GNSS Satellite Orbit Modeling at ESOC

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Abstract

For the second IGS reprocessing effort, and since April 2014 also for our routine IGS products, ESA/ESOC changed the a priori orbit model for the GNSS satellites to include a Solar Radiation and Earth Albedo model based on a simple box-wing model for the GNSS satellites.

Here we firstly explain our motivation, the rational and the initial tests we performed with the new a priori box-wing model. Secondly, we show the significant orbit differences that result from applying the box-wing model. SLR residuals are shown to proof the correctness of the box-wing model as well as some results from other ACs.

Motivation

The Enhanced CODE Orbit Model has since 1999 resulted in very good GNSS orbit estimates. However, a physical explanation for the periodic terms in the "B" direction has never been found.

The work at the TUM by Carlos Rodriguez provided a complete set of information for the GPS and GLONASS satellites. And although intended for Albedo modeling the values should also be applicable for the direct Solar Radiation modeling. In our NAPEOS software we use box-wing models since several years for all LEO satellites. So it was very easy to test the box-wing models for the GNSS satellites.

Approach

We decided to start with the well known approach, used at CODE and JPL for generating their respective GNSS orbit models, of fitting long arcs through the IGS orbits. We performed such orbit fits for the full year of 2012 estimating the satellite state vectors and all 9 parameters of the Enhanced CODE Orbit Model. This was done once without any a priori model and once with the box-wing model for the GPS and GLONASS satellites.

The time series of the estimated CODE parameters was analyzed to see the effect of the a priori box-wing model.

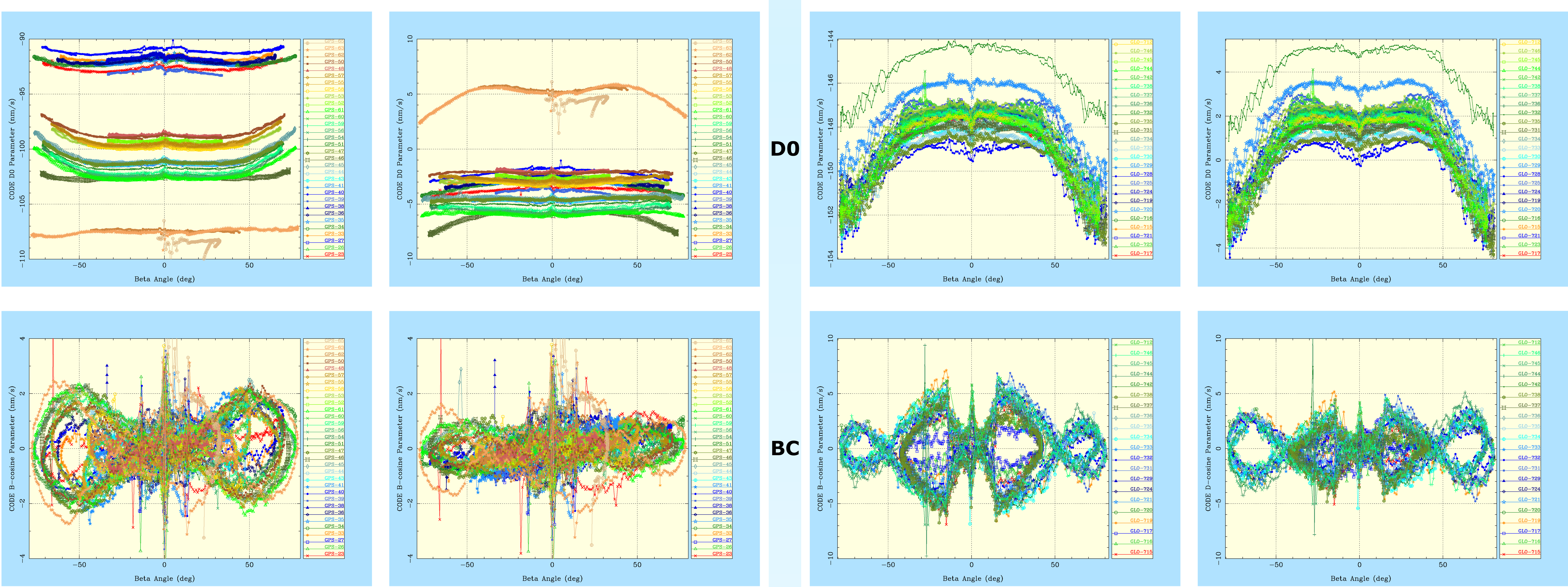
Initial Results (figures below)

The results of the full year orbit fit for GPS and GLONASS are demonstrated in the 8 figures below. On the left are the GPS results and on the right the GLONASS results. The results are shown for two of the three key parameters of the CODE model, the direct solar radiation pressure (**D0**), and the periodic cosine term in the B-direction (**BC**). The time series are plotted as function of the elevation of the Sun above the orbital plane (Beta).

The differences between the two series are very significant! The very simple box-wing model is able to explain a significant part of the B-periodic signals we observe.

GPS Satellites | GLONASS Satellites

No Apriori Model | Box-Wing Model | No Apriori Model | Box-Wing Model

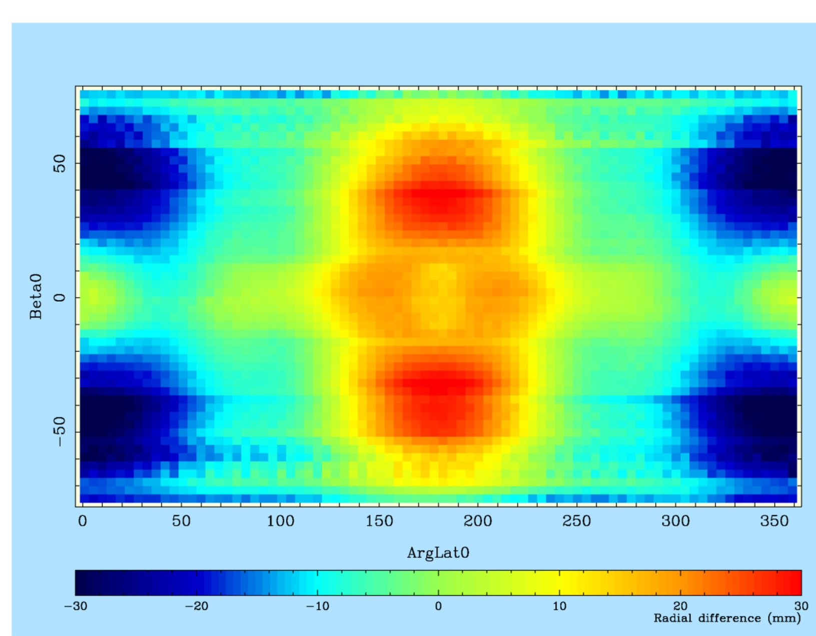


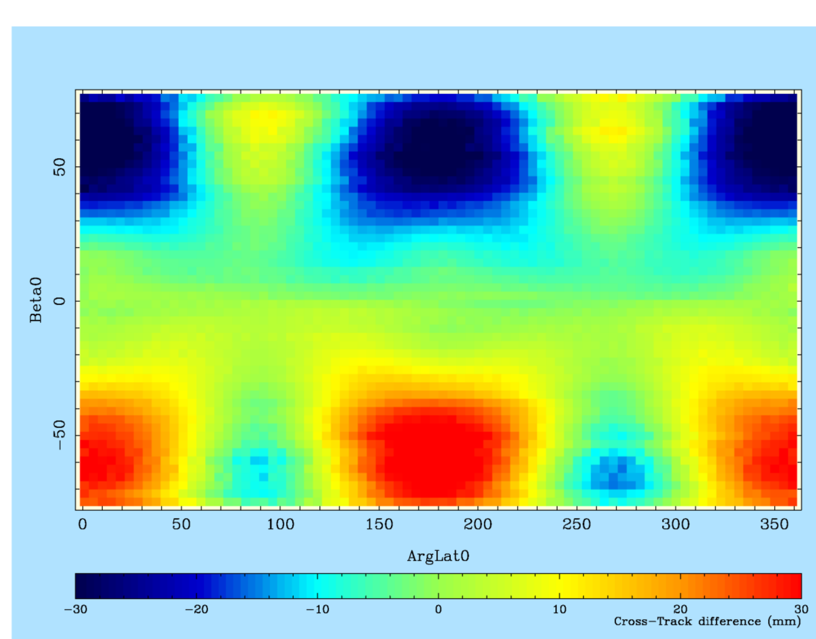
Real Data Processing

The orbit fits figures above show that the box-wing model does account for the majority of the direct solar radiation (D0) and also for a large part of the periodic terms in the B-direction. This motivated us to test the box-wing model in a real IGS like processing. We reprocessed the year 2012, twice. First, in our "standard" IGS way and a second time completely identical but now using the box-wing model as a priori model. The data that was used and all parameters that were estimated were completely identical in the two runs. Only the **a priori model** was changed.

The two figures on the right show the resulting mean radial and cross-track orbit differences for the full year as function of the argument of latitude and the elevation of the Sun above the orbital plane (Beta angle) for all GPS satellites. Very clear patterns are visible with a surprisingly large magnitude of 40 mm. There is also a pattern in the along-track direction but the size is much smaller with a magnitude of 20 mm.

For GLONASS similar but smaller patterns are visible at a level below the 20 mm.

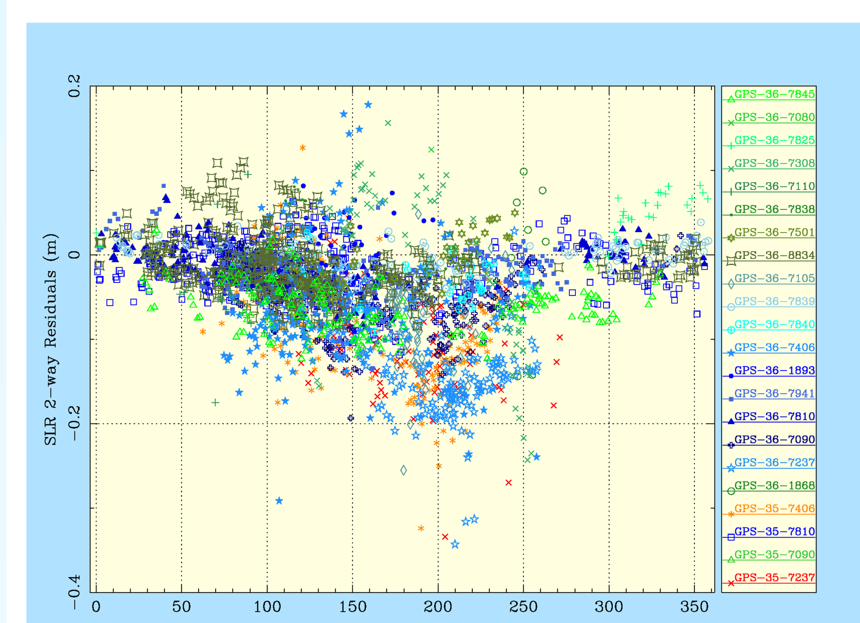


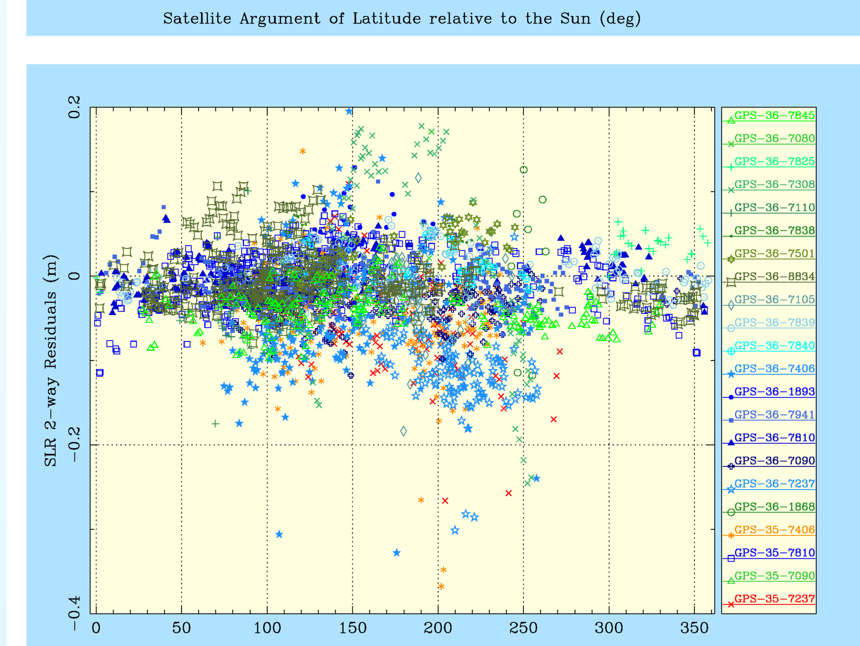


Validation of the box-wing model

The very systematic mean radial and cross-track differences of 40 mm are really surprising. We therefore analyzed the times series of our two reprocessed solutions (full year of 2012) to determine which of the two is "better". Very significant differences were observed in our orbit consistency check where we compare the last epoch of day n, i.e. the 24:00 hour epoch, with the first epoch of day n+1, i.e. the 00:00 hour epoch. For the standard solution the RMS over the whole 2012 period was 29, 42, and 33 mm for the radial, along, and cross-track directions, respectively. For the solution with the box-wing a priori model the RMS values were significantly better with 28, 39, and 29 mm. More then 10% improvement! Smaller, but significant, improvements were also visible in the station coordinate repeatability and the ERP consistency.

Last but not least we evaluated the orbits using the SLR observations of the GPS satellites. The O-C residuals statistics are plotted in the two figures on the right. A dramatic improvement can be observed that corresponds well with the observed mean radial orbit differences.



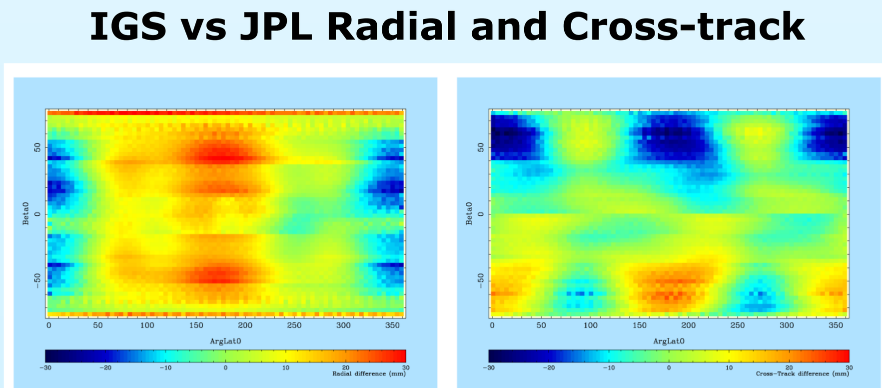


Other IGS Orbits

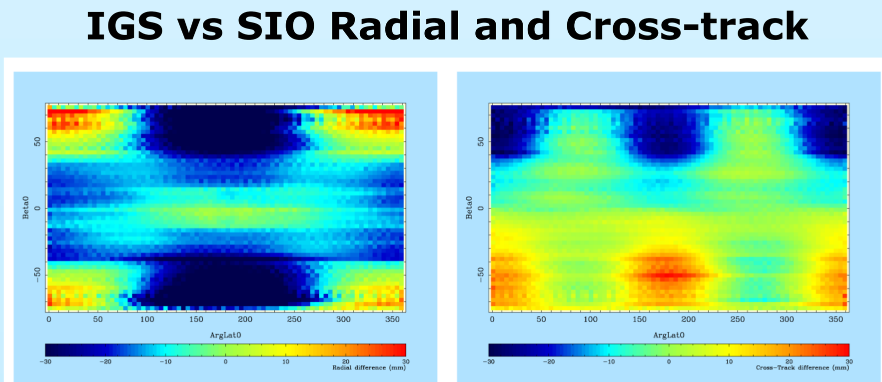
For 2013 we compared the orbits of all IGS routine and repro-2 solutions against each other in the argument of latitude and Beta-angle axis systems. We found that:

- EMR and JPL orbits show a very similar pattern as our box-wing orbits. The JPL GSP model mimics the box-wing model fairly well (top two figures on the right)
- The GRGS orbits show the opposite patterns in all three directions. GRGS does not estimate any B-periodic signals nor does it use a box-wing model
- The SIO orbits show a similar signal in the cross-track direction but the radial pattern is completely different (see the two bottom figures on the right)

IGS vs JPL Radial and Cross-track



IGS vs SIO Radial and Cross-track



Conclusions

- The mis-modeling of the Solar Radiation Pressure causes systematic radial and cross-track orbital differences
- The box-wing model fully explains the long known pattern in the SLR residuals and it significantly reduces the orbital periods in the different GNSS based time series
- Box-wing modeling (or alternatively the JPL GSP models) for the GNSS satellites should become the standard in the IGS, subject to availability of info about geometry and material properties of GNSS satellites!
- SIO and GRGS should be able to improve their orbits significantly with very little effort
- ESA/ESOC used the box-wing model for the reprocessing (ES2 products) and since April for our routine products (GPS week 1789). Orbital periods in our time series should be significantly reduced.

European Space Agency