Time Series From Inter-technique Combinations

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1) Strategy for Combination

In order to combine normal equation systems, common parameters have to be identified first. Once the parameters are found, a strategy how they can be combined has to be developed. In principle, the methods used for the combination can be subdivided into two groups:

- The parameters are identical. Therefore, they can directly be stacked.
- The corresponding parameters are not identical but their relationship is known, so that a condition forcing the difference between the related parameters to a known value can be applied.

Concerning the parameters considered within the project GGOS-D, the first method mentioned above is applied to the Earth orientation parameters (EOP), the horizontal troposphere gradients and the gravity field coefficients. In the contrary, the station coordinates derived from different space-geodetic techniques normally do not refer to the same reference point, so that additional information has to be used if the individual contributions should be combined. A similar situation exists for the troposphere zenith delays (ZD), although only the height difference is of interest for combining the ZD.

Undoubtedly, the so-called local ties play a key role within the inter-technique combination as they do not only connect the station coordinates but they have a significant influence on the other parameters as well. The method of identifying good local ties for a multi-year combined TRF solution is described in Krügel et al. (2007). But when generating time series of parameters based on daily or weekly solutions, the selection of good local ties is not of minor importance than for the multi-year solution.

In the following we will concentrate on the combination of GPS and VLBI as the single-technique SLR solution still has to be investigated in more details. Altogether 1377 daily combined solutions were generated for the time span 1994 until 2006, i.e. the VLBI sessions have been combined with that daily GPS normal equation that covers the major part of the session. The datum definition was done by applying no-net-rotation and no-net-translation conditions based on a sub-set of GPS core sites, and appending the VLBI network by the geometrical local ties. The number of available

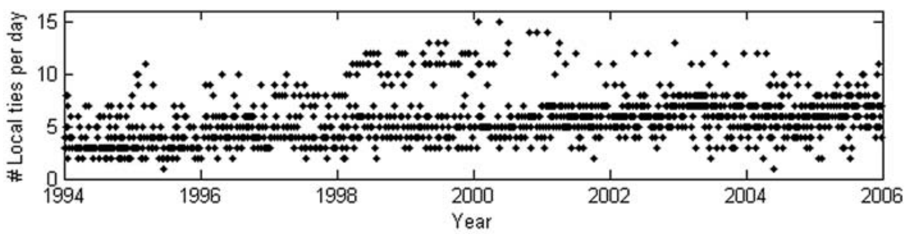

Figure 1: Number of official GPS-VLBI local tie values available for each daily combined solution

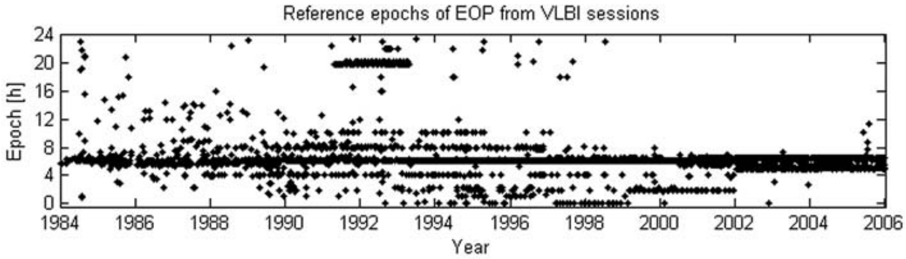

Figure 2: Reference epochs of the EOP for the VLBI sessions (i.e., the mean epoch of the session)

local ties differs from day to day (see Fig. 1): The daily combined solutions rely on one to 15 local ties, with 5.75 local ties as a mean value, and for the major part of the daily solutions three to eight local ties are available. It is clear that appending the VLBI network to the GPS network by only one or two local ties does not give enough datum information to the VLBI part of the combined solution as VLBI has three translational and three rotational degrees of freedom. Therefore, either additional parameters have to be combined (e.g. the pole coordinates) or those parameters relying solely on the VLBI contribution must not be interpreted.

Another topic that has to be considered in advance of including the VLBI sessions into an inter-technique combination is the reference epoch for the EOP. As EOP are epoch-specific parameters, they must refer to the same epoch if they are to be stacked. This requirement causes no problem for GPS and SLR because the observations are continuously available and the intervals for the 24-hour resolution can easily be set from midnight to midnight. In the contrary, as VLBI observations are not continuously available and the 24-hour sessions are not scheduled from midnight to midnight, the reference epochs for the EOP do not coincide with those from GPS and SLR. Figure 2 gives an overview of the reference epochs for all VLBI sessions used within GGOS-D. Thus, the EOP contributed by VLBI has to be transformed to epochs common with GPS and SLR, although this procedure weakens the VLBI contribution, of course.

In the following, the focus will be on the EOP. The TRF-related issues are treated in Krügel et al. (2007), and the combination of the troposphere parameters is only in a test phase up to now.

2) Time Series of Earth Orientation Parameters

Three types of solutions were studied: single-technique solutions, a combined solution of GPS and VLBI where only the station coordinates were combined, and a solution where station coordinates and polar motion have been combined. The intention of this three-step procedure is to evaluate whether the solution gains stability due to the combination of each parameter type. For an external comparison, the IERS-C04 series will be used.

a) Polar Motion

The weighted RMS (WRMS) of the differences w.r.t. IERS-C04 after removing a bias and a linear trend are listed in Table 1 for several solution types. In view of validating whether the time series benefit from a combination, the comparisons for the single-technique solutions are listed as well. It can be seen from these comparisons, that the GPS and VLBI solutions as well as their combination agree with the IERS-C04 series at the same level of about 90 to 110 µas. The residuals of the combined pole coordinates w.r.t. the IERS-C04 series are shown in Fig. 3.

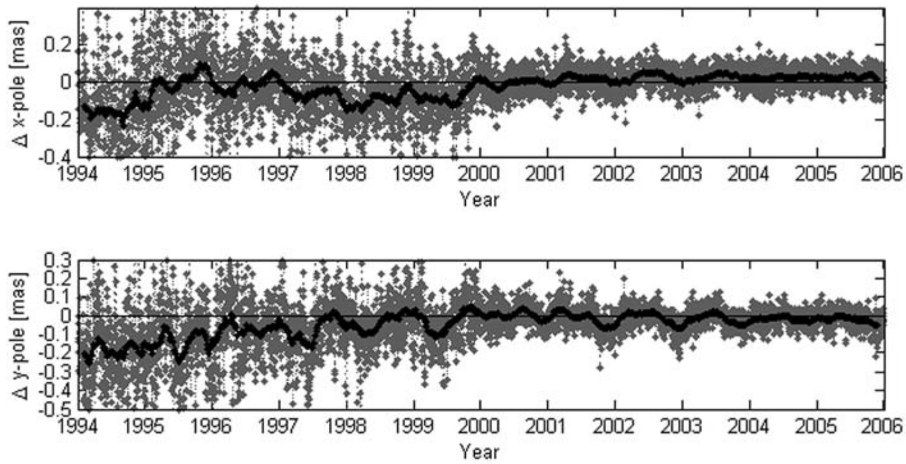

Figure 3: Comparison of the combined pole coordinates with the IERS-C04 series (grey). The black line represents the weighted mean values every week sampled over +/– 35 days

b) Universal Time

The parameter UT1-UTC can be determined solely by VLBI. If daily combined solutions are considered, the estimates of UT1-UTC strongly depend on the number of local ties applied. Therefore, multi-year instead of daily solutions will be considered in the following. Comparing the three solution types with the IERS-C04 series, the WRMS of the residuals are 5.5 µs, 5.8 µs and 6.4 µs for the VLBI-only solution, the solution with combined TRF and the solution with combined TRF and polar motion, respectively. Thus, it seems that the contribution of a stable reference frame and polar motion by combining VLBI with GPS cannot deliver more stability to the UT1-UTC time series, although it must be kept in mind, that taking the IERS-C04 series as a reference has some deficiencies as well. However, an external validation with geophysical data (AAM, OAM) still has to be done.

c) Nutation

Similar to UT1-UTC, the two nutation angles can be determined only by VLBI in an absolute sense, whereas the satellite-techniques GPS and SLR can contribute solely the time-derivative, i.e., the nutation rates. Therefore, we first look at the time series derived from VLBI-only multi-year solutions for the time span 1984 to 2006. Three different types of solutions were computed: For the first solution, the temporal resolution of the nutation angles was not changed, i.e., one set of nutation angles has been estimated for each session. The resulting time series is shown in Fig. 5. For the second

Table 1: WRMS of the residual pole coordinates from a comparison of different multi-year solutions with the IERS-C04 series. A bias and a linear trend have been removed

	WRMS x-pole [µas]	**WRMS x-pole [µas]**
VLBI-only	109.0	100.7
GPS-only	99.5	99.5
SLR-only	207.9	214.1
TRF combined, VLBI pole	117.7	106.4
TRF combined, GPS pole	95.9	94.0
Combined pole	93.4	91.9

and third solution, the session-specific parameters have been transformed into a piecewise linear polygon with an interval length of 14 days (not shown) and 28 days (see Fig. 5). As the major difference between the estimated nutation angles and the a priori model IAU2000 is the so-called free core nutation (FCN) with a period of about 432 days, the representation with such long intervals is justified in order to reduce the scatter in the time series, as it is visible from Fig. 5. It can be seen from this figure as well, that the amplitude of the FCN is not constant. Therefore, a sinus fit with sliding time windows has been performed for estimating the time-dependent amplitude of the FCN. The time windows are separated by seven days, each with a length of 865 days. As it is known from theory that the FCN is a retrograde signal, the sinus fit was done for both nutation angles together, so that the phase shift of 90° is automatically guaranteed. The estimated amplitudes are

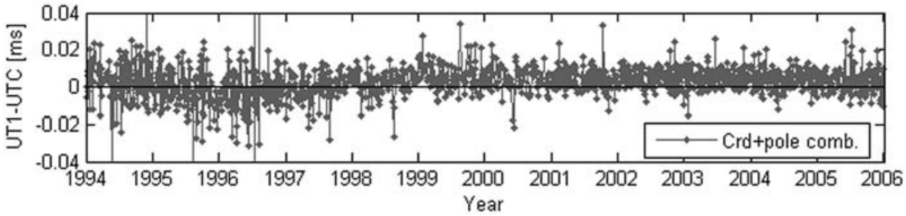

Figure 4: Comparing the UT1-UTC estimates of the multi-year solution of GPS and VLBI with combined station coordinates and polar motion with the IERS-C04 series

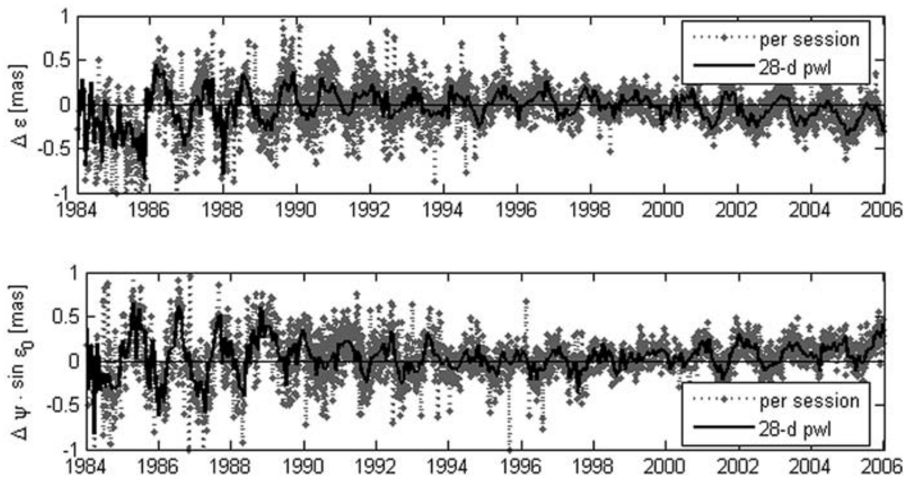

Figure 5: Nutation in obliquity and longitude estimated from VLBI-only multi-year solutions with two different temporal resolutions. The estimates are corrections to the IAU2000 model

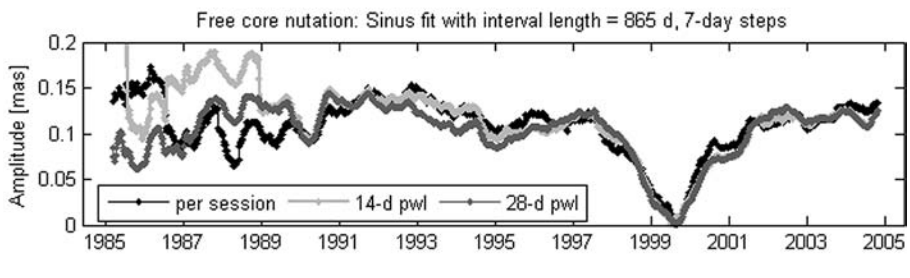

Figure 6: Amplitude of the FCN estimated by a two-dimensional sinus fit to the multi-year VLBI-only solutions using sliding time windows

shown in Fig. 6 for all three types of solutions. Except of the fact that the 14-day polygon is very weak during the first years, the two polygon time series deliver results for the amplitude with less scatter than the solution with a session-wise parameterization. The estimated amplitudes of the FCN are around 0.12 mas, except of the time span 1997 until 2002. During these years, the amplitude rapidly decreased and increased again, with zero value around the middle of 1999. This result agrees well with earlier analysis, e.g. by Herring et al. (2002) who states that there is an indication that the amplitude of the FCN is increasing again after 2000.
The solutions with combined station coordinates or combined coordinates and polar motion deliver time series for the nutation angles that are similar to that of a VLBI-only solution, therefore, the results are not shown here. The inclusion of the GPS-derived nutation rates into the time series has not yet been performed.

References

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