3.6.2.6 GeoForschungsZentrum Potsdam (GFZ)

Introduction

Most of the work related to the IERS CRC at GFZ is embedded in the project “GGOS-D” (see Section 3.7.2 “WG on Combination” for more details). The major features of this project are the high degree of standardization of the modeling and parameterization between the software packages used, the consistent reprocessing of all observations and the exchange of datum-free normal equation systems (NEQs). Thus, the resulting time series of parameters are very homogeneous and a rigorous combination of the individual contributions is possible. The following topics were studied in 2006:

- Comparison of station coordinates and troposphere parameters from long time series of GPS and VLBI
- Combination of Earth orientation parameters (EOP) based on homogeneous NEQs
- Combination of GPS data from a ground network and Low Earth Orbiting satellites (LEO)

Reprocessed GPS and VLBI long time series of station positions and troposphere parameters

The impact of different mapping functions on station heights and troposphere zenith delays has been studied by comparisons of homogeneously reprocessed GPS and VLBI solutions. Altogether four different GPS solutions covering the time interval 1994–2005 have been computed in a joint effort of GFZ Potsdam, TU München and TU Dresden (Steigenberger et al., 2006). These solutions only differ by the mapping function applied:

- NMF: Niell Mapping Function, Niell 1996
- GMF: Global Mapping Function, Boehm et al. 2006a
- IMF: Isobaric Mapping Function, Niell 2001
- VMF1: Vienna Mapping Function, Boehm et al. 2006b

Whereas NMF and GMF are empirical mapping functions, IMF and VMF1 require input data from a numerical weather model providing a more realistic modeling of the troposphere. The Deutsches Geodätisches Forschungsinstitut (DGFI) München computed four VLBI solutions also applying these four mapping functions for comparisons with the GPS solutions.

Figure 1 shows the mean differences of the station heights (lower triangle of the figure) and the troposphere zenith total delays (ZTD, upper triangle of the figure) between solutions NMF, GMF, IMF and VMF1. All comparisons with solution NMF show a clear latitude-dependent systematic pattern due to the deficiencies of the NMF. In particular the height differences of up to more than 1 cm and the ZTD differences of up to 6 mm in Antarctica are striking. But also in the northern hemisphere a slightly latitude-dependent pattern is visible. As this systematic effect is present in both, the GPS and

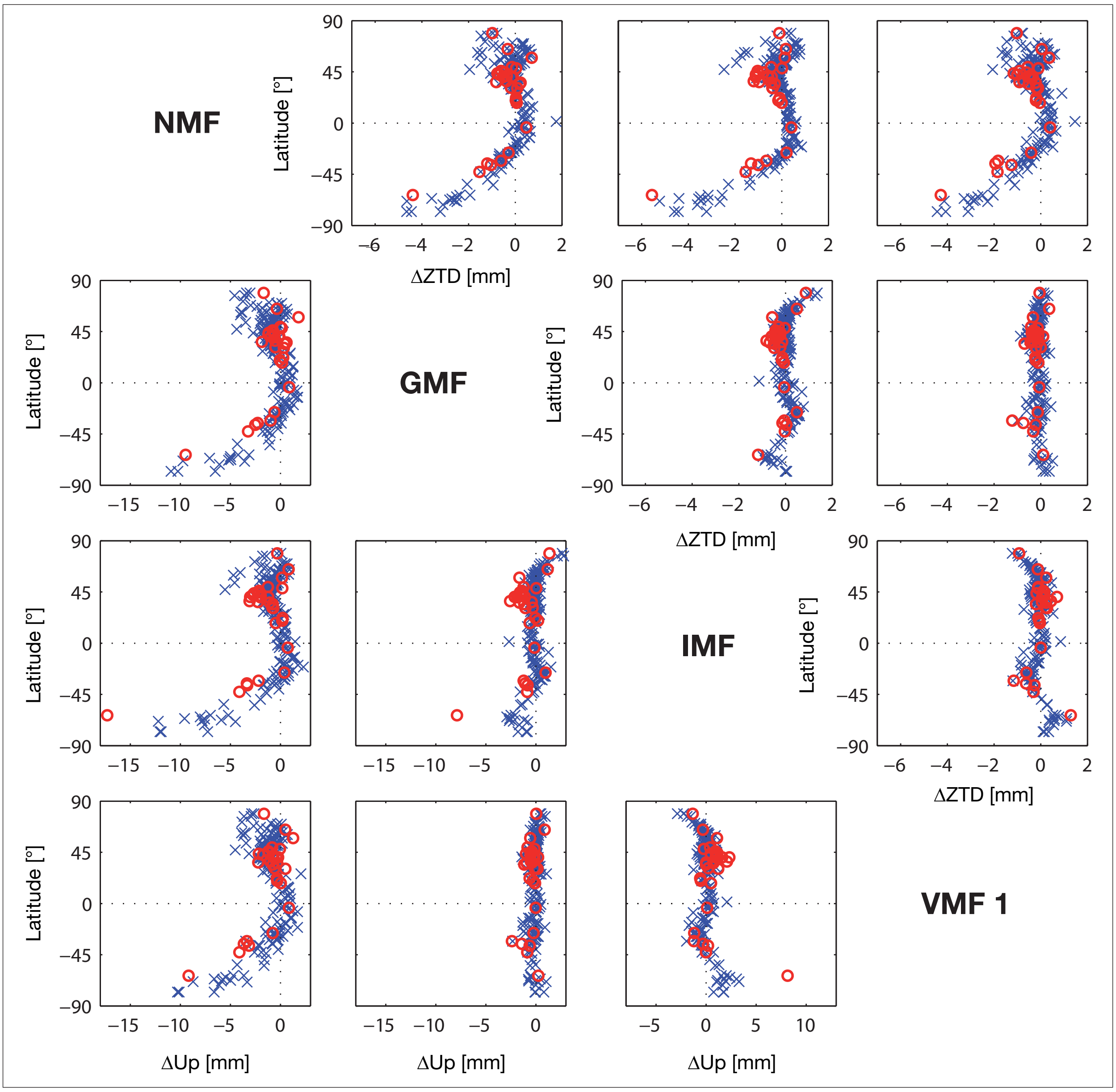

Fig. 1: Effect of different troposphere mapping functions on GPS- and VLBI-derived station heights and troposphere zenith total delays: the differences refer to the solution IDs given on the diagonal (e.g., the lowest plot on the left hand side shows the coordinate differences between solutions NMF and VMF 1). GPS-derived differences are indicated by blue crosses, VLBI-derived differences by red circles. (For a color version of the figure see the online version of this report at <www.iers.org>.)

the VLBI solutions, it is obvious that this behavior is related to the mapping function. Solution IMF also shows a slight latitude-dependent bias compared to GMF and VMF1 although this effect is much smaller than for the NMF. On the other hand, there is no systematic pattern visible in the comparisons of solutions GMF and VMF1. This is what we would have expected, as the GMF and the VMF1 were generated in a consistent way (Boehm et al. 2006a).

These significant differences between the GPS- and VLBI-derived troposphere zenith delays and station heights computed with *different* mapping functions emphasize the importance of using the *same* mapping function when combining solutions of both space-geodetic techniques. On the other hand, the good agreement of GPS and VLBI station positions and troposphere zenith delays computed with the *same* mapping function encourages the rigorous combination of both techniques.

Combination of Earth Orientation Parameters

When performing an inter-technique combination of Earth Orientation Parameters, the different epochs and time spans covered by the individual techniques have to be handled. In the case of GPS and SLR, the data are more or less continuous, so that a time series of EOP with a temporal resolution of 24 h can be coupled to the “normal” day, i.e., from 0 h UTC until 24 h UTC. Unfortunately, the 24-h VLBI sessions do not fit into this scheme as they start typically between 17:00 and 19:00 UTC. Independent of whether the EOP are parameterized as offset and drift for each 24-h interval or as a piece-wise linear polygon with values at the interval boundaries, the EOP estimated from VLBI do not represent the same information as those estimated from GPS or SLR, and, thus, the combination is not straightforward. One method is to attribute the EOP derived from the VLBI session to that 24-h interval of the GPS/SLR estimates to which the major part of the VLBI session belongs (see Fig. 2a), although this implies that there will be no contribution to the parameters set up for the first day.

However, in the ideal case, all observations should be correctly attributed to the appropriate interval of EOP, which means implicitly that the VLBI sessions must be split into two parts: one part from the start of the session until midnight, and, the second part, from midnight until the end of the session. In order to realize this ideal case, we used NEQs containing EOP with an hourly resolution. When combining these NEQs from VLBI and GPS (and SLR), the sub-daily resolution is transformed into a 24-h resolution (see Fig. 2b). With this procedure it is guaranteed that the estimated daily parameters represent solely the information of the corresponding time span and no information is neglected.

For assessing the difference between these two methods shown in Fig. 2, NEQs for one year of VLBI and GPS data have been generated and combined. Figure 3 shows the difference for the y-pole as an example. In terms of WRMS of the residuals, the difference is 18.2 µas and 18.3 µas for the x- and y-pole, respectively. In order to better evaluate the order of magnitude of the differences, the correctly combined time series using the NEQs with a sub-daily resolution is compared to the single-technique solution of GPS and to the C04 series as well (Fig. 3), resulting in a WRMS for the y-pole residuals of 39.8 µas and 82.0 µas, respectively. Thus, one can see that the impact of the combination method is not as large as the fact of combining different contributions or even the differences to external series. However, the differences are not negligible if high-quality time series are to be generated.

Further analyses of the EOP time series are documented in Thaller et al. (2006).

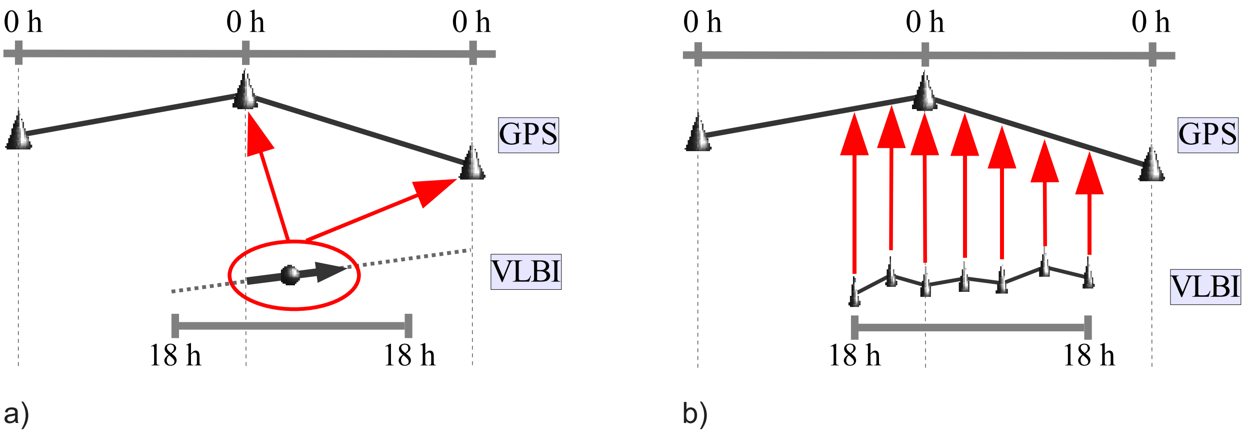

Fig. 2: Integration of the VLBI sessions into the 24-h polygon 0:00 – 24:00 UTC: a) based on offset and drift per session, b) based on a piece-wise linear polygon with sub-daily resolution ("correct" combination).

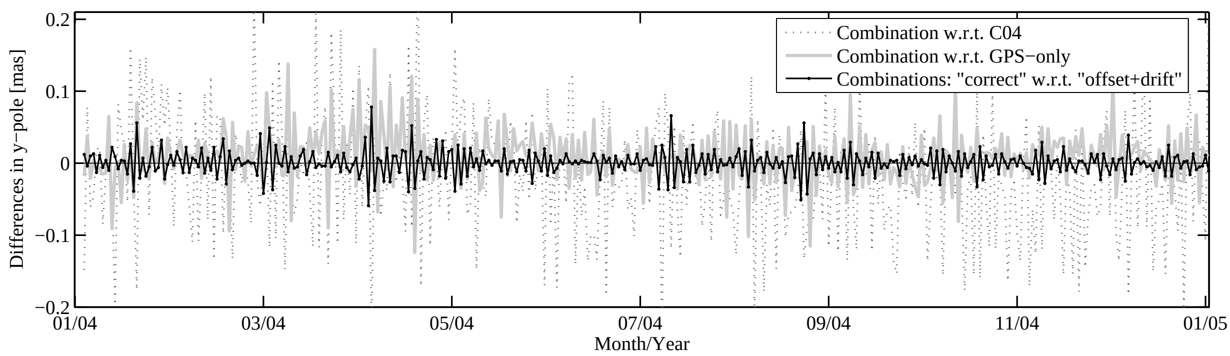

Fig. 3: Comparison of different time series of y*-pole coordinates.*

Combination of GPS and Low Earth Orbiters (LEOs)

The IERS CRC at GFZ has continued determining station positions, Earth Orientation Parameters, and spherical harmonic gravity field coefficients of low degree in the integrated mode using its EPOS software, see Zhu et al. (2004). The advantage of the integrated approach is the simultaneous and consistent processing of all available observational data and the estimation of all parameters including those needed to accurately account for the deficiencies of dynamic, geometric and observational models. The constellation processed comprises GPS ground stations of the IGS and GFZ network, the GPS satellites, as well as the Low Earth Orbiters (LEOs) CHAMP and GRACE. The observational data include GPS and SLR tracking data to the GPS and LEO satellites, as well as accelerometer, attitude, and K-Band inter-satellite measurements collected on-board the LEOs, where the K-Band data are specific to the two GRACE satellites. The dense and accurate CHAMP and GRACE data allow a high resolution of the sought for reference frame parameters.

Processing data of the year 2004 in the framework of the GGOS-D project, it could be proved in terms of reduced residuals and reduced scatter of parameter time series that the integrated mode delivers more accurate results than the commonly applied sequential processing of the GPS and the LEO constellations. With a rather loose datum definition and solving for the aforementioned parameters, the integrated mode directly gives insight into the correlations and the separability of the estimated parameters. Thus it became clear that the possibility exists of estimating the geometric and the dynamic reference frame in one run. The results have been compared to time series derived independently from pure SLR observations to the LAGEOS satellites and to routine products from the GRACE mission.

Acknowledgements

This work was partly funded by the project “GGOS-D” within the Geotechnologien-Projekt of the Deutsches Bundesministerium für Bildung und Forschung (BMBF, Federal Ministry of Education and Research), under the promotional reference 03F0425A.

References

Boehm, J., A. Niell, P. Tregoning, H. Schuh (2006a): Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data. Geophysical Research Letters, 33, doi: 10.1029/2005GL025546

Boehm, J., B. Werl, H. Schuh (2006b): Troposphere mapping functions for GPS and very long baseline interferometry from European Centre for Medium-Range Weather Forecasts operational analysis data, Journal of Geophysical Research, 111, doi: 10.1029/2005JB003629

Koenig, R., Shi, C., Neumayer, K.H., Zhu, S. (2006): Conventional and New Approaches for Combining Multi-Satellite Techniques. In Flury, J., Rummel, R., Reigber, C., Rothacher, M., Boedecker, G., Schreiber, U. (Eds.), Observation of the Earth System from Space, pp. 413–424, Springer, Berlin, Heidelberg, 2006.

Koenig, D., Koenig, R., Neumayer, K.H., Rothacher, M. (2006): Station Coordinates and Low Degree Harmonics with Daily Resolution from GPS/CHAMP/GRACE Integrated and Two-step Solutions, and with Weekly Resolution from LAGEOS. Abstract, AGU Fall Meeting, 2006.

Koenig, R., Koenig, D., Neumayer, K.H. (2006): Station Coordinates and Low Degree Harmonics with Daily Resolution from GPS/CHAMP Integrated and with Weekly Resolution from LAGEOS. Abstract, IAG Symposium Geodetic Reference Frames GRF2006, October 09–14, 2006, Munich.

Koenig, D., Koenig, R., Neumayer, K.H. (2006): GPS/CHAMP Integrated and LAGEOS Solutions of Geodetic Earth System Parameters. Abstract, Geodetic Week 2006, 10–12 October 2006, Munich.

Koenig, R., Mueller, H. (2006): Station Coordinates, Earth Rotation Parameters, and Low Degree Harmonics from SLR within GGOS-D. Abstract, 15th International Laser Ranging Workshop, 15–20 October 2006, Canberra, Australia.

Koenig, D., Koenig, R., Neumayer, K.H., Rothacher, M., Flechtner, F., Schmidt, R. (2006): Station Coordinates and Low Degree Harmonics with Daily Resolution from GPS/CHAMP/GRACE Integrated and Two-step Solutions, and with Weekly Resolution from LAGEOS. Poster G23B-1285, AGU Fall Meeting, 2006.

Niell, A.E. (1996): Global mapping functions for the atmosphere delay at radio wavelengths. Journal of Geophysical Research, 101, 3227–3246, doi: 10.1029/95JB03048

Niell, A.E. (2001): Preliminary evaluation of atmospheric mapping functions based on numerical weather models. Phys. Chem. Earth, 26, pp. 475–480, doi: 10.1016/S1464-1895(01)00087-4

Steigenberger, P., M. Rothacher, R. Dietrich, M. Fritsche, A. Rülke, S. Vey (2006): Reprocessing of a global GPS network. Journal of Geophysical Research, 111, B05402, doi: 10.1029/2005JB003747

Thaller D., Krügel M., Rothacher M. (2006): Combining one year of homogeneously processed GPS, VLBI and SLR data. To appear in: Proceedings of the IAG Symposium on Geodetic Reference Frames (GRF2006), held at Munich, October 9–13, 2006.

Zhu S, Reigber C, Koenig R (2004): Integrated Adjustment of CHAMP, GRACE, and GPS data. Journal of Geodesy, Vol. 78, No. 1–2, pp. 103–108.

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Peter Steigenberger, Rolf König