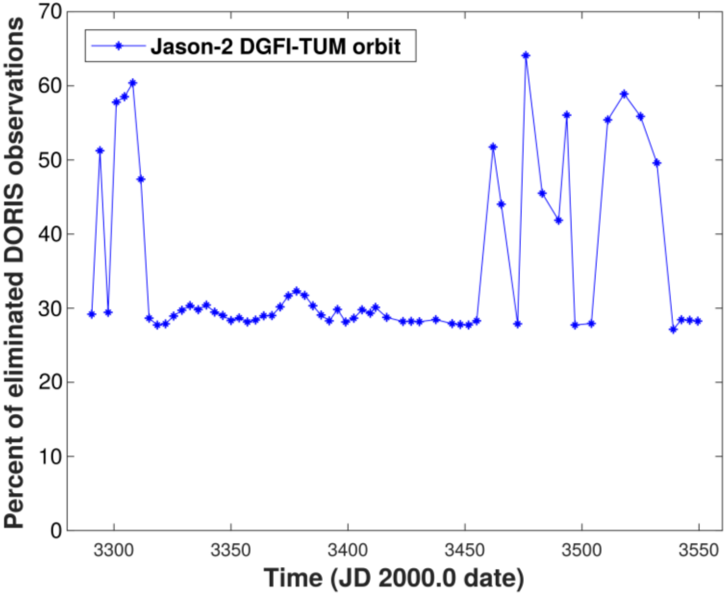
Jason-2 DORIS-only orbit fits (nominal)

- Mean DORIS RMS: **0.46 mm/s** (compared to 1.7 mm/s end of September 2018)
- Correlation with draconitic period harmonics
- Still tropospheric correction provided by IDS 2.2 data used
- Frequency biases are reasonable (master beacon frequency offsets ~ zero)
- Longer time series for interpretation is needed



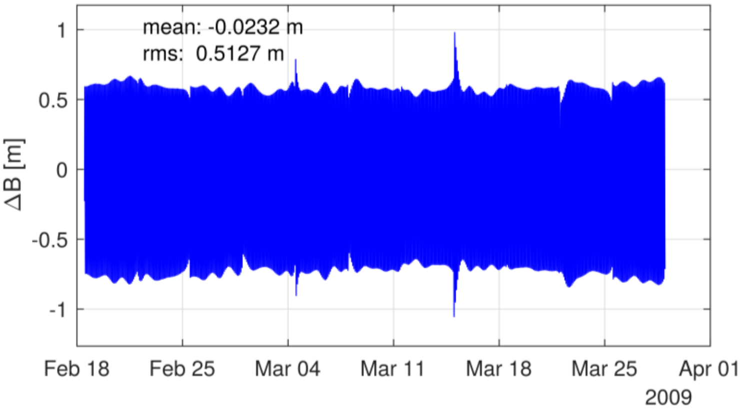
Jason-2 DORIS-only percentage of eliminated observations (nominal)

- Normally, around **30 %** of all DORIS observations are eliminated (3σ-criteria, 10 deg elevation cutoff)
- Strong elimination-criteria dependency!
- Still some arcs to be checked!



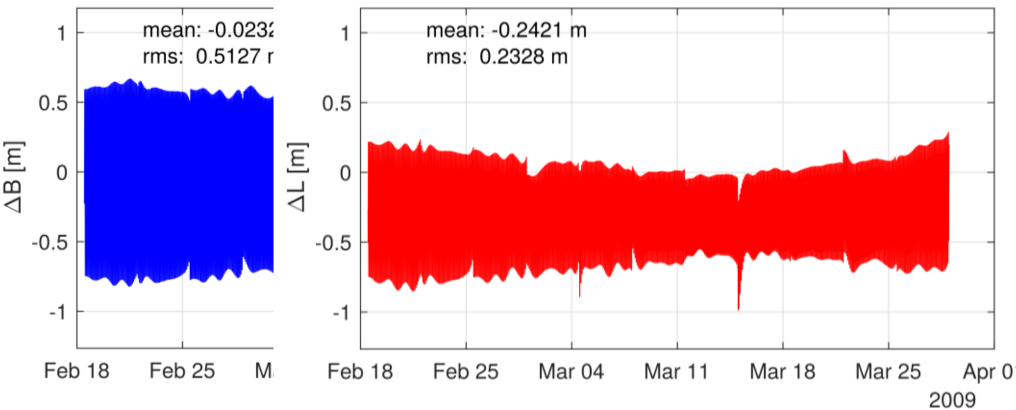
DGFI-TUM internal orbit comp.: SLR-only vs. DORIS-only

- Orbit differences in latitude, longitude and height (radial)
  - Scatter of 50 cm in latitude



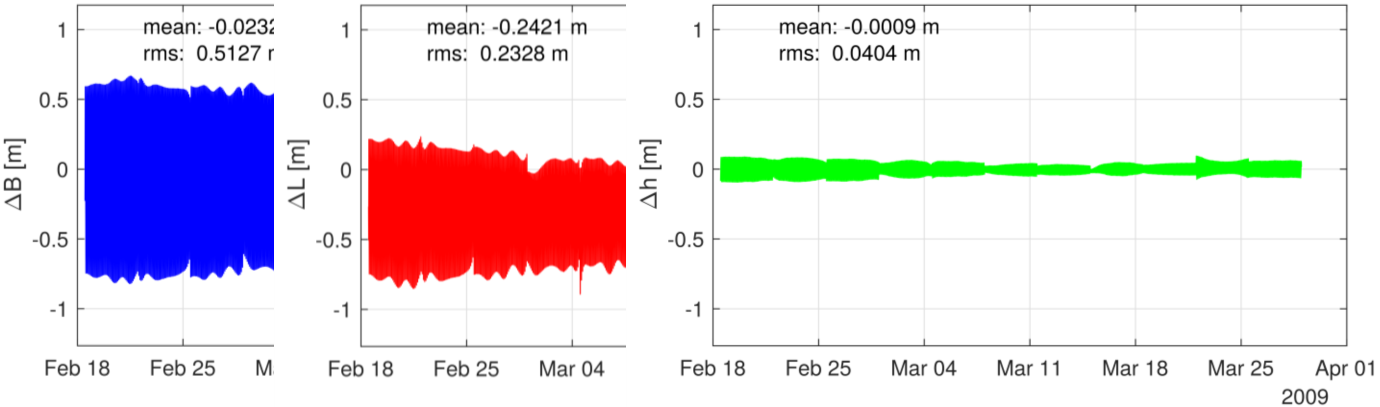
DGFI-TUM internal orbit comp.: SLR-only vs. DORIS-only

- Orbit differences in latitude, longitude and height (radial)
  - Scatter of 50 cm in latitude
  - Offset in longitude (about ~ 24 cm)



DGFI-TUM internal orbit comp.: SLR-only vs. DORIS-only

- Orbit differences in latitude, longitude and height (radial)
  - Scatter of 50 cm in latitude
  - Offset in longitude (about ~ 24 cm)
  - **Good radial agreement** between SLR and DORIS (about 4 cm RMS, zero mean!)



Conclusions

- **Jason-1/-2/-3** for the full mission period (until Jan. 2019) reprocessed using SLR data
- DORIS implementation now successful (mean RMS values around **0.46 mm/s**)
- **Pre-processed attitude observations** might be valuable for the POD community (please wait for publication on this issue;-)
- DGFI-TUM now starts to **intensively analyze DORIS data**

- Any hints for us how to proceed (e.g., IDS software comparison campaigns planned, etc.?)

Future work

- Estimation of **tropospheric corrections** (scaling factors, gradients)
- Account for **frequency shift** of 3rd generation beacons
- Implementation of **SAA correction** (model/corrected observations)
- Analysis of DORIS-only TRF, EOP, and gravity field time series
- Combination of SLR and DORIS
- More satellites
- Implementation of **RINEX data format**

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In addition to the GSFC team, we want to thank P. Willis, F. Mercier and R. Biancale!!

IDS Analysis Working Group Meeting

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