Modeling of the GIOVE-B clock as a tool for studying radiation pressure models

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The idea

Satellite orbit and clock parameters are highly correlated. New generation GNSS satellite clocks show a high stability. This allows modeling of the satellite clocks which in its turn reduces the correlation between satellite and clock parameters.

In the experiments described here several radiation pressure models for GIOVE-B are investigated for high and low Sun elevation above the orbital plane and with constraining the epoch-wise estimated satellite clock parameters to a linear model. Is it possible to discriminate between models by assessing the orbit behavior for varying clock constraints?

CONGO network and GIOVE-B POD

Data of GIOVE-B from the CONGO network was used for the experiments. The CONGO (COoperative Network for GIOVE Observation) is a global GNSS tracking network operated jointly by DLR, BGK, GFZ, CNES and with the help of a number of local site operators. Data from the new GNSS satellites is routinely acquired and streamed in real-time to TUM where precise satellite orbits are computed and to DLR where real-time clock parameters are generated.

Fig 1: CONGO network currently consisting of 22 globally distributed real-time permanent GNSS stations.

Daily GIOVE-B orbit and clock parameters are computed in a two-step procedure:

(1) Calculation of station coordinates, station troposphere parameters and receiver clock parameters are estimated using point positioning with GPS phase observations.

(2) Station parameters are kept fixed and GIOVE-B orbit and clock parameters are computed.

GIOVE-B clock performance

The H-maser onboard GIOVE-B shows an excellent stability. The clock variations are dominated by a once-per-revolution pattern that is most probably caused by orbit modeling deficiencies and temperature effects.

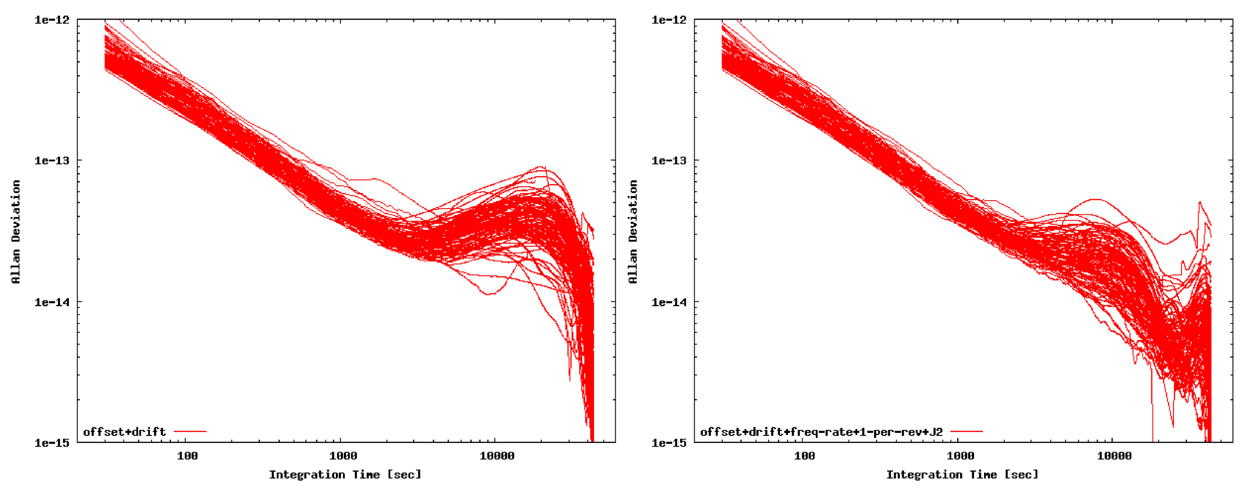

Fig 2: Allan deviations of daily clock parameters from 184-296/2009. Left: with offset and drift removed. Right: with offset, drift, 1-per-rev and relativistic J2-correction removed. The bump around 20'000 caused by 1-per-rev variations vanishes leaving a bump at 2-per-rev.

Clock modeling

The high stability of the H-maser onboard GIOVE-B allows to employ a linear clock model which allows to decorrelate orbit and clock parameters. In the following experiment epoch-wise GIOVE-B clock corrections with varying contraints towards a linear model with estimated daily offset and drift are estimated together with orbit parameters.

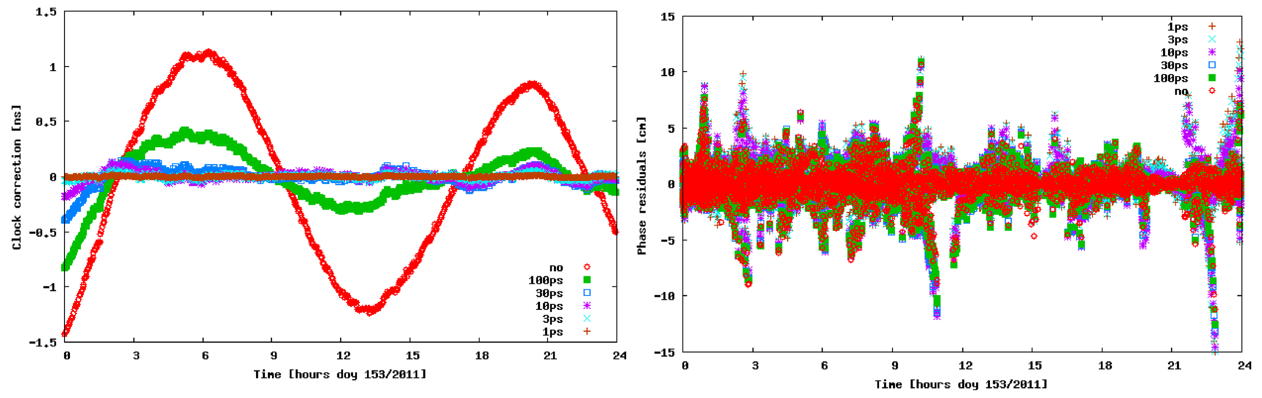

Fig 3: Left: Estimated GIOVE-B clock corrections with varying constraints towards a linear model. Right: Corresponding phase residuals.

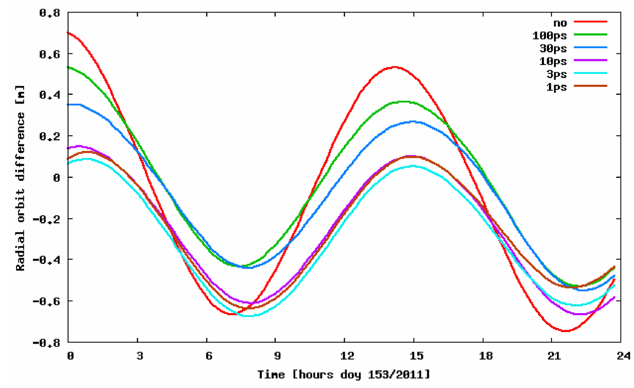

Fig : 4

The constraints on the satellite orbit parameters force the orbit parameters to adapt. The radial offset of the daily orbits to a 5-day reference orbit with no constraints shows varying offset and amplitude of once-per-rev variation.

Sun elevation above orbital plane

The elevation of the Sun above the orbital plane impacts the behavior of orbit and clock parameters. Clock corrections show higher amplitudes of once-per-revolution variation if standard radiation pressure model is used.

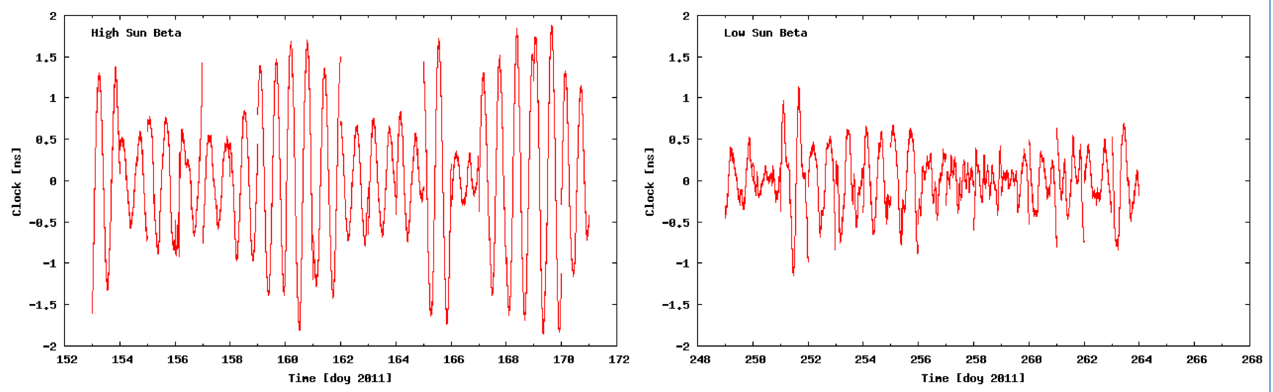

Fig 5: Estimated GIOVE-B satellite clock corrections, left for 18 days around maximum Sun elevation of 78° in May 2011, right for 15 days around minimum Sun elevation in September 2011.

Tab 1: Data used for experiments

Date	Doy	Sun elevation
May 15-24, 2011	153-171	71.3° – 78.2°
Sep. 06-20, 2011	249-263	8.8° – -5.9°

Variations of the clock parameters in Fig. 5 show consistency from day to day and are related with the position of the satellite along its orbit with respect to the location of the Sun. Reasons could be temperature effects in the satellite and impact of radiation pressure model deficiencies.

Ten radiation pressure models are investigate:

1) CODE model with different number of parameters
2) Box-wing model (Rodriguez-Solano et al., 2012)
3) Models similar to CODE but with 2-per-rev and 4-per-rev terms. Independent argument is the argument of latitude w.r.t. the Sun position.

Radiation pressure models

The following ten radiation pressure models are investigated:.

Model	#Par	Sun-direction	Panel-axis	Orthogonal
CODE	9	D0 DC DS	Y0 YC YS	X0 XC XS
CODE	7	D0	Y0 YC YS	X0 XC XS
CODE	5	D0	Y0	X0 XC XS
BOXWING	9	(optical surface properties with constraints)		
DY2X12	9	D0	Y0 Y2C Y2S	X0 XC XS X2C X2S
D24YX124	9	D0 D2C D4C	Y0	X0 XC XS X2C X4C
D12YX2	9	D0 DC DS D2C D2S	Y0	X0 X2C X2S
D1YX12	9	D0 DC DS	Y0	X0 XC XS X2C X2S
D12YX12	9	D0 DC DS D2C	Y0	X0 XC XS X2C
D2YX12	9	D0 D2C D2S	Y0	X0 XC XS X2C X2S

Once-, twice- and four-times-per-revolution terms typically appear in the radiation pressure acceleration for a satellite body consisting of a box-shaped body and solar panels.

Results: Orbit overlaps

For each model about two weeks of daily phase tracking data around high Sun elevation and low Sun elevation above orbital plane are processed with clock constraints from 100 to 1 ps towards a linear clock model. Estimated parameters are initial conditions, radiation pressure parameters, clock offset and drift, constrained epoch-wise clock parameters, phase ambiguities.

The following figures show results for each of the ten radiation pressure models, ordered for each model from left to right according to the applied clock constraint from no constraint to strong constraint (no, 100, 30, 10, 3, 1 ps). Values for same constraints correspond to different days (s. Tab. 1).

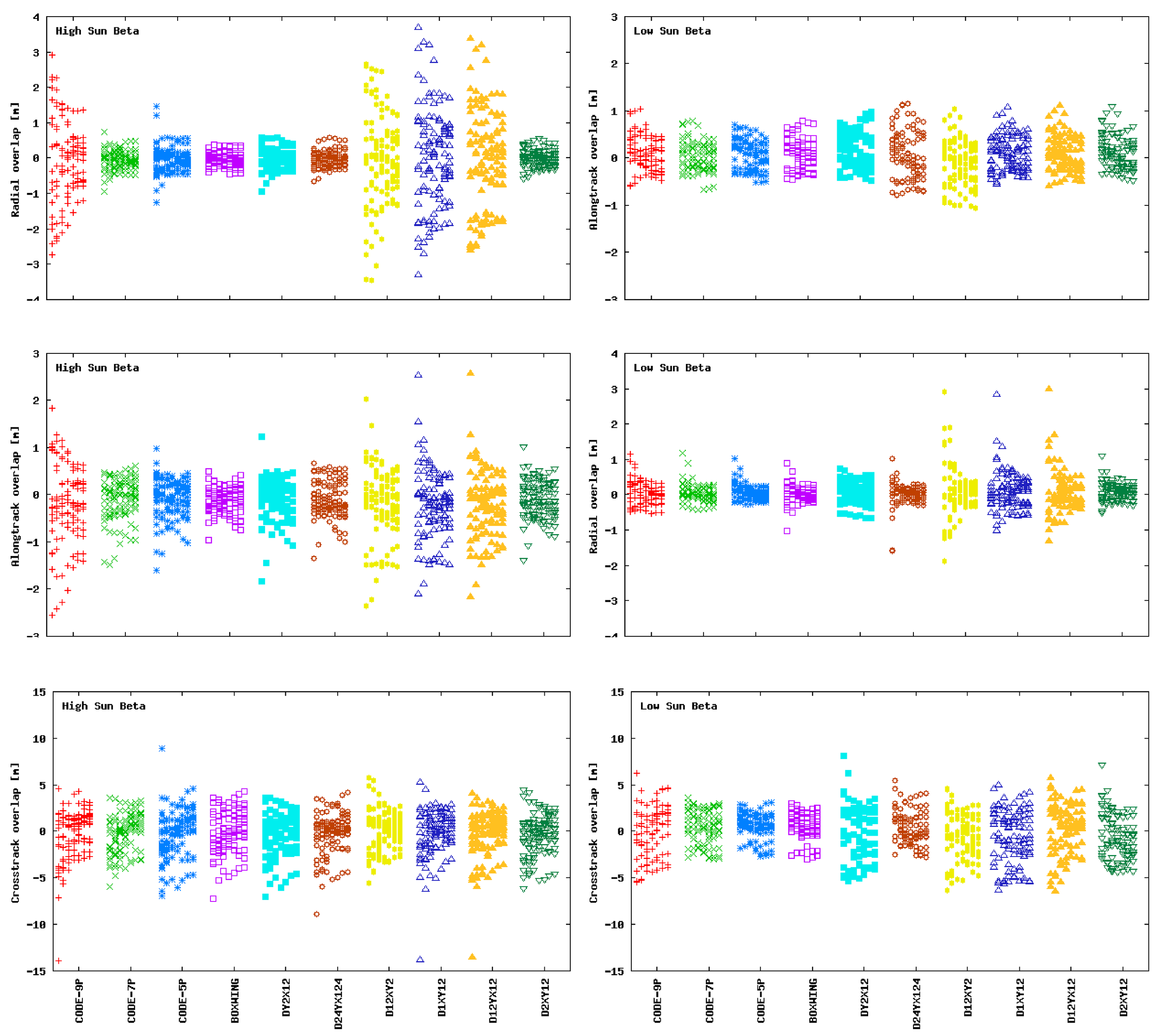

Fig 6: Overlap of daily orbit arcs at day boundaries.

Radiation pressure models with once-per-rev harmonic terms in Sun-direction show a bad performance mainly in radial and alongtrack components which improves when constraining the clock parameters to a linear model. Other models show minor effect on different clock constraints.

Results: Comparison with longarc orbit

The following figures show the comparison of the daily orbits with the middle day of a 5-day reference orbit based on the 9-parameter CODE model.

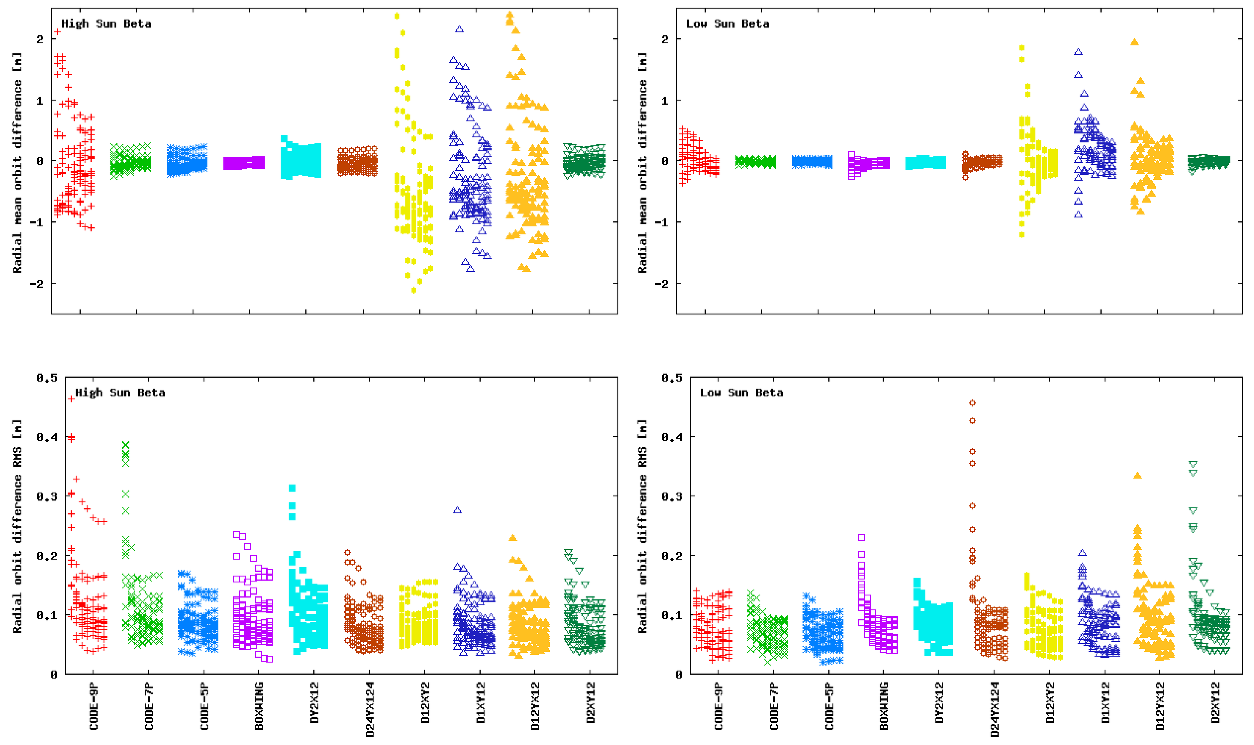

Fig 7: Comparison with longarc reference orbit. Top: Daily mean radial orbit difference. Bottom: Radial orbit difference RMS.

Orbit models with once-per-rev parameters in D-direction (to the Sun) again show generally a bad behavior. With increasing clock constraints the orbits approach the reference orbit. Box-wing and CODE 5 parameter model show a good performance.

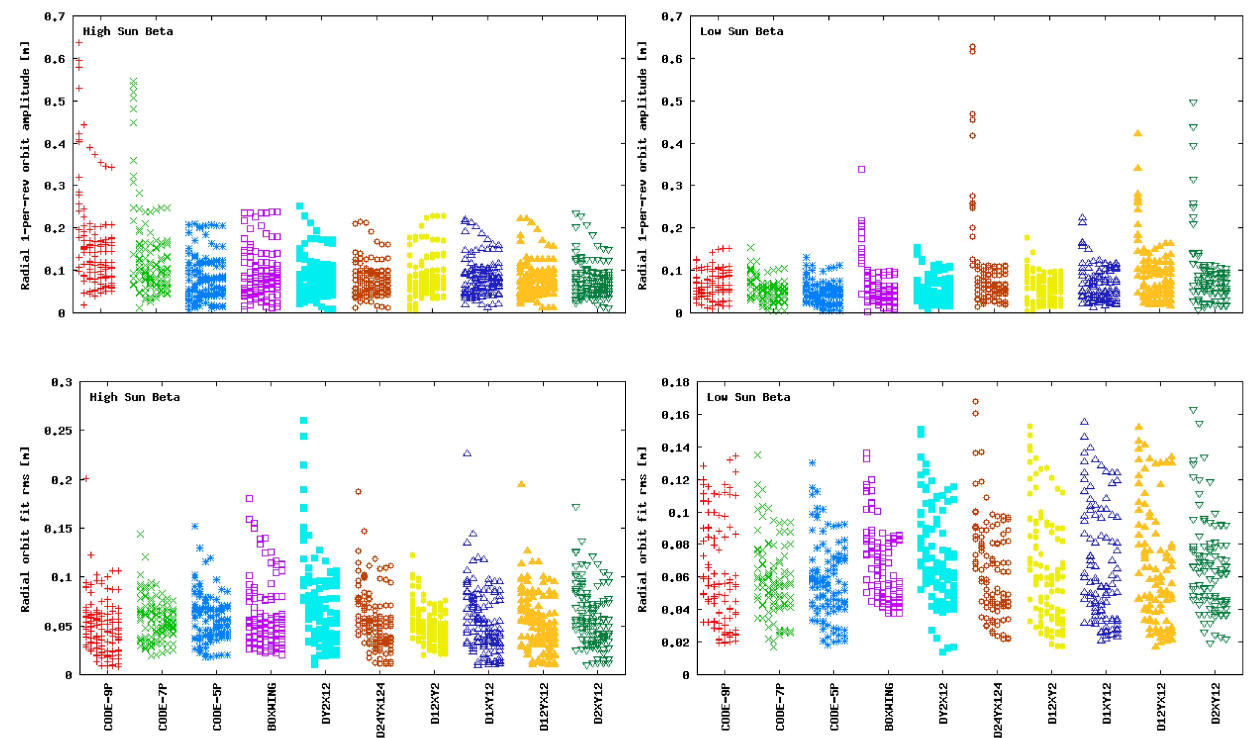

Fig 8: Top: amplitude of a once-per-rev variation in the radial difference between 1-day orbit and reference longarc orbit. Bottom: Orbit difference RMS after adjusting a bias and a once-per-rev variation.

For high Sun elevation the amplitude of the periodic variation in the radial orbit difference is larger and decreases with increasing clock constraint. For low Sun elevation the radial orbit behavior can less well be adjusted by a bias and a once-per-revolution periodic function.

Conclusions

- Modeling of new generation stable satellite clocks allows to mitigate the correlation between orbit and clock parameters.
- Radiation pressure models with periodic terms in Sun-direction show bad performance.
- Good performance can be observed for the 5-parameter CODE model currently used for GPS satellites in the IGS, and for the box-wing model.
- Performance varies with Sun elevation above the orbital plane.

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