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CONT02 Campaign - Combination of VLBI and GPS

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Abstract

In October 2002, the International VLBI Service for Geodesy and Astronomy (IVS) arranged the VLBI campaign CONT02 which was designed to provide 15 days of continuous VLBI observations of eight participating stations. Using this data as well as the observations from a global GPS network, free daily normal equations were generated for both techniques, adapting the functional models as much as possible. The following parameters contained in these normal equations were combined: station positions (using a set of selected local ties), tropospheric parameters (zenith delays and horizontal gradients) and Earth Orientation Parameters (EOP). The paper gives an overview of the solution setup and provides first combination results for the common parameters.

1. Introduction

Combining solutions or normal equations from one technique is a method to remove outliers, to detect systematics and to reduce the "analysts-noise" and thus to achieve a better robustness of the corresponding parameters. But, in contrast to the case when solutions or normal equations of different techniques are combined, no independent information is introduced, because the contributions make use of the same observations only. If much care is taken to perform an inter-technique combination as rigorously as possible, some of the techniques' inherent strengths and weaknesses can be overcome. E.g., if VLBI and GPS data are combined, the benefit for both techniques is expected to be high because of the large number of common parameters (station coordinates, EOP and troposphere parameters). An excellent basis for studying combination aspects is the two-week VLBI campaign CONT02 which was used for this work: all eight observing VLBI sites provide a co-location with GPS, and all are of high quality.

2. Required Preparations Concerning the Data and the Software Packages

In a first step, the VLBI data was concatenated to daily files from 0 h to 0 h UTC, in contrast to the original data files starting and ending at 17 h UTC. This was done to optimise the comparability of parameters, especially those estimated in 24 h intervals.

The generation of the VLBI normal equations was performed with the OCCAM software at DGFI (Titov et al. 2001). The GPS contributions, consisting of about 150 globally distributed stations were generated with the Bernese GPS Software (Hugentobler et al. 2001) at the FESG (Forschungseinrichtung Satellitengeodäsie TU München). To be able to perform a combined solution as rigorous as possible, the functional models of the two techniques were adapted as much as possible: on the one hand, identical a priori models were used (solid earth tides, pole tide, ocean loading, tropospheric delay, a priori EOP values as well as their interpolation to the observation epoch, subdaily EOP model, nutation model). Furthermore, unknown parameters were set up identically (one set of station coordinates per day, daily nutation parameters, two-hourly pole coordinates and UT1-UTC, two-hourly tropospheric zenith delays, one daily set of tropospheric gradients). It should be emphasised that the mathematical representation of some parameters was kept simple to reach homogeneity, as e.g. for the tropospheric zenith delay, which is often parameterised in a more sophisticated way.

3. Combination and Comparison

The weighting of the normal equations of both techniques was done empirically: In a first approximation, the matrices were scaled to the same variance level, using the mean standard deviations for the station coordinates. In a second step, the "real accuracies" were considered, generating weight factors using the RMS values of residual positions after a Helmert transformation of each techniques' two-weekly combined solution w.r.t. ITRF2000.

3.1. Coordinates

If station coordinates of different techniques are to be combined, it is necessary to include inter-station vectors (local ties) between the corresponding reference points (e.g. ftp://lareg.ensg.ign.fr/pub/itrf/itrf2000/tiesnx/*.SNX). The approach to select or exclude given local tie information is like the weighting procedure: preliminary and of empirical nature. Several criteria for selecting suitable local ties were applied: to detect gross outliers in a first step, the given local tie information was compared to differences between coordinates of co-located instruments, determined from technique-specific solutions. The second step was to consider how much each single local tie affects the other inter-station vectors on the one hand and the estimated EOP values on the other. Finally, seven local ties were assessed to be useful, i.e. only the local tie for Kokee Park was excluded.

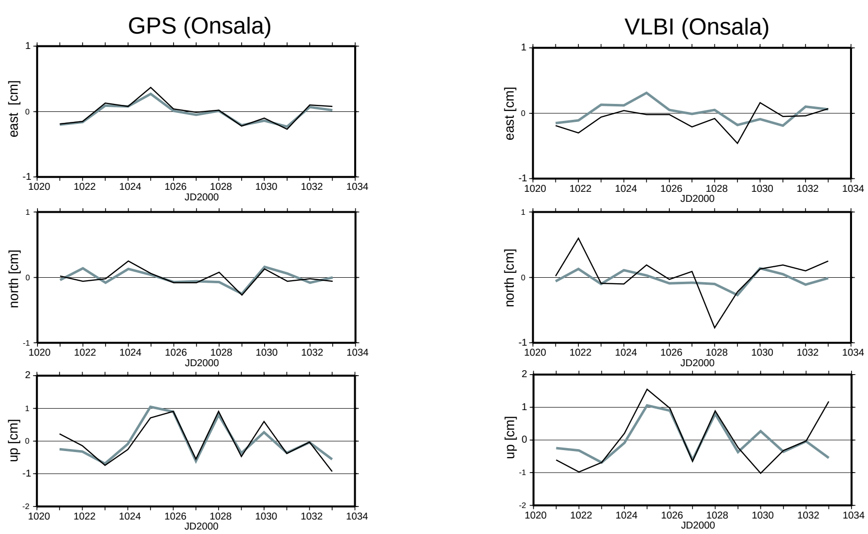

Figure 1. Time series of station coordinates for Onsala, before (black) and after (grey) combination.

Figure 1 shows the time series for the station coordinates of the VLBI and the GPS station in Onsala before and after the combination. Comparing the time series of the height components before the combination (black lines), we can recognise a similar characteristic, especially during the days 1021-1029. That suggests that both techniques are affected by the same physical effect in this time period. Comparing the time series before and after the combination, the combination leads to a smoothing effect for both stations. For the selected example the effect is stronger for the VLBI station, but this is not the case for all co-locations as we can see in Figure 2, which shows the repeatabilities of all stations.

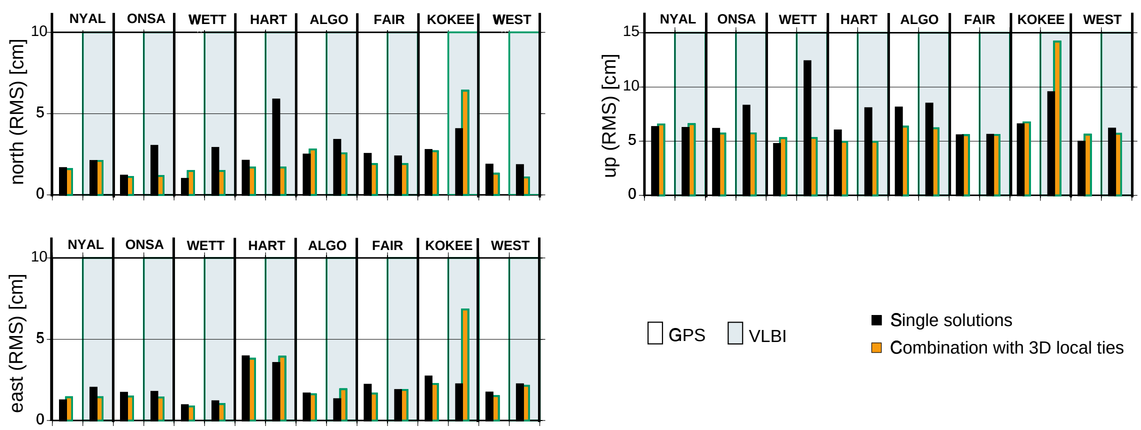

Figure 2. Repeatabilities of station coordinates, before and after the combination.

For most of the stations, the repeatabilities in the north and east component improve as a consequence of the combination. An exception is the VLBI station in Kokee Park, for which the corresponding local tie information was not used. For this station, the degradation of the repeatabilities suggests a problem in one of the space techniques (either in the data or in the solution) or in the local ties for the other stations. Alike for the horizontal components, the height components' repeatabilities improve for both techniques at most of the stations. Exceptions are the sites Ny Alesund, the GPS stations Wettzell and Westford and, again, Kokee Park. One reason for the generally slightly larger repeatabilities of the VLBI stations w.r.t. GPS might be the poorer network configuration. It should be mentioned, however, that the computed repeatabilities (RMS, root mean square) do not account for the formal errors of the estimated parameters.

3.2. Troposphere

The estimation of the tropospheric zenith delays was performed for GPS and VLBI in the same way. Therefore the zenith delay is divided into two parts, a dry part, modelled a priori using the Saastamoinen model as it is implemented in the Bernese GPS software (Hugentobler et al. 2001) and an estimated wet part. Both are mapped using the Niell mapping functions. For the VLBI stations we used the same dry delay as for the co-located GPS stations as a priori. Thus the estimated delays for the VLBI stations must differ by a small fraction from the ones estimated with GPS, caused by the height differences w.r.t. the GPS stations. Figure 3 shows the zenith delay time series for the GPS and the VLBI station in Algonquin Park. This is the co-location site with the largest height difference of about 23 m between the GPS and the VLBI reference points. We recognise a very good agreement for the time dependent characteristics of the two time series. The mean offset of 5.9 mm is mainly caused by the height difference.

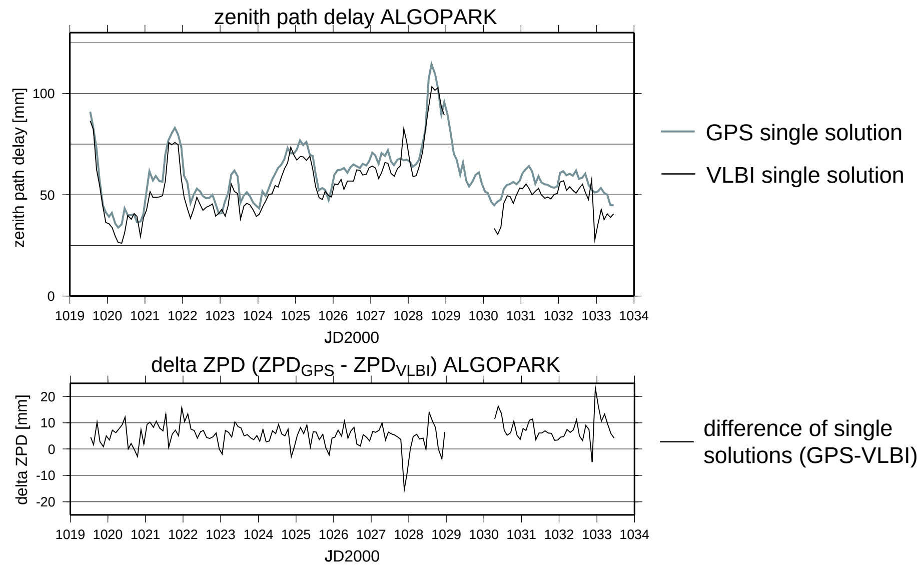

Figure 3. Tropospheric zenith delays for Algonquin Park.

If the zenith delays should be combined, this offset has to be considered, e.g. as a tropospheric tie. We used the Saastamoinen model and a standard atmosphere to derive theoretical zenith delay differences. Table 1 displays these theoretical offsets and the mean differences derived from technique specific solutions. For some stations the agreement between the theoretical and estimated value is very good (Algonquin Park, Wettzell, Westford). But there are also co-locations with differences in the order of 3-5 mm (Kokee Park, Ny Alesund, Fairbanks and Onsala). It is also remarkable that for some stations (the European stations as well as Hartebeesthoek and Fairbanks) the estimated zenith path delay for GPS is smaller than for VLBI although the reference point for GPS has a lower ellipsoidal height than that for VLBI. The reason is still unknown and further investigations are necessary.

Table 1. Theoretical offsets and mean differences between the single technique solutions.

	Δ height (VLBI-GPS) [m]	Δ ZPD (theory) (GPS-VLBI) [mm]	ΔZPD (estima.) (GPS-VLBI) [mm]	Δ ZPD (theory) - ΔZPD (estima.) [mm]
Ny Alesund	3.1	1.1	-2.8	3.9
Onsala	13.7	4.3	-0.7	5.0
Wettzell	3.1	0.8	-1.1	1.9
Hartebeesthoek	1.5	0.3	-1.4	1.7
Algonquin Park	23.1	6.2	5.9	0.3
Fairbanks	13.1	3.5	-0.8	4.3
Kokee Park	9.2	2.3	5.4	-3.1
Westford	1.7	0.5	1.6	-1.1

We combined the tropospheric zenith delay estimates of both techniques, including tropospheric ties with an a priori sigma of 0.1 mm. It was expected that this combination would stabilise the height determination. Unfortunately, first combination results show increased position repeatabilities (about 0.5-1 mm) for most stations. This indicates that there are problems regarding the combination of tropospheric parameters, and further investigations must be performed.

A comparison of tropospheric gradient estimates obtained from VLBI and GPS shows an excellent agreement for most of the stations. As an example, the pair of daily estimated gradients at the site Ny Alesund is presented in Figure 4. We combined the gradients of both techniques by introducing constraints with an a priori sigma of 0.1 mm. The effect on the estimated parameters was very small, suggesting that possibly stronger constraints should be applied, which need to be studied in more detail.

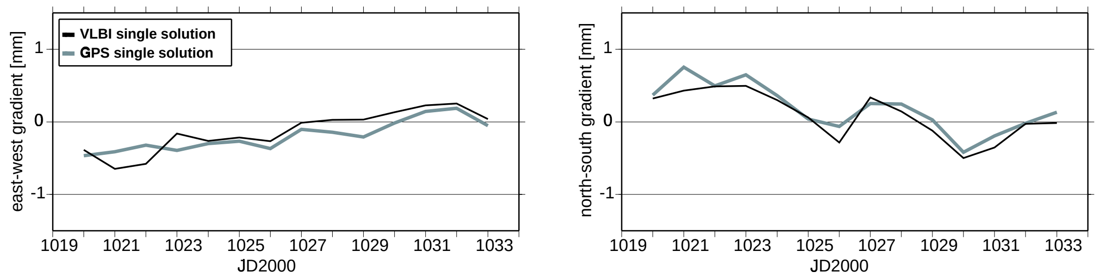

Figure 4. Tropospheric gradients for Ny Alesund.

4. Conclusions, Remaining Questions and Motivation for the Future

The CONT02 campaign is an excellent basis to study combination issues in detail. In a first step we compared the parameters resulting from single GPS and VLBI solutions. Because of the good agreement, we assumed that a combination of common parameters is unproblematic and we expected to see a stabilising effect for the solutions, especially for the combined parameters. As a matter of fact, combining the coordinates, the time series for most of the stations, both VLBI and GPS, were smoothed. If tropospheric zenith delays are combined, we recognise unfortunately a small worsening of the repeatabilities of station positions.

The combination of the EOP, which is not shown here, implies that further studies are necessary to understand the reasons for offsets between the GPS and VLBI derived parameters and to investigate the effect of local ties on the estimated EOP (see also Thaller et al. 2003). Additionally, it is planned to introduce SLR to our combination, because this technique is most capable for defining the origin of a terrestrial reference frame.

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