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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- 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
  - data gaps (switch to nominal)
  - raw data artefacts?
Refined attitude handling of Jason satellites

- Jason-2 nominal yaw steering vs. attitude observations in local orbital frame [RPY]

  - example: GPS week 1730

raw data artefacts?

  data gaps (switch to nominal)
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:
  - Jason-1: ~2.2 cm
  - Jason-2: ~2.1 cm
  - Jason-3: ~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)

Graphs showing degradation and improvement over time for each Jason mission.
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
SLR-only orbit comparison (nominal vs. attitude obs.)

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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
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- 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
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 computed using the following equation:

\[ V(r) = \frac{c}{f(\text{bea})} \left[ f(\text{bea}) - f(\text{sat}) \right] - \frac{D}{dt} \]

\[ = \left[ \frac{c}{f(\text{bea})} \right] f(\text{bea}) - f(\text{sat}) + \left[ \frac{c}{f(\text{bea})} \right] \frac{-D}{dt} \]  \hspace{1cm} (1)

with

- \( V_r \) = range rate \( \text{(m/s)} \)
- \( dt \) = count interval \( \text{(s)} \)
- \( D \) = cycle count
- \( c = 299792458 \text{ (m/s)} \)
- \( f(\text{bea}) \) = nominal beacon frequency (change from Version 1)
- no relativity correction has been applied
- \( f(\text{sat}) \) = 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 \( f(\text{bea}) \) and \( f(\text{sat}) \) 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:

\[ V(r) = \frac{c}{f(\text{bea})} [f(\text{bea}) - df(\text{bea})/fsat] + \left[ \frac{1 + df(\text{bea})/f(\text{bea})}{[f(\text{bea})]} \right] \frac{-D}{dt} \]

\[ = \text{bias} + \left[ \frac{c}{f(\text{bea})} \right] \frac{-D}{dt} + df(\text{bea}) \left[ \frac{c}{f(\text{bea})} \right] \frac{-D}{dt} \]  \hspace{1cm} (2)

where

- \( df(\text{bea}) \) = difference between actual beacon frequency and the nominal value used to generate the data
- \( df(\text{sat}) \) = 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 (3\(\sigma\)-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)
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  - 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!)

![Graphs showing orbit differences](image)
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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