3.6.2.3 Forschungseinrichtung Satellitengeodäsie, Technical University of Munich (FESG)

Introduction

The following research topics were covered during 2004 at the FESG as a Combination Research Centre (CRC) of the IERS:

- Combination studies using the CONT02 campaign
- Combination of sub-daily EOPs
- Analysis of troposphere parameters
- Analysis of nutation series

Combination Studies Using the CONT02 Campaign

CONT02 was a two-weeks continuous VLBI campaign and is therefore well-suited for combination studies with other space geodetic techniques, e.g. with GPS and SLR. The combination strategies we were studying are based on free normal equations generated for all techniques, including station coordinates, sub-daily Earth Rotation Parameters (ERP), daily nutation estimates, sub-daily tropospheric zenith delays for GPS and VLBI, and daily tropospheric gradients. Compared to former analyses, the temporal resolution for ERP and tropospheric zenith delay parameters were increased from two hours to one hour.

The combined pole coordinate series shows a better agreement with an independent sub-daily pole model (IERS2000) than the single technique solutions. This can be demonstrated by means of RMS values from the comparison with the IERS2000 model: for the x-pole the RMS decreased from 0.143 mas for a GPS-only and 0.259 mas for a VLBI-only solution, respectively, to 0.120 mas for the combined solution. A similar improvement can be recognized for the y-pole: 0.144 mas (GPS-only) and 0.253 mas (VLBI-only) for the single technique solutions compared to 0.130 mas for the combined solution.

With the results from the CONT02 combination studies it can be shown that the combination of UT1–UTC values from VLBI and LOD values from the satellite techniques is possible for a sub-daily resolution as well as for daily values. For all techniques the parameterization was changed from offset and rate to an offset-only piece-wise linear parameterization, and then the offsets at the predefined one-hour interval boundaries were combined. Figure 1 nicely demonstrates that the information on UT1–UTC coming from VLBI is not destroyed by the LOD values (with systematic biases) from GPS. And regarding the agreement with the IERS2000 sub-daily model it can be seen that the GPS LOD contribution even stabilizes the UT1–UTC time series, since the RMS for a VLBI-only solution is 0.015 ms, whereas it is only 0.011 ms for the combination.

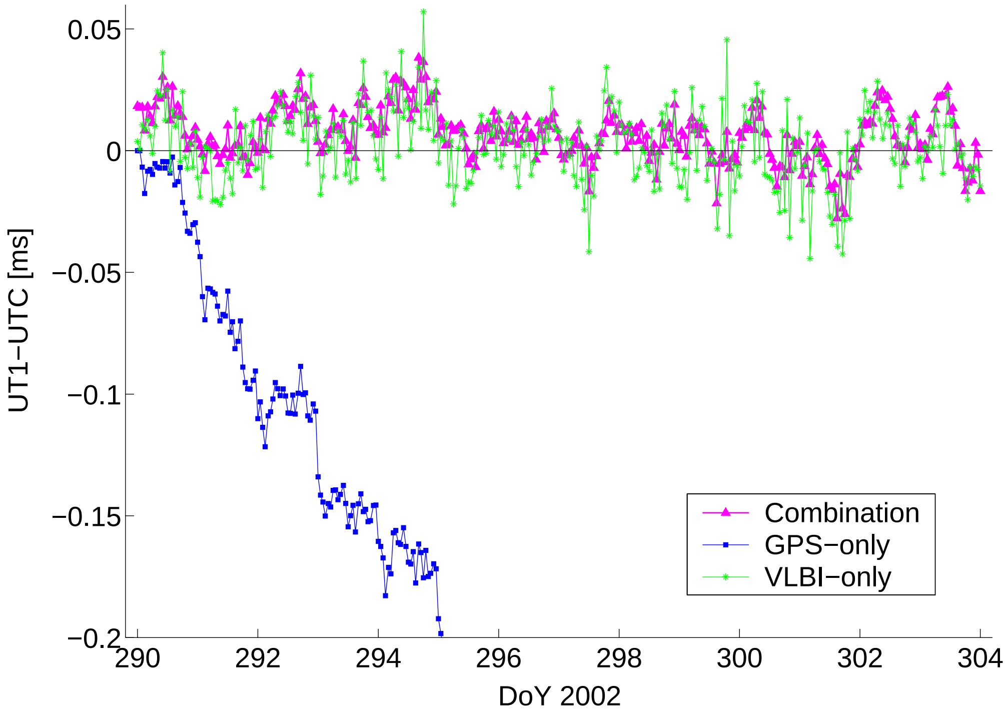

Fig. 1: Hourly UT1–UTC estimates derived from VLBI, GPS and a combined solution w.r.t. C04/IERS2000.

Combination and Analysis of Sub-Daily ERPs from GPS and VLBI

The latest harmonic analysis of sub-daily Earth rotation parameter (ERP) series from GPS and VLBI show already a very good agreement with studies of the sub-daily tidal excitation in polar motion and variation of length of day. Nevertheless, there are still many inconsistencies between the results from GPS, VLBI and geophysical models. Besides a rigorous combination of normal equations (or variance-covariance matrices) from different geodetic space techniques, a combination of the sub-daily ERP time series in advance of any further analysis could be useful to obtain a single sub-daily geodetic time series. Therefore we extended J. Vondrak's combined smoothing method (Vondrak and Cepek, 2000) to use it for high-frequency data. Combined smoothing is a constrained combination procedure, fitting the original GPS and VLBI time series by a weighted least squares estimation minimizing the sum of three coefficients for smoothness, fidelity to the original GPS series and fidelity to the original VLBI series. This method allows also the combination of UT1–UTC series from VLBI with ΔLOD from GPS within one step. Due to the necessary smoothing the original combined smoothing method filters out frequencies higher than two days (using hourly input data).

In order to use combined smoothing for sub-daily ERP data, we split the input series into a high-frequency and a low-frequency part by using either a low-pass filter or the combined smoothing method on a single time series setting the weights for a high smoothing. Adapting different smoothing coefficients to each frequency part we can preserve even the highest frequencies while solving the problems with larger data gaps and unevenly spaced data of VLBI including the adjustment of different, time variable offsets and different error levels between GPS and VLBI. The combined series is much more homogeneous, the RMS is reduced due to the smoothing process and the elimination of outliers, and the signal-to-noise ratio is enhanced due to the higher density of observation points (sum of GPS and VLBI observations). The improvement of the new combination procedure became more apparent for UT1–UTC than for the prograde polar motion component. The GPS series can benefit from VLBI observations by adjusting the integration of ΔLOD to UT1–UTC with well defined sampling points. On the other hand the VLBI series gets much more homogeneous, because the adjustment to the smoother GPS series eliminates time variable offsets, drifts and outliers. The quality of the combined series was tested by an estimation of tidal harmonic coefficients and spectral analysis.

For GPS we used hourly data from 02.01.1995 until 21.12.2000 with 52584 sample points delivered from the IGS analysis centre CODE. For VLBI we used sessions from 03.01.1995 until 29.12.1999 with 12464 hourly ERP values from the IVS analysis centre GSFC. We obtained 63008 different sample points for the combination. Further information on the original GPS and VLBI input series can be found in Rothacher et al. (2001). The analysis of 68 sub-daily tidal harmonic constituents for the new VLBI/GPS combination matches generally very well to the latest estimations of Rothacher et al. (2001) using a combined estimation of both series. Both analyses were based on the same GPS and VLBI series. We also compared these geodetic results with the official tidal harmonics from the IERS, based on hydrodynamic ocean models and additional assimilation of TOPEX/Poseidon sea-surface height differences. The atmospheric tidal excitations of polar motion and UT1–UTC were neglected, because they are much smaller than the oceanic ones: 1–2 orders of magnitude for prograde polar motion and 30 times for UT1–UTC (Brzezinski et al., 2002).

The number of tidal constituents, estimated with more than 95% confidence, increases from 21 (GPS-only) to 23 (new combination). The estimated tidal constituents can reproduce 77.4% of the sub-daily UT1–UTC variations (51.9% for VLBI-only, 66.9% for GPS-only series) and 64.3% of sub-daily prograde polar motion (37.7% for VLBI-only, 58.4% for GPS-only).

The main advantage of the combination arises from the reduced errors of the amplitude and phase estimation of the major tidal constituents. But there are also some small tidal harmonics, where the uncertainty in phase of the estimated tidal constituents increases, probably due to small phase inconsistencies in the harmonic components between the GPS and the VLBI input series. In conclusion the results from the new combination fit somewhat better to the hydrodynamic tidal model results than the estimations from each single input time series.

The spectral analysis offers the possibility to check, if the smoothing process in the combination is weak enough to preserve the sub-daily signal content of the input series.

The combination process suppresses most of the GPS-specific, unexplained periods between 2 and 6 hours, mainly due to the missing of equivalent signals in the VLBI series and partly because of the inevitable smoothing process within the combination. The known peaks of solar and lunar tides are smeared, but the amplitude power over the whole series remains at almost the same level. In conclusion the smoothing in the combination procedure seems to be weak enough to preserve even the highest frequencies. Furthermore, the combined series brings out some new, not reasonably explained periods, especially between 20 h and one day. There are almost no corresponding sub-daily tidal constituents. These characteristics can be found in the spectra for polar motion as well as in the UT1–UTC spectra. Further investigations should clarify the origin of these new periods. The extended smoothing method seems to be a practicable procedure to obtain long and stable sub-daily time series for geodetic and geodynamic investigations.

Homogeneously Reprocessed GPS and VLBI Troposphere Parameters

In cooperation with the Technical University in Dresden, FESG has reprocessed 11 years of GPS observations starting from the raw RINEX files (Steigenberger et al., 2004). The troposphere parameters of this homogeneously reprocessed solution have been compared with the also reprocessed VLBI solution DGFI04R04, computed by DGFI Munich. Much effort has been spent to use identical modelling and parameterization to minimize systematic effects. 36 co-located GPS antennas at 27 stations could be used for comparisons. First results were presented at the EGU General Assembly 2005 in Vienna (Steigenberger et al., 2005). The comparison of zenith wet delays (ZWD) and troposphere gradients showed in general a good agreement: the RMS of the ZWD difference time series is in the order of 4–10 mm and the correlation for most of the stations above 0.98. But also some critical issues could be identified by comparing the GPS and VLBI troposphere parameter time series: discontinuities due to equipment changes as well as systematic effects due to degradations in the tracking performance of GPS receivers and antennas. The bias between troposphere ZWDs from GPS and VLBI (corrected for the height difference between the GPS and VLBI antennas) can also be used as a tool for validation of different solutions: by using absolute antenna phase centre correc-

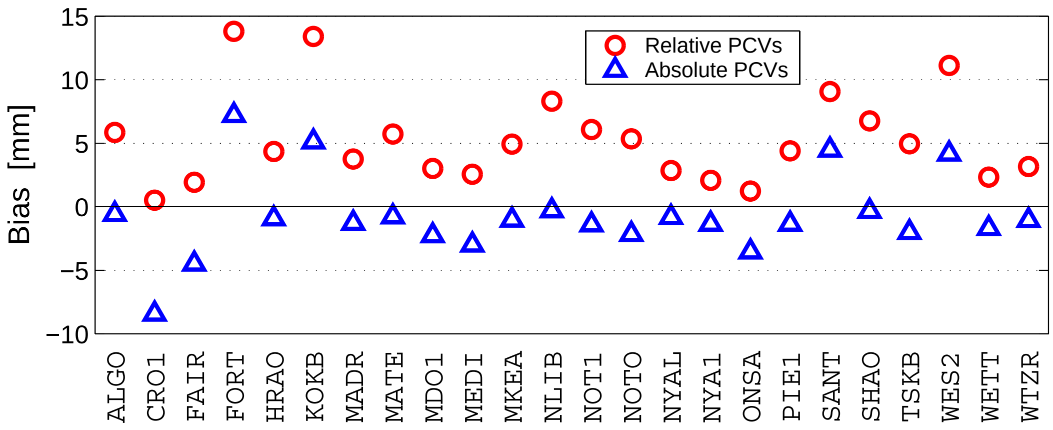

Figure 2: Bias between GPS and VLBI zenith wet delays corrected for station height differences using relative (for receivers only) and absolute (for receivers and satellites) GPS antenna phase centre corrections.

tions (for receivers and satellites) instead of relative ones (for receivers only), the mean bias between GPS and VLBI could be reduced from 5.3 to –0.8 mm (see Figure 2). With a careful handling of tracking problems and discontinuities a rigorous combination of the GPS and VLBI time series looks promising and is a future area of research.

Nutation

Although the direct estimation of nutation parameters using GPS is not possible due to the correlation with the orbital elements, GPS is capable to solve for nutation rates. In a special solution of the GPS reprocessing mentioned above, daily nutation rates in longitude and obliquity have been estimated. The comparison of a nutation model estimated from these nutation rates with earlier results by Rothacher et al. (1999) showed that a significant improvement could be achieved by the longer time series and the homogeneity due to the reprocessing. Figure 3 shows differences of the estimated nutation amplitudes for periods below 16 days with respect to the IAU2000 nutation model. A combination of the GPS nutation rates with VLBI nutation parameters is planned in the near future.

Acknowledgements

The combination research work is funded within the framework of the Geotechnologien-Projekt by the German BMBF.

The GPS reprocessing project of the Technical Universities in Dresden and Munich is funded by the Deutsche Forschungsgemeinschaft (DFG).

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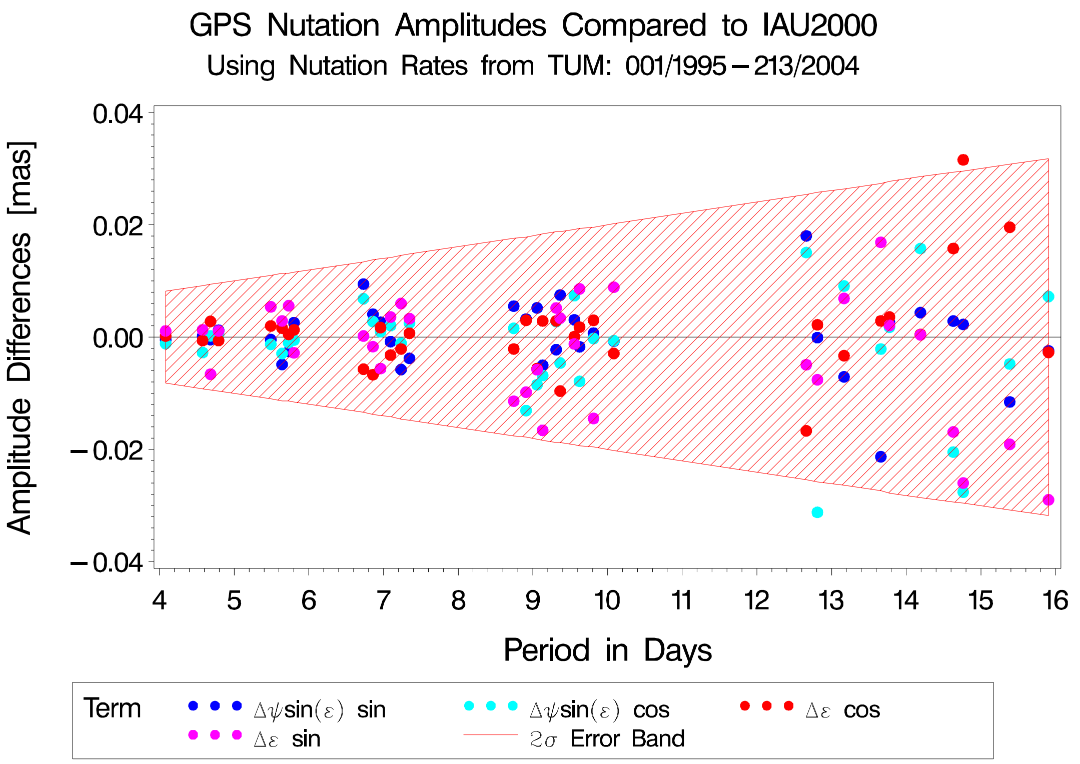

Figure 3: Differences between the GPS-derived nutation model and the IAU2000 nutation model. Noisy data from 1993 and 1994 has been excluded from the analysis and only periods smaller than 17 days are shown.
(For a colour version of this figure see the online version of this report at <www.iers.org>.)

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Markus Rothacher, Daniela Thaller, Robert Dill, Peter Steigenberger