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Bridging of VLBI dUT1 by Integration of GNSS and AAM LOD

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1. Introduction

This poster examines the accuracy of dUT1 predictions over time, based on different LOD sources such as different GNSS solutions and effective AAM functions. It is meant as a preliminary investigation for bridging VLBI UT1 measurements.

VLBI is unique among the geodetic space techniques, as it is the only one that gives us access to a inertial reference frame and thereby allows us to measure UT1. However, other geodetic space techniques such as GNSS are able to measure the (negative) rate of change of dUT1, which is called Length Of Day (LOD). Thus, it is possible to predict dUT1 over time by integrating LOD and adding the known dUT1 value at t_0.

Furthermore, the main drivers of variations in the Earth rotation rate are the variable mass distribution of the atmosphere and zonal winds as well as zonal tides of the solid Earth and oceans. The latter can be calculated from the IERS (International Earth Rotation and Reference Systems Service) model, while the atmosphere's variations are available as Atmospheric Angular Momentum (AAM) functions. Thus LOD and in turn dUT1 can be estimated that way.

2. Data & Methodology

- C04 (iers.org)
  The C04 dataset from the IERS is used as a reference for both the LOD values from different sources themselves and for the estimated dUT1 values. It is also used in the estimation process, by providing the dUT1 at t_0 as the integration constant as well as LOD at t_0 for calibrating the offset of LOD values.
- GNSS LOD data (Horozovic, Weber (2018))
  In total 4 different GNSS datasets were used which varied in terms of the length of the calculated solution (1 or 3 day solution) and which GNSS systems were used (only GPS or GPS and Galileo). The investigation period is from 07-01-2017 to 11-01-2017.
- AAM (Dobslaw, Dill (2018))
  For the AAM data the effective angular momentum functions from atmospheric mass and motion terms from the GFZ-Potsdam are used. They have a temporal resolution of 3 hours. (File: ESMGFZ_AAM_v1.0_03h_2017)

The time correction dUT1 is the difference between dUT1 and UTC. It is directly linked to the Earth Rotation Angle (ERA) which is important for transformations between celestial and terrestrial reference frames. The Length Of Day (LOD) refers to the excess time of a full earth rotation with regard to the fictitious sun compared to an SI-day with 86400 s and it is the negative time derivative of dUT1:

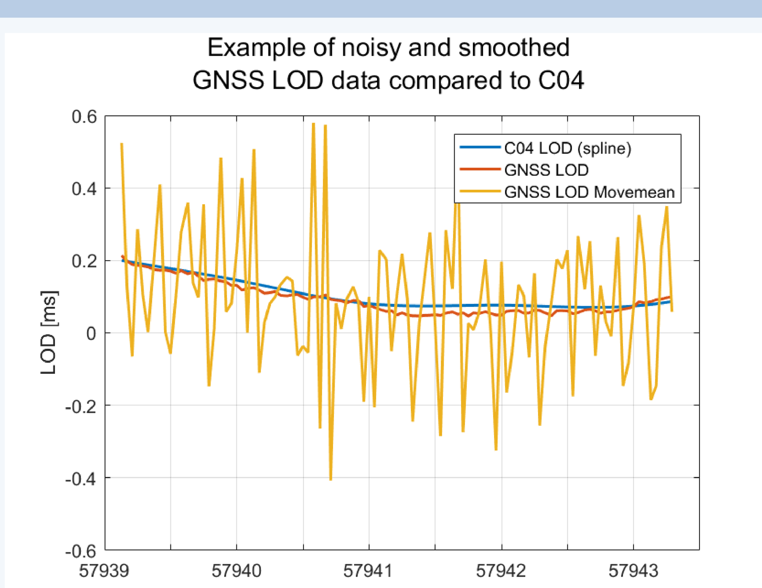
$$dUT1 = \int_{t_0}^{t_{end}} -LOD(t)\,dt + dUT1_{t0}$$

In the case of discrete measurements the integral is replaced with a sum. For all following calculations the cumulative trapezoidal numerical integration function of Matlab is used.

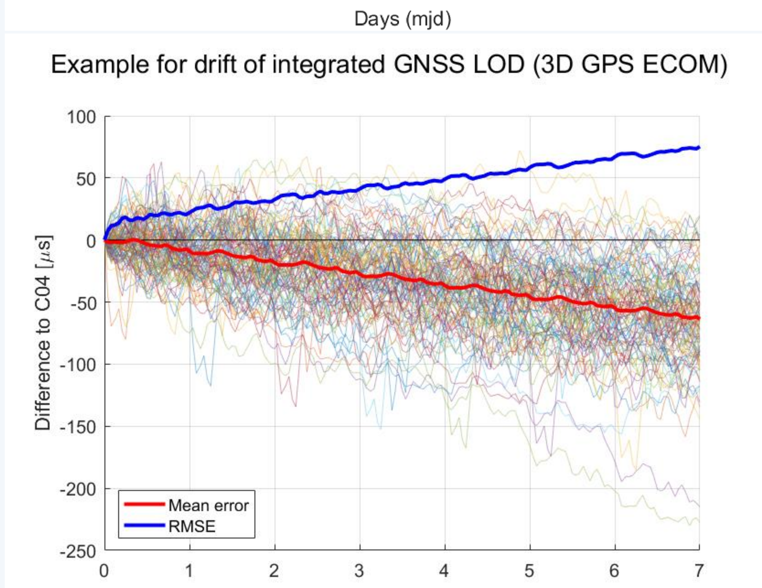
In order to assess the accuracy of the dUT1 estimates, the LOD data is integrated over the period of one week and the results are compared to the C04 which is interpolated with a quadratic spline. Then the integration window is shifted by one day and the process is repeated. After the end of the investigation period is reached, the mean error and the root mean square error (RMSE) are calculated.

3. Offset in the GNSS LOD data

All used GNSS LOD datasets seem to have an approximately constant offset when compared with the C04 reference data. A correction based on the LOD value at t_0 as done with the AAM and tides LOD data is not possible due to the noisy nature of the data. Even with a smoothed signal the calculated offset at t_0 doesn't represent the mean offset over the week well enough (see figure) and ultimately even causes a degradation of accuracy.



This constant offset of the LOD values results in a linear drift in the calculated dUT1 values. In order to circumvent this, part of the GNSS data is used to estimate the offset which gets applied to the rest of the data. The offset is calculated by weekly integration of the LOD data and subsequent fitting of a linear function through the mean error for each timestep of each integration period (red line in figure).



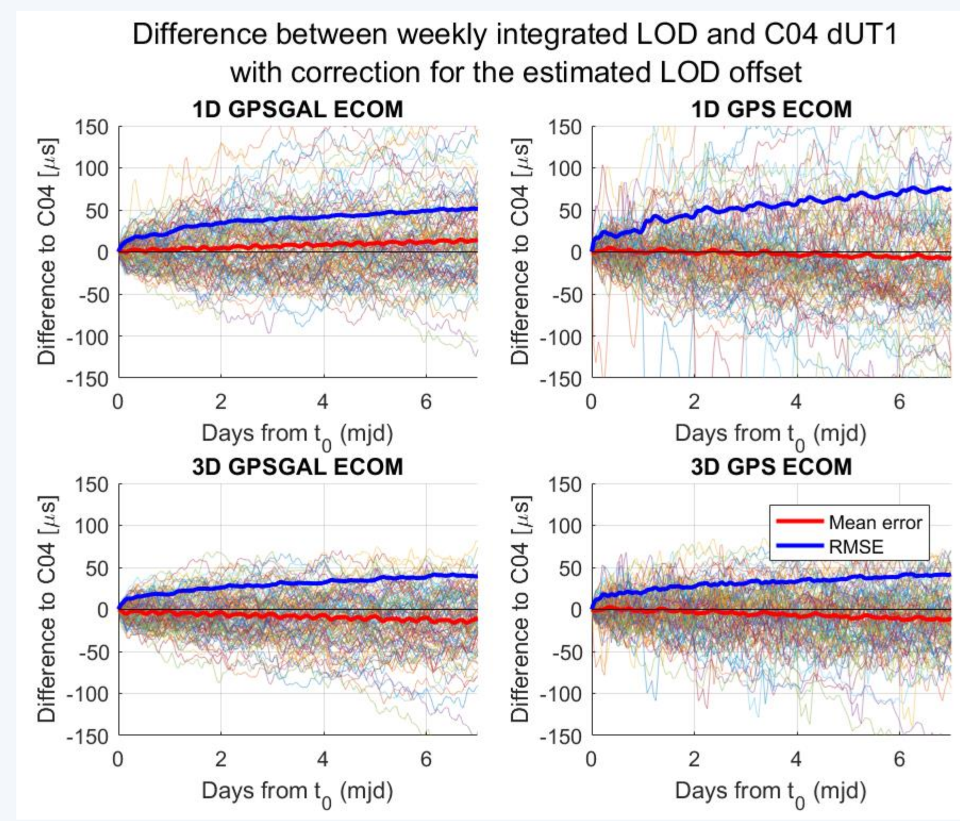
This correction eliminates most of the constant offset in the LOD data and thus also the linear drift in the calculated dUT1. With a remaining mean error of about 0 in the LOD data the error of the calculated dUT1 follows a random walk error.

4. Offset in AAM data

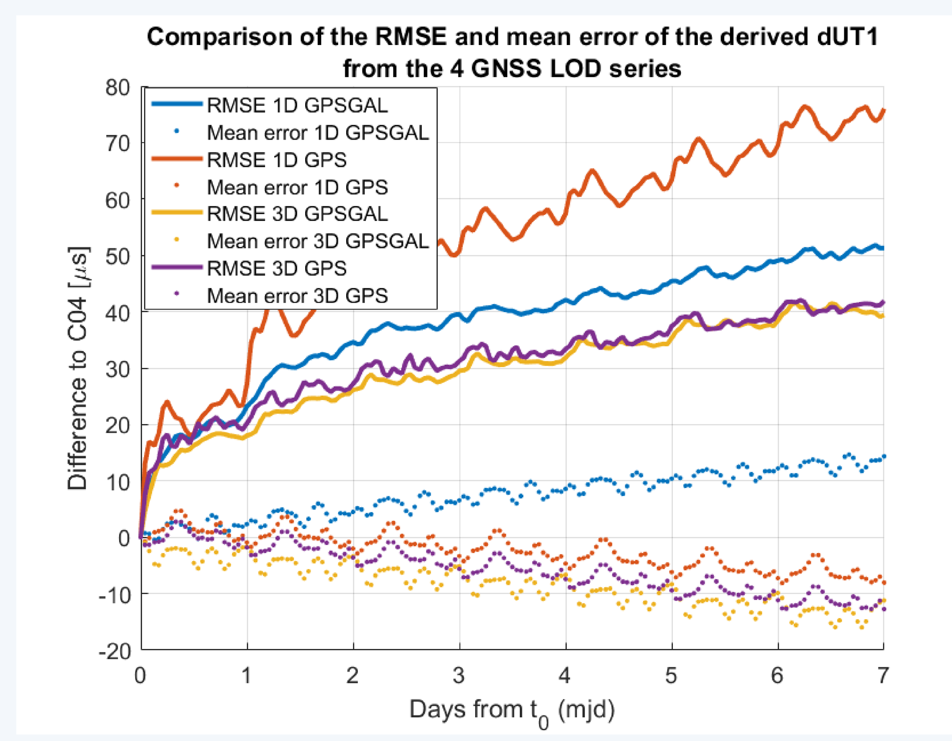
The LOD derived from the effective AAM functions doesn't contain the effects of tides which is rectified by adding their effects on the length of day as calculated by a Matlab function that follows IERS Conv. 2010, chapter 8. In addition, the AAM data doesn't include long term variations of the rotation speed of earth that are caused by core-mantle interaction, very long periodic tidal effects and other factors. This leads to a quite substantial, not constant offset of the LOD values which is corrected by subtracting the difference between the LOD at t_0 and the C04 reference. This eliminates the offset at t_0, but since it is not constant the error increases over time. This makes dUT1 estimation difficult.

5. Results

Using the offset correction described in section 3 the resulting dUT1 estimates from GNSS have a mean error of almost 0 and a max root mean square error (RMSE) of 40-70 µs after one week, depending on the used dataset. 3-day solutions are clearly superior to 1 day solutions, both in terms of the RMSE and the biggest deviations. Although the solution with 1d GPS is "only" worse by a factor of 1.5 when comparing its RMSE to the best solution, it is much less reliable since the error during certain weeks is considerably larger (see individual lines in the figure). When looking at the 3-day results only the difference between GPS and GPS + Galileo is surprisingly small.

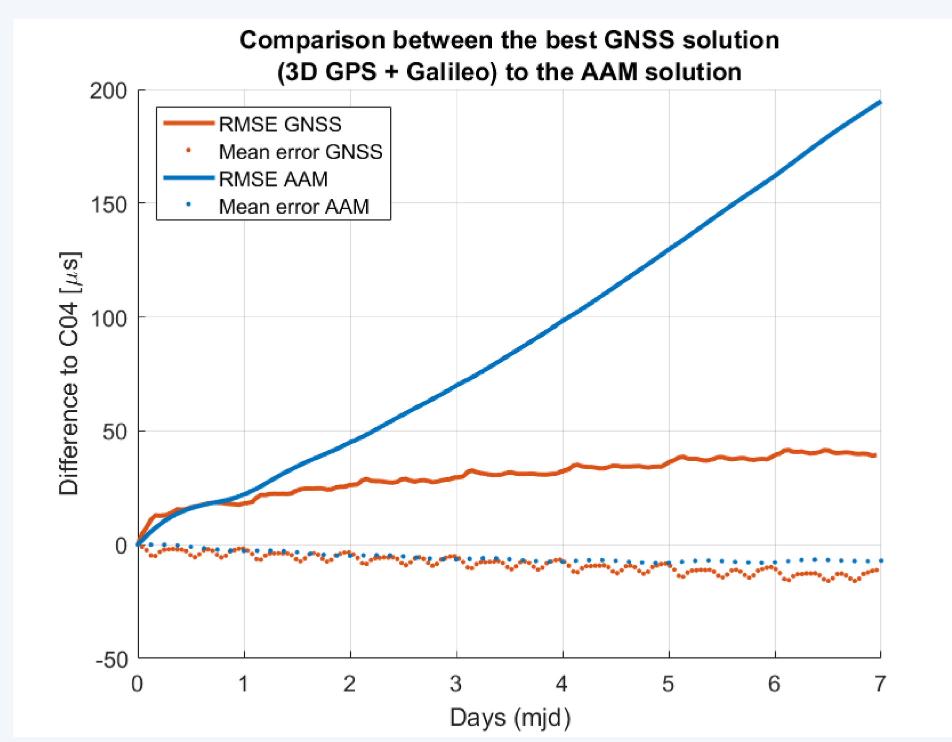


These results coincide over all very well with similar investigations (J. Böhm unpubl.).



The RMSE as well as the mean error of the integrated GNSS LOD have periodic components with periods of 12 and 24 hours. The 1D GPS has by far the greatest amplitudes at those frequencies. Further investigation into this is planned.

On the AAM side of things the results aren't nearly as good. Interestingly the RMSE of the AAM solution looks like a random walk error at the beginning (just as with GNSS) but after approximately 16 hours there is a kink and the error increases rapidly. This points to not included effects on the LOD that become significant at a certain distance to the LOD calibration at t_0.



6. Conclusions

GNSS LOD timeseries seem to be well suited to bridge dUT1 measurements from VLBI especially if potential offsets in the LOD data can be eliminated. It remains to be seen how well this offset can be eliminated over longer periods of time. 3-day solutions are to be much preferred over 1-day solutions. Considering that the accuracy of dUT1 from the best VLBI intensive sessions is about 20 µs (H. Schuh, J. Böhm (2013)) and about 40 µs for European Intensives, bridging up to a one week gap between VLBI solutions seems doable. More investigations in the periodic nature of the RMSE and mean error of the dUT1 estimates should be done. The AAM dUT1 estimates on the other hand could be maybe used for up to 2 days. After that the accuracy dwindles rapidly.

References:
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