IDS WORKSHOP 2024

Estimation of the Length of Day from DORIS observations

Vikash Kumar[1], Petr Stepanek[2], Vratislav Filler[2], Onkar Dikshit[1], Nagarajan Balasubramanian[1]

[1]Indian Institute of Technology, Geoinformatics, Civil Engineering Department, Kanpur, India

[2]Research Institute of Geodesy, Topography and Cartography, Ustecka 98, 25066 Zdiby, Czech Republic

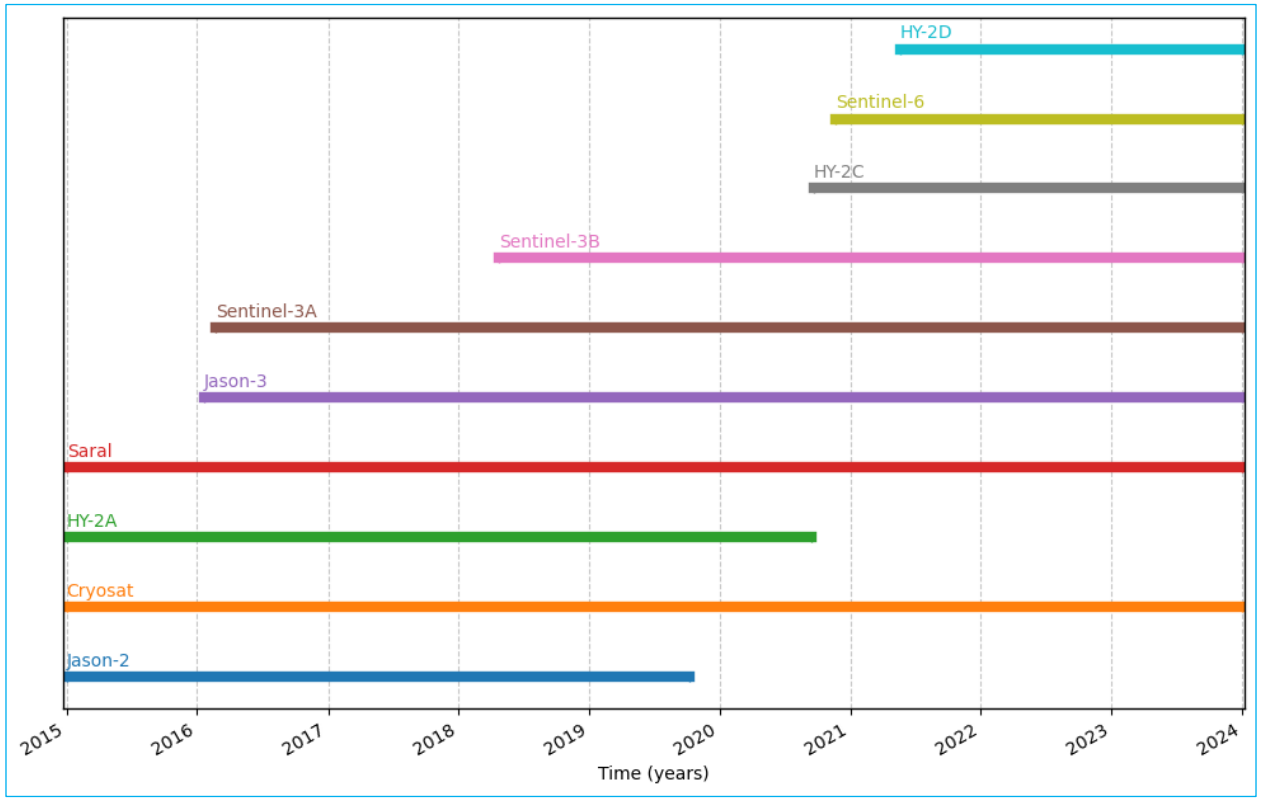
Processing of DORIS RINEX Data

- At the GOP, the DORIS RINEX data has been processed by the DORIS development version of the Bernese GPS Software 5.2.
- DORIS data is processed separately for each satellite on the basis of daily arcs.
- In daily processing, co-ordinates and ERPs are strongly constraint, troposphere and beacon frequency offset have no constraint while orbit have some minor constraint.
- In weekly processing, co-ordinates and ERPs are very loose constraint, troposphere, beacon frequency offset and orbit are eliminated.
- From the free-network weekly solution the transformation parameters w.r.t. ITRF 2020 (precisely w.r.t. the DORIS extension DPOD 2020) are calculated.
- After applying the 7-parameter Helmert transformation the RMS w.r.t. DPOD 2020 is calculated.

LOD estimation with DORIS observations

- The LOD estimates have been obtained from a not-transformed free network solution.
- The LOD value derived from DORIS measurements is also compared to the LOD values from IERS 20 C04 model, where LOD is derived from the daily values of the difference between the Universal time UT1 and the Coordinated Universal Time, UTC.
- We chose L1, L2 and L3 as our internal solutions with different settings, in particular with different handling of cross track once per revolution harmonic parameters (adjusted with different constraints for L2 (5×10^{-9} $\mathrm{m}/\mathrm{sec}^2$), L3 ($5\times10^{-8}\mathrm{m}/\mathrm{sec}^2$), or not adjusted for L1), since the amplitude of sine term correlates with LOD.

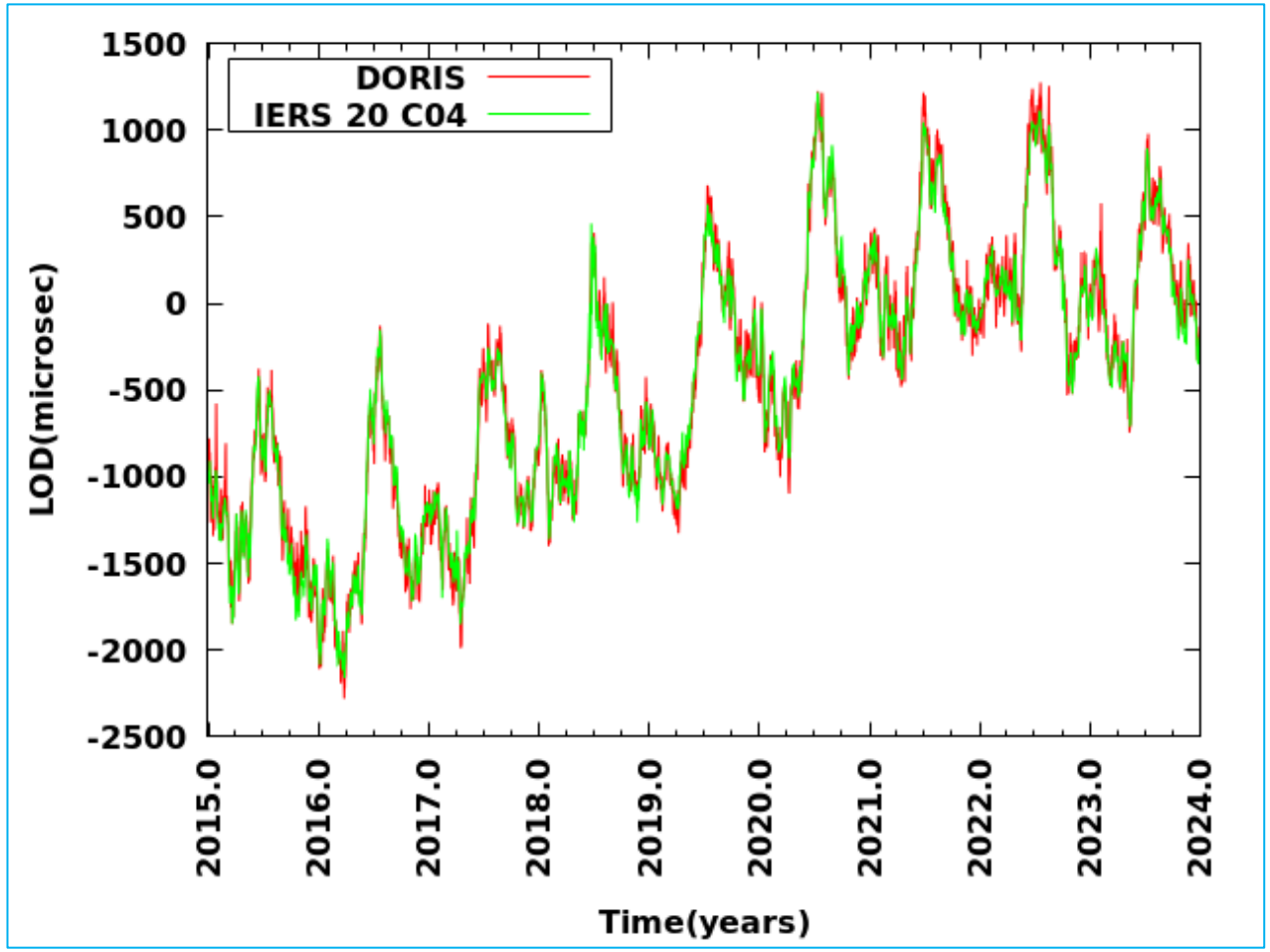
Satellites Availability



DORIS observation availability for different satellites from beginning of the year 2015 to the end of year 2023.

- The main part of the analysis focused on the combination of all available satellites except SPOT-5 as only RINEX data were processed and SPOT-5 doppler observations were excluded which were available for a short time span only.

LOD Time Series



- An increase in (UT1−UTC) indicates that the Earth's rotation is slowing down.
- This is a normal process influenced by gravitational forces and other long-term geophysical processes.

LOD time series derived from DORIS measurements and from the IERS 20 C04 model by combination of all available satellites. The LOD/DORIS time series is derived from multi-satellite solutions.

Estimated LOD Statistics

Satellite	WM (µs)	UM (µs)	WRMS (µs)	URMS (µs)
J2	101.4	106.9	213.8	223.6
J3	67.4	75.3	284.8	295.4
S3A	13.6	19.8	206.8	205.3
S3B	55.8	63.8	202.1	203.4
S6	38.9	39.8	266.2	273.7
CR	-0.27	5.6	224.8	244.1
SA	-114.3	-106.2	248.2	231.9
HA	-13.8	-15.2	222.3	227.1
HC	74.3	78.2	330.4	342.5
HD	59.8	60	229.5	238.6
Comb.	6.7	6.8	86.4	89.3

For L1 Campaign

Satellite	WM (µs)	UM (µs)	WRMS (µs)	URMS (µs)
J2	104.8	107.3	218.8	223.6
J3	72.4	77.1	292.7	297.5
S3A	10.8	13.6	206.2	203.2
S3B	51.5	57.2	202.6	200.2
S6	41.2	43.4	271.9	278.8
CR	-1.72	1.12	225.6	243.3
SA	-111.9	-105.2	246.6	232.2
HA	-9	-11.7	231.6	248.3
HC	74.3	78.1	339.2	344.9
HD	67.6	67.1	238	242.2
Comb.	12.6	11.8	86.4	87.7

For L2 Campaign

Year	Weighted mean [µs]	Weighted standard deviation [µs]
2015	37.3	97.6
2016	-34.5	72.0
2017	-10.2	85.4
2018	17.6	89.0
2019	-0.8	84.6
2020	-35.4	77.3
2021	29.7	83.1
2022	32.0	83.0
2023	23.6	76.8

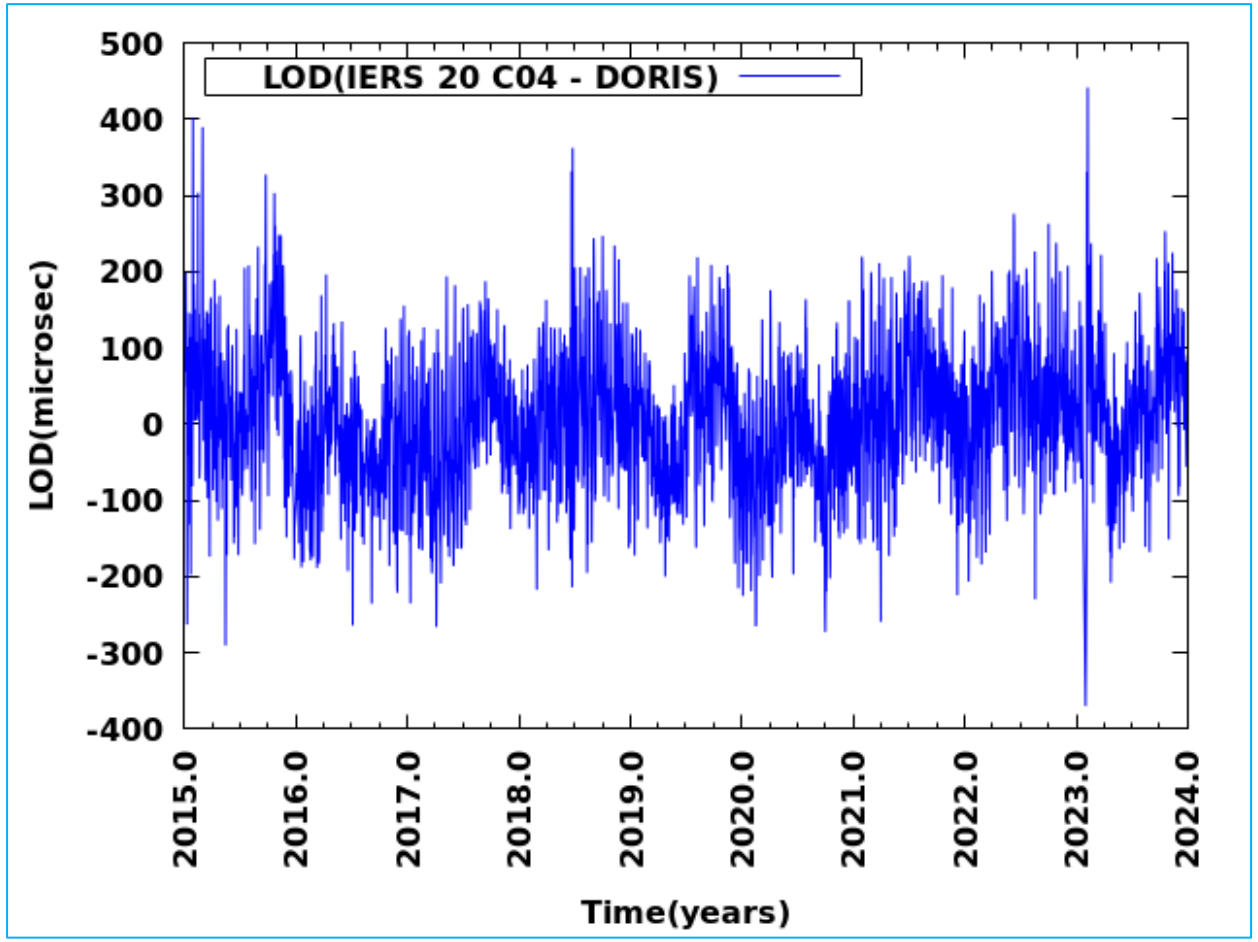
For L Campaign

Estimated weighted mean (WM), unweighted mean (UM), weighted RMS (WRMS) and unweighted RMS (URMS) for difference in LOD parameter between IERS 20 C04 and DORIS solutions. The statistical values are computed for the interval of nine years and separately for the combination of all available satellites as well as for the single satellite solutions.

Results Analysis

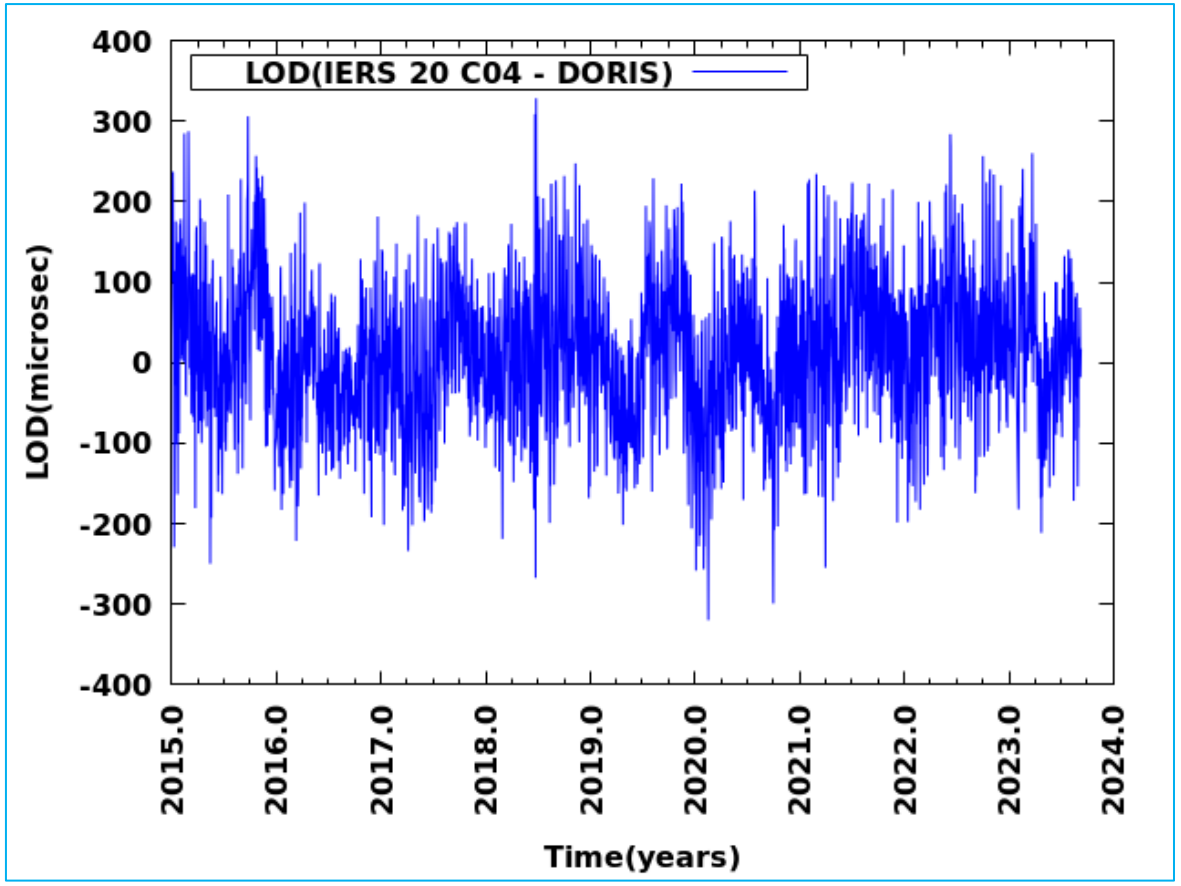
- The LOD values are not stable for the whole-time span but varies for the years between -35.4 µs to 37.3 µs for the L1 campaign.
- From 2015 to 2016, there is an improvement of the weighted standard deviation from 97.6 to 72 µs. In the starting years from (2016-2018) there is an increase of standard deviation from 72 to 89 µs but in the later years (2021-2023), the weighted standard deviation varies from 83.1 to 76.8 µs.
- This improvement could be related to the evolution of both DORIS system components, the network and the space segment.
- For L2 campaign the values are slightly comparable with L1 campaign, while for L3 campaign, it is the worst.

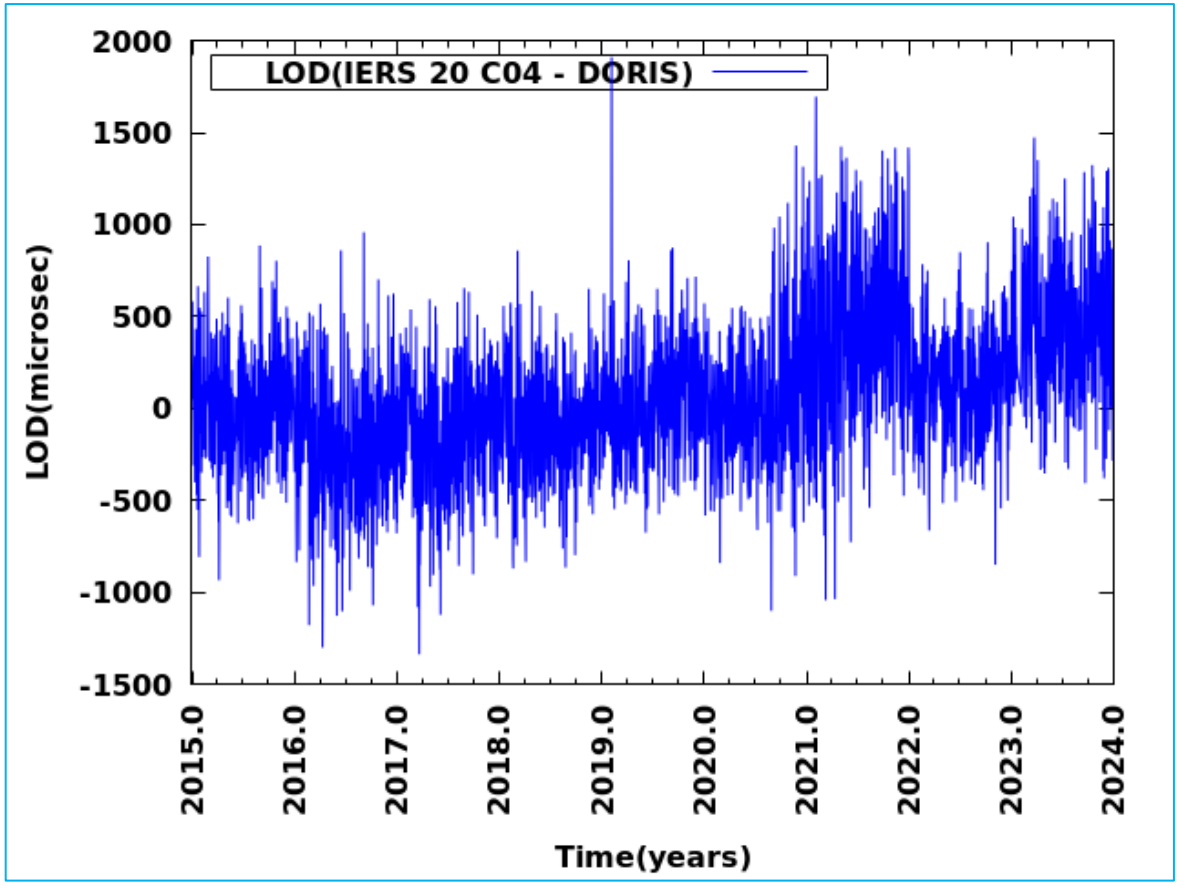
LOD Difference for L1 Campaign



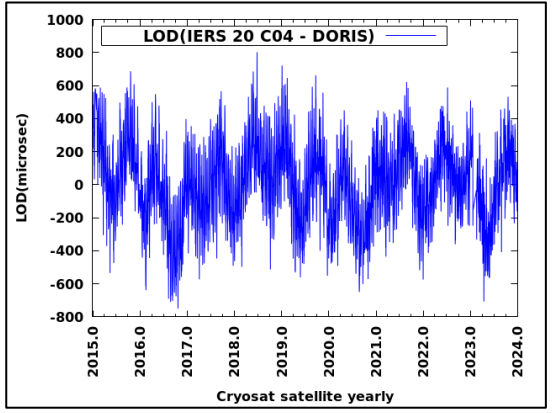
Difference between the LOD time series derived from DORIS measurements and the LOD time series from the IERS 20 C04 model for satellite combination of L1 campaign.

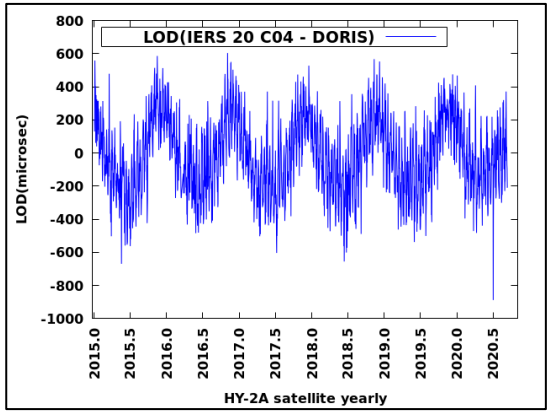
LOD Difference for L2 and L3 Campaigns

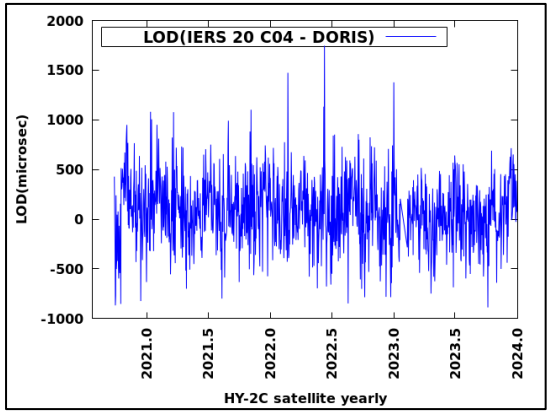


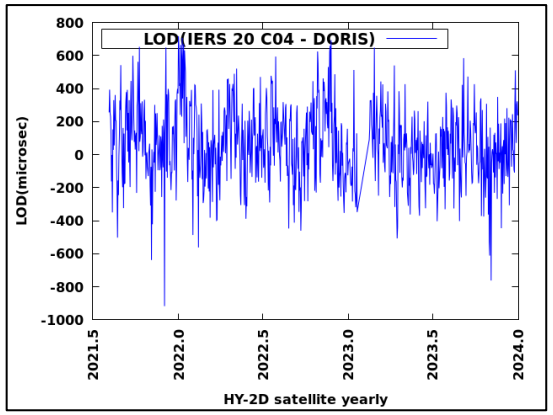


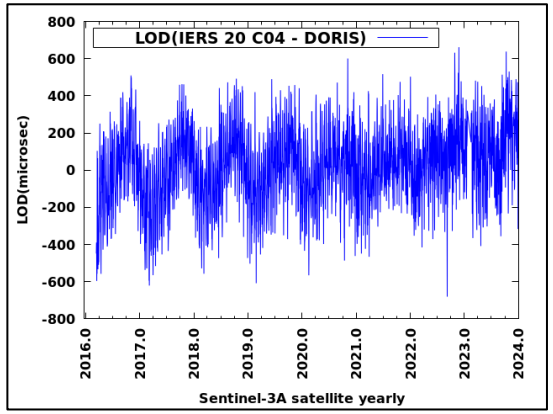
Difference between the LOD time series derived from DORIS measurements and the LOD time series from the IERS 20 C04 model for satellite combination of L2 (left) and L3 (right) campaign.

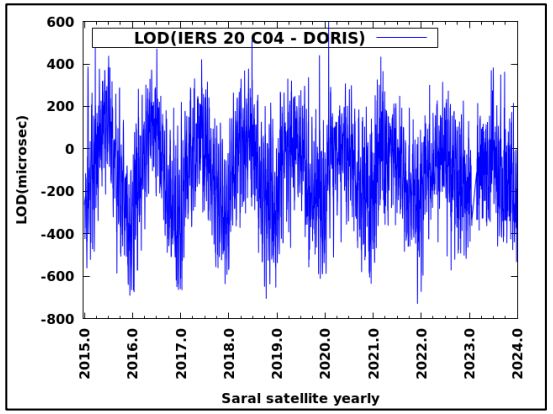


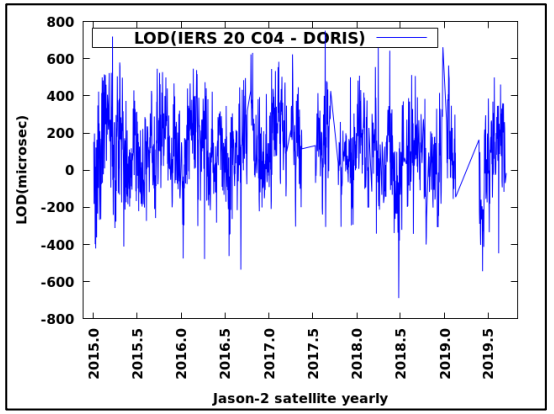


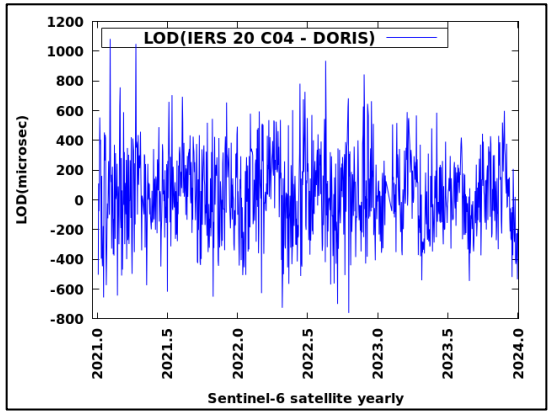


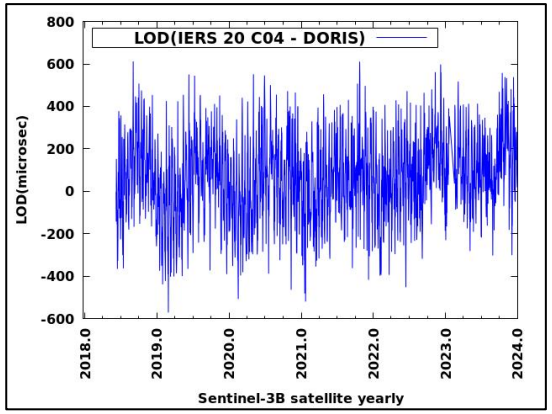


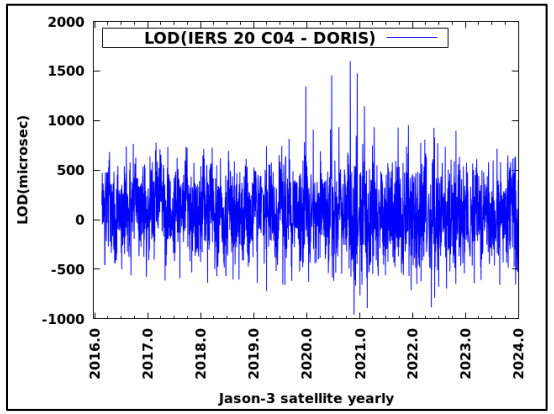












Difference between the LOD time series derived from DORIS measurements and the LOD time series from the IERS 20 C04 model for single satellite solution of L1 campaign.

Estimated statistics for difference in LOD parameter

The statistical values are computed for the interval of 9 years and separately for the combination of satellites and for the single satellite solutions.

Year	Weighted mean [μs]	Weighted standard deviation [μs]
Satellites combination	6.7	87.0
Jason-2	101.4	193.3
Jason-3	67.4	279.6
Sentinel-3A	13.6	205.5
Sentinel-3B	55.8	194.7
Sentinel-6	38.9	266.8
Cryosat	-0.3	241.1
Saral	-114.3	206.1
HY-2A	-13.8	224.7
HY-2C	74.3	325.5
HY-2D	59.9	225.9

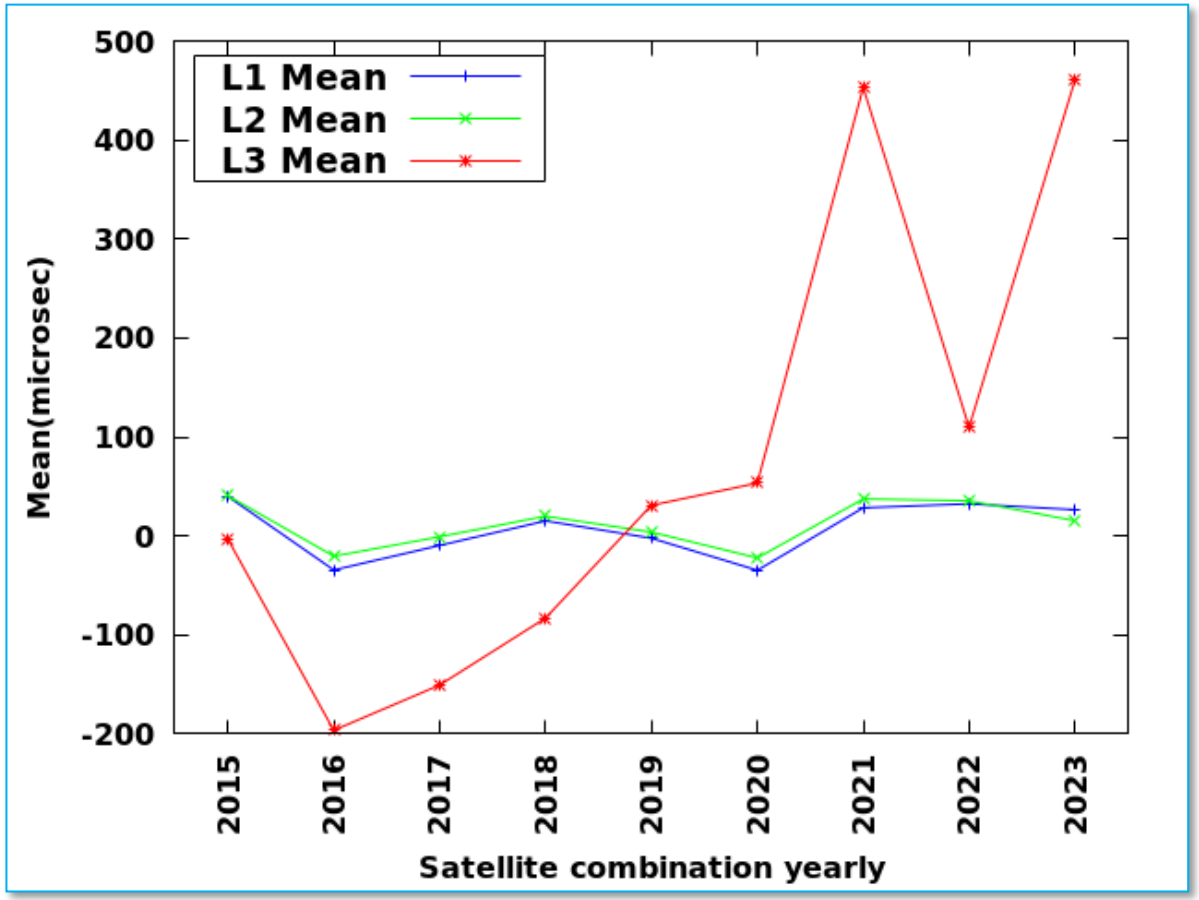
For L1 Campaign

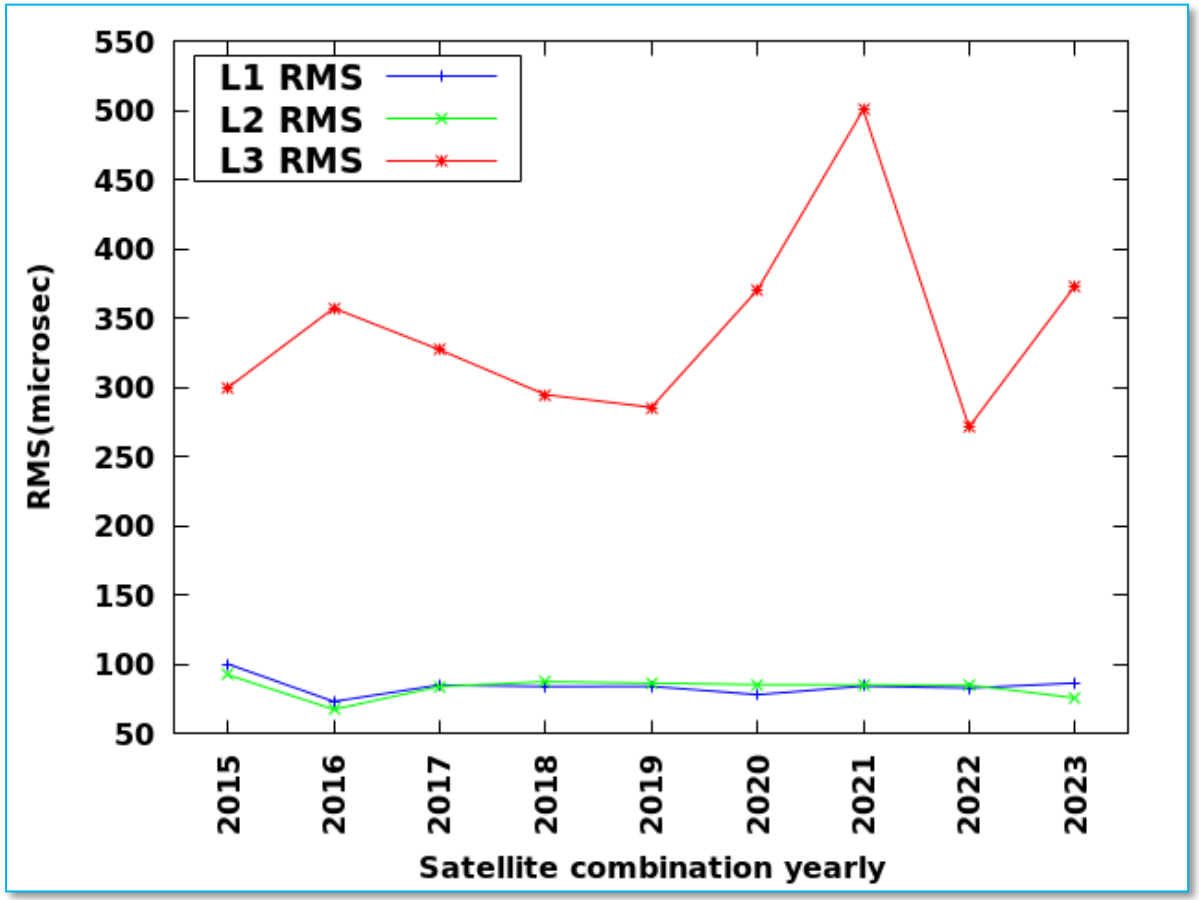
- The mean value of the difference for the L1 campaign is 6.7 μs, estimated as a weighted average, while the weighted standard deviation reaches 87 μs.
- The individual satellite bias is negative for the satellites launched after 2010, i.e., for HY-2A, Cryosat and Saral.

Estimated Statistics Analysis

- As per (P. Stepanek et al., 2018) there is a direct relation between the cross-track harmonic amplitude and the LOD bias.
- The unconstrained or loosely constrained simultaneous adjustment of both parameters leads to an unstable solution.
- The highest LOD biases for the L1 campaign are -114.3 μs for Saral and 101.4 μs for Jason-2, with the highest weighted RMS of 330.4 μs for HY-2C.
- For the satellite combination, the weighted mean and weighted RMS are 6.7 μs and 86.4 μs, respectively. For the L2 and L3 campaigns, the satellite combination weighted means and weighted RMS are 12.6 μs and 86.4 μs, and 83.9 μs and 424.2 μs, respectively.
- A more appropriate approach would be to improve the analytical modeling of non-conservative perturbations to reduce the amplitudes of the empirical accelerations.

Comparison of Mean and RMS Values



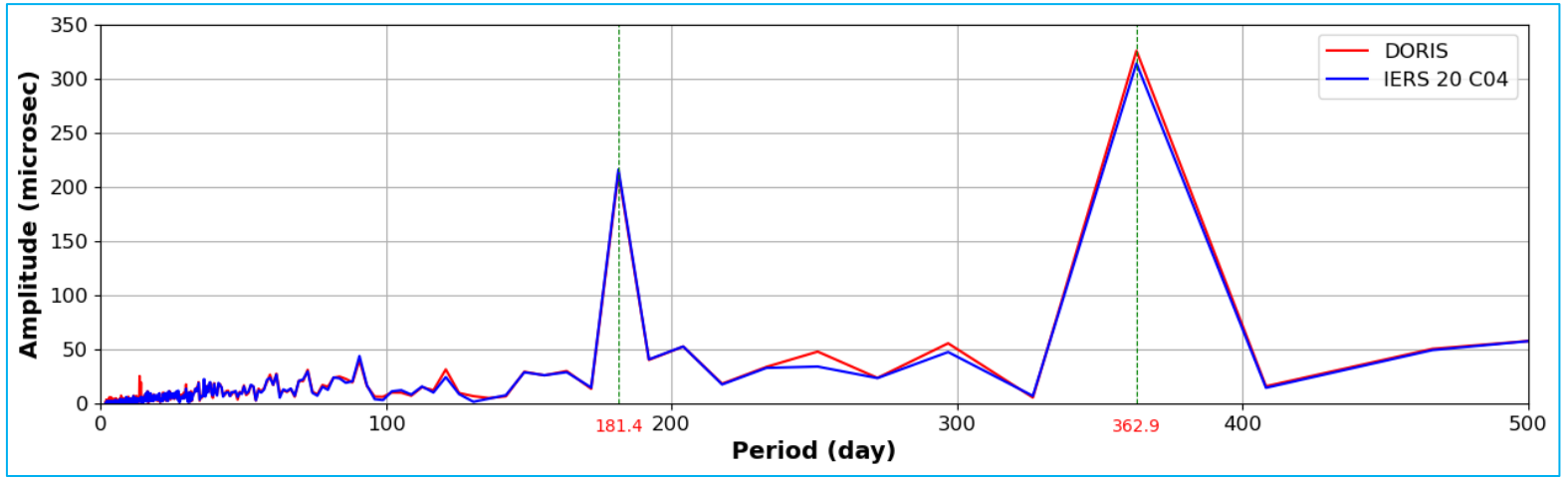


Mean and RMS values for L1, L2 and L3 campaigns for annual solutions.

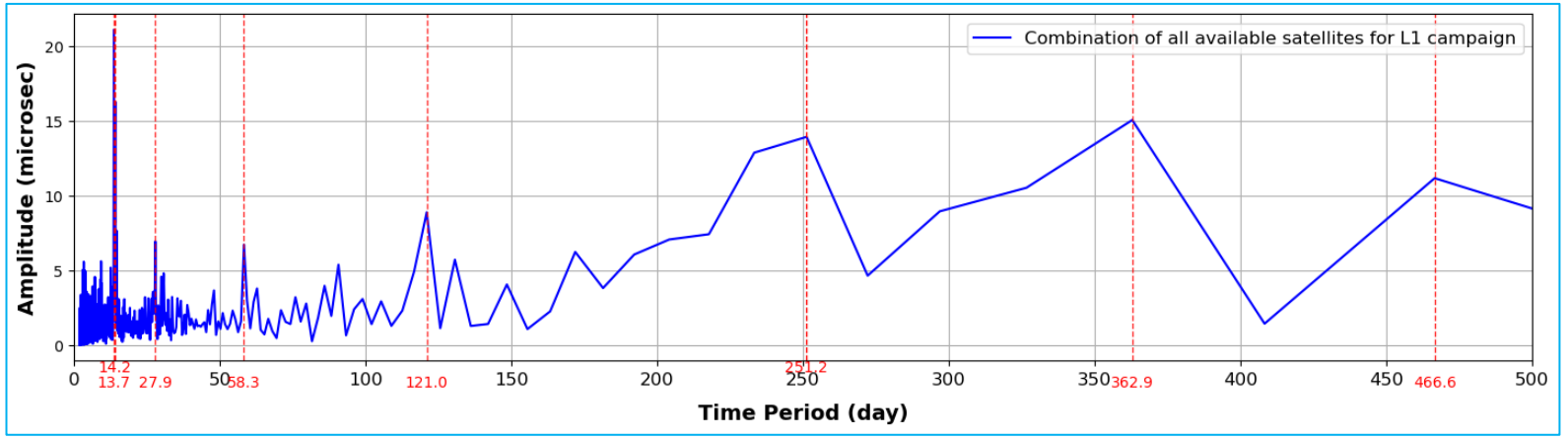
Spectral Analysis

- The most direct approach to obtain the periodogram is by using the power spectrum density (PSD) function, obtained as an average of the Fourier transform amplitudes squared over a large time interval.
- The amplitude of the annual and semi-annual signals is heavily reduced, the semi-annual signal almost vanishes while short periodic signals appear. The LOD difference shows the highest power at the annual period.
- The largest high frequency amplitude (16.3 μs) has a period of 14.2 days. A signal at similar frequency (14.7 days) is known also in the Earth pole coordinates series derived from DORIS solutions (Blosfeld at al., 2016). The origin of the signal is not yet known, but together with the signal with the period 27.9 days, it is commensurable to the lunar period suggesting tidal mismodeling as a possible cause.
- A 14–15 days signal is observed for all the satellites rendering a satellite-specific problem improbable.

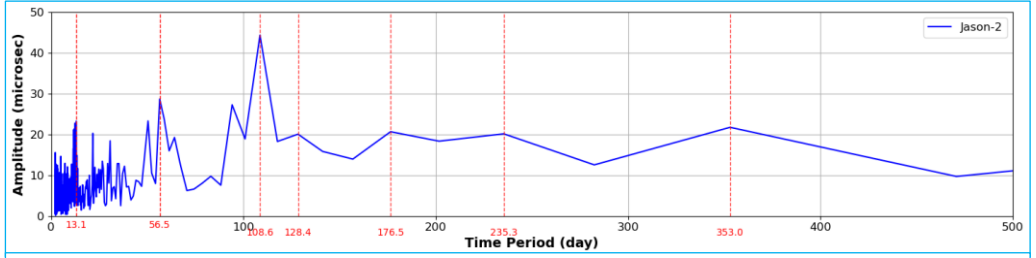
Periodogram of LOD

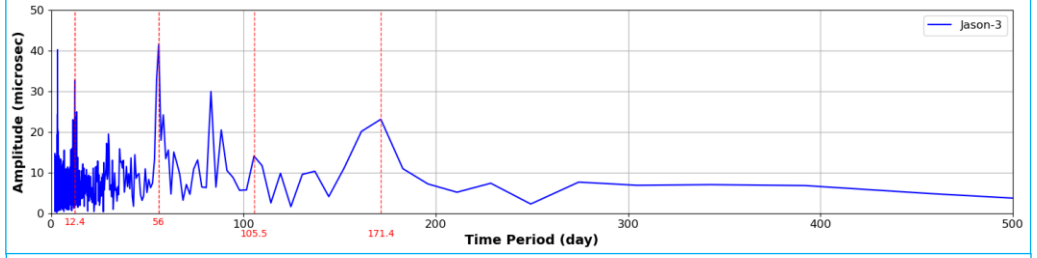


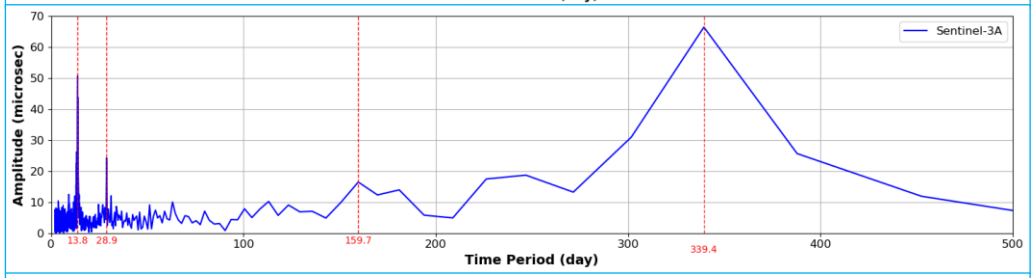
The periodogram of the LOD time series obtained from the combination of all available DORIS satellites for the time interval of 9 years and for the LOD value from IERS 20 C04 (tide effects removed).

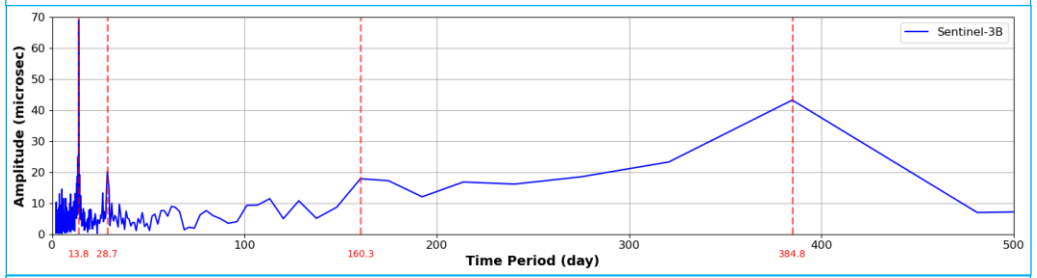


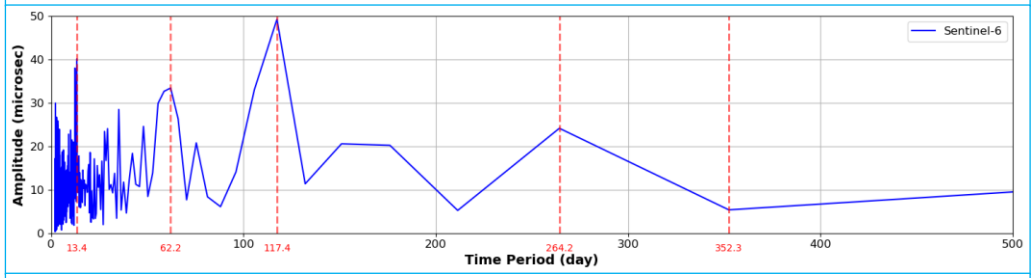
Periodogram of the difference between LOD from IERS 20 C04 and from DORIS combination of all available satellites for a time interval of 9 years.

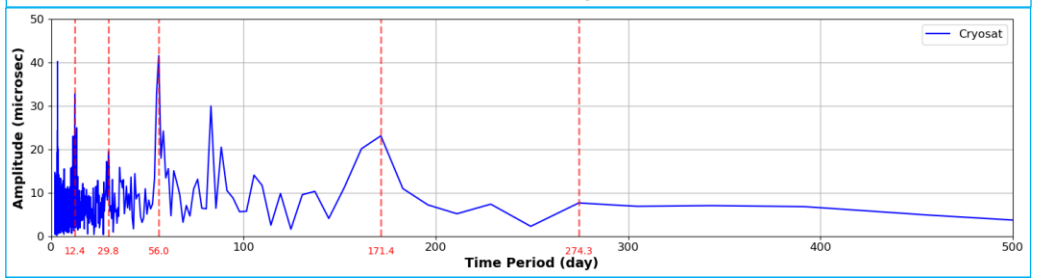

Jason-2
Amplitude (microsec)
Time Period (day)
13.1
56.5
108.6
128.4
176.5
235.3
353.0

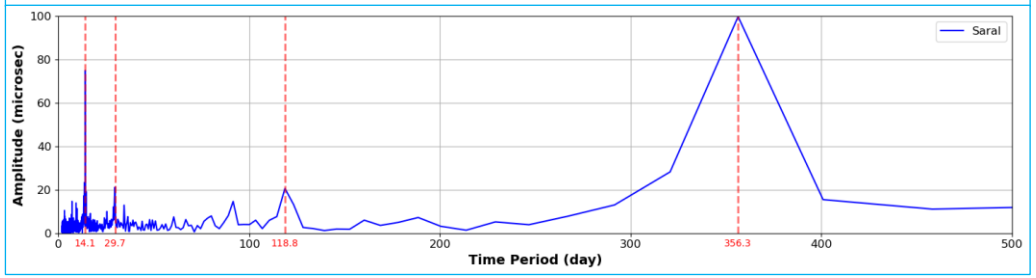

Jason-3
Amplitude (microsec)
Time Period (day)
12.4
56
105.5
171.4

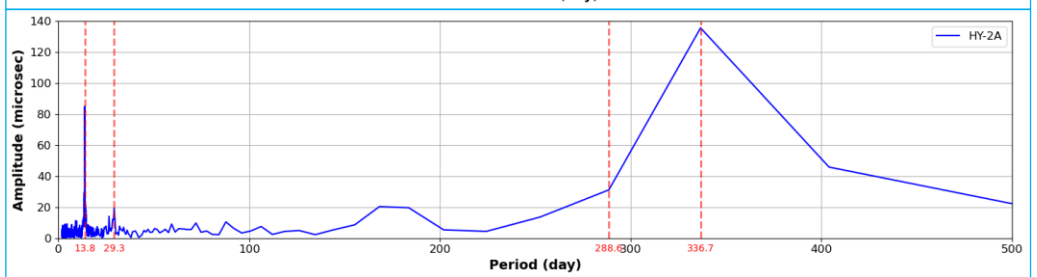

Sentinel-3A
Amplitude (microsec)
Time Period (day)
13.8
28.9
159.7
339.4

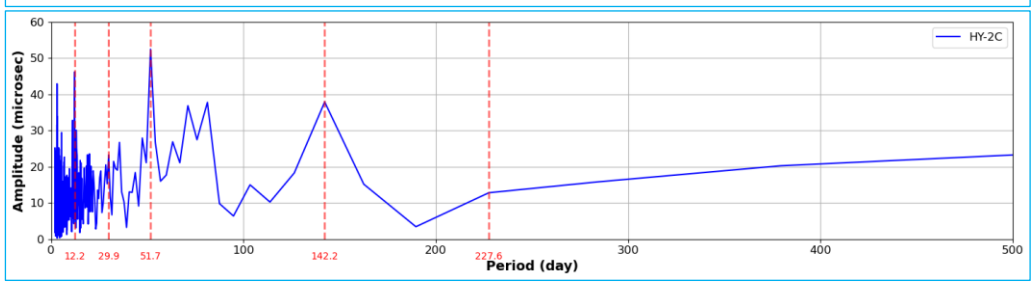

Sentinel-3B
Amplitude (microsec)
Time Period (day)
13.8
28.7
160.3
384.8

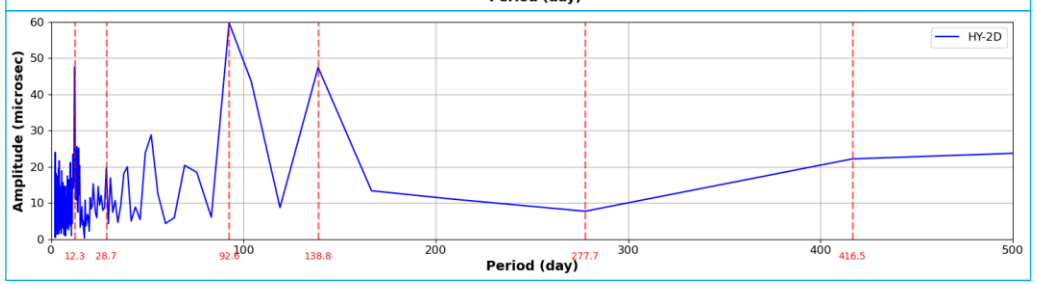

Sentinel-6
Amplitude (microsec)
Time Period (day)
13.4
62.2
117.4
264.2
352.3


Cryosat
Amplitude (microsec)
Time Period (day)
12.4
29.8
56.0
171.4
274.3


Saral
Amplitude (microsec)
Time Period (day)
14.1
29.7
118.8
356.3

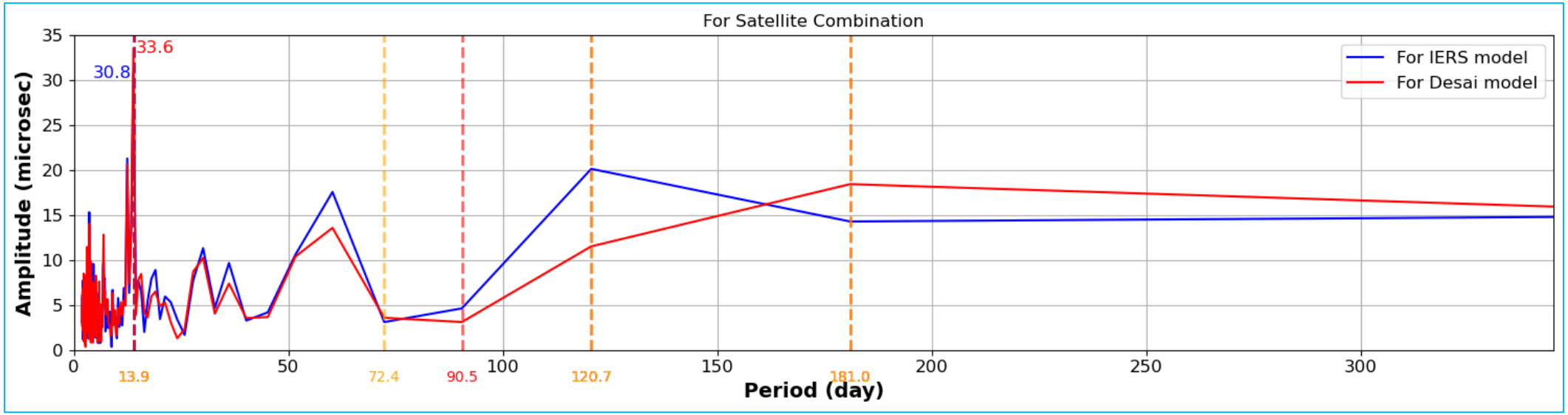

HY-2A
Amplitude (microsec)
Period (day)
13.8
29.3
288.6
336.7


HY-2C
Amplitude (microsec)
Period (day)
12.2
29.9
51.7
142.2
227.6


HY-2D
Amplitude (microsec)
Period (day)
12.3
28.7
92.6
138.8
277.7
416.5

Experiment with Polar Motion Model

- Instead of using the Desai-Sibois (Desai and Sibois, 2016) subdaily polar motion model, we used the model specified in the IERS 2010 conventions.
- For satellite combinations, for the recent Desai and Sibois subdaily polar motion model, the amplitude at 13.9 days is 33.6 μs while for IERS conventions it is 30.8 μs.
- For Jason and S6, the draconitic period is around 118 day so the peak is very significant for both.



Periodogram for LOD difference between DORIS and IERS 20 C04 for Desai-Sibois subdaily polar motion model, the model specified in the IERS 2010 conventions for satellites combination.

Conclusions

- A stronger constraint (L1 and L2 Campaigns) of cross-track harmonics improves the LOD quality from DORIS significantly.
- Earth's rotation is slowing down by gravitational forces and other long-term geophysical processes.
- Significant signal of period observed was around 14, 28, and 59 days for a shorter window span.
- Desai and Sibois subdaily polar motion model, and IERS conventions results are comparable for LOD estimation of satellite combination.
- Better accuracy would be achieved by IDS combination, while combining all AC's results.
- Future plan is to estimate the impact of relativistic effects (applied besides Schwarzschild-effect) on LOD estimation.

Thanks for the attention !