Integrating GPS zenith path-delay measurements into the analysis of geodetic VLBI observations from the European network

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Abstract

Estimates of vertical components of site coordinates from 'standard' geodesy techniques of analysis of VLBI observations have uncertainties about 3-4 times larger than the other components. This is a consequence of the large correlation between the zenith path delay and the vertical component of the stations. We want to contribute to the effort of investigating the potencial of new routes, combining the products of different geodesy techniques, to lighten that situation. We present preliminary results from a 'hybrid' route of analysis which implements external GPS tropospheric estimates into the VLBI analysis, along with a comparison with results from the 'standard' route. At this early stage of our project the 'hybrid' route appears as a very promising approach, with first time clear evidence of improvement with respect to the 'standard' route.

1. Introduction

Since 1990 an European geodetic network consisting of fixed VLBI antennas has regularly performed simultaneous S/X observations at a rate of six 24-hour experiments per year. The participating stations are located at Onsala (Sweden), Wettzell (Germany), Medicina (Italy), Madrid (Spain), Matera (Italy), Noto (Italy), also, since 1994, Ny-Alesund (Norway) and Crimea (Ukraine). The Effelsberg 100 m. antenna near Bonn (Germany) take part once a year to an European VLBI geodetic experiment. During 1997 the new mobile VLBI antenna, part of the TIGO project, has been installed at the Wettzell station and was regularly inserted in European VLBI experiments during 1998.

In the meantime the IGS GPS network has been established throughout the world, and it is regionally enhanced with more permanent GPS sites. At present all European VLBI geodetic stations, except Crimea, are equipped with permanent GPS receivers.

The processing of the european geodesy observations is regularly performed at the correlator centre at MPIfR, in Bonn (Germany). The geodetic observables are accessed by different groups to proceed with the data analysis, using distint software tools and/or strategies. It is a general aspect in all analysis that the uncertainty in the estimated values of the vertical components of the sites, or baseline vectors, is about 4 times larger than for the rest of components. The vertical components are largely affected by the propagation of elevation dependent errors in the group delay model, for example in the formulation of the tropospheric contribution.

We are currently investigating the potential of a novel route, which combines both VLBI and GPS techniques, as a way to improve the estimates of vertical components for the sites. In principle, the simultaneous multi-directional nature of GPS observations could yield an advantageous configuration for the modelling of tropospheric contributions into the observables. Our aim is to make a sistematic comparison of the results obtained following the "standard route" of analysis of VLBI observations, and a "hybrid route" which implementes simultaneous GPS tropospheric estimates. We present comparative preliminary results from the implementation of external GPS tropospheric estimates, computed every hour, in the VLBI analysis with CALC/SOLVE package. We are also presenting an easy way to introduce zenith path delays derived from GPS, into the CALC/SOLVE standard software, with few modifications in the program DBCAL. Previous attemps have been done by other authors (Carlsson et al. 1995) with no conclusive results.

2. Data Analysis

We have started to work on a novel route to disentangle the coupling between the values for the vertical coordinates of the stations (or baselines) and the tropospheric contributions at each site, estimated from VLBI analysis. In the past, many attempts have been made to use water vapor radiometers (WVR) in order to produce the same results. Due to the large cost of the equipment, an advanced algorithm has been introduced into the CALC/SOLVE package in order to determine the zenith path delay, or more specifically the wet contribution, at each station. In this case we are using, as produced by a WVR, the zenith path delay produced by the International GPS Service for Geodynamics (IGS) at the Berna center, in the analysis of the VLBI observations from the European geodesy network during 1998.

Our final working database will consist of the six European VLBI observations from 1998, and the simultaneous standard IGS products for the 1-hourly tropospheric zenith-delay estimates, whenever available, for each participating site. The results presented in this contribution comprise a subset of the complete database which consists of the first 4 epochs of VLBI observations.

We have performed parallel analysis, with CALC/SOLVE, following (1) the 'standard route', and (2) a 'hybrid route' which implements external tropospheric zenith delay values from GPS. In both cases we have used an identical configuration of parameters, except for the sub-section concerned with the troposphere. In the 'standard route' we have used a piece-wise linear function to estimate 1-hourly residuals, to the *a priori* values, with typical values to constraint the rate and atmospheric gradients. In the 'hybrid route' we used the tropospheric zenith delays resulting from linear interpolation of the 1-hourly estimates from IGS, whenever available, at each site, and no further adjustment in the analysis. The tropospheric contribution from sites with missing IGS entries (such us Medicina, Madrid and Crimea) were estimated following an identical procedure as in the 'standard route'. In all cases we used the corresponding Nielt mapping functions for the dry and wet components of the neutral atmosphere.

The IGS delivers total values of the zenith path delay. We have extracted the wet component contribution for our comparative studies by substracting the dry Saastamoinen component, which is used in both VLBI and GPS data analysis.

We present a comparison of the achievements from both routes attending at repeatability results for the length and vertical components of the participating baselines.

We have also performed individual analysis and cutoff elevation angle tests of each VLBI session of observations, in February, April, June and August. If these sessions may be taken as representative for a certain epoch of the year, the results reflect interesting seasonal effects of the impact of elevation dependent errors, we believe that largely associated with the wet component of the troposphere, in the analysis.

3. Preliminary Results - Repeatability tests

Figure 1 shows plots of baseline length repeatability versus baseline length, corresponding to a series of 'standard' analysis using different cutoff elevation angles, in SOLVE, from 5 to 25 degrees, in steps of 5 degrees. The database includes the first 4 epochs of VLBI observations in 1998. Best linear fits have been estimated for each solution. Among them, the fit with the minimum slope corresponds to the analysis with a cutoff elevation angle of 5 degrees. Figure 2 shows the same information as figure 1, corresponding to a parallel 'hybrid' analysis including external GPS tropospheric zenith-delay values. The fit with minimum slope in figure 2 corresponds to a cutoff elevation angle in SOLVE equal to 10 degrees. For comparison, figure 3 shows the results derived using most favourable parameter configuration from both analysis routes.

It should be pointed out that, in principle, the 2 cutoff tests presented in figures 1 and 2 are quite different, and that might explain, at least in large extent, the different results. In the case of the 'standard' analysis, we are computing both the baseline length and the tropospheric zenith delay at the 2 ends of the baseline. In the case of 'hybrid' analysis, we are just computing the baseline length. This can explain the rapid "degradation" of the results shown in figure 1, going from lower to an upper cutoff. In addition to the fact that the number of data points used in the analysis is decreasing, and hence producing a larger statistical uncertainty, there is a large correlation between zenith path delay and vertical component of the stations, almost equal to 100% when using a cutoff elevation angle larger than about 15 degrees.

We have made a comparison of the tropospheric zenith delay estimates from VLBI and GPS techniques for the participating stations and at the time of the VLBI observations. We find a sistematic

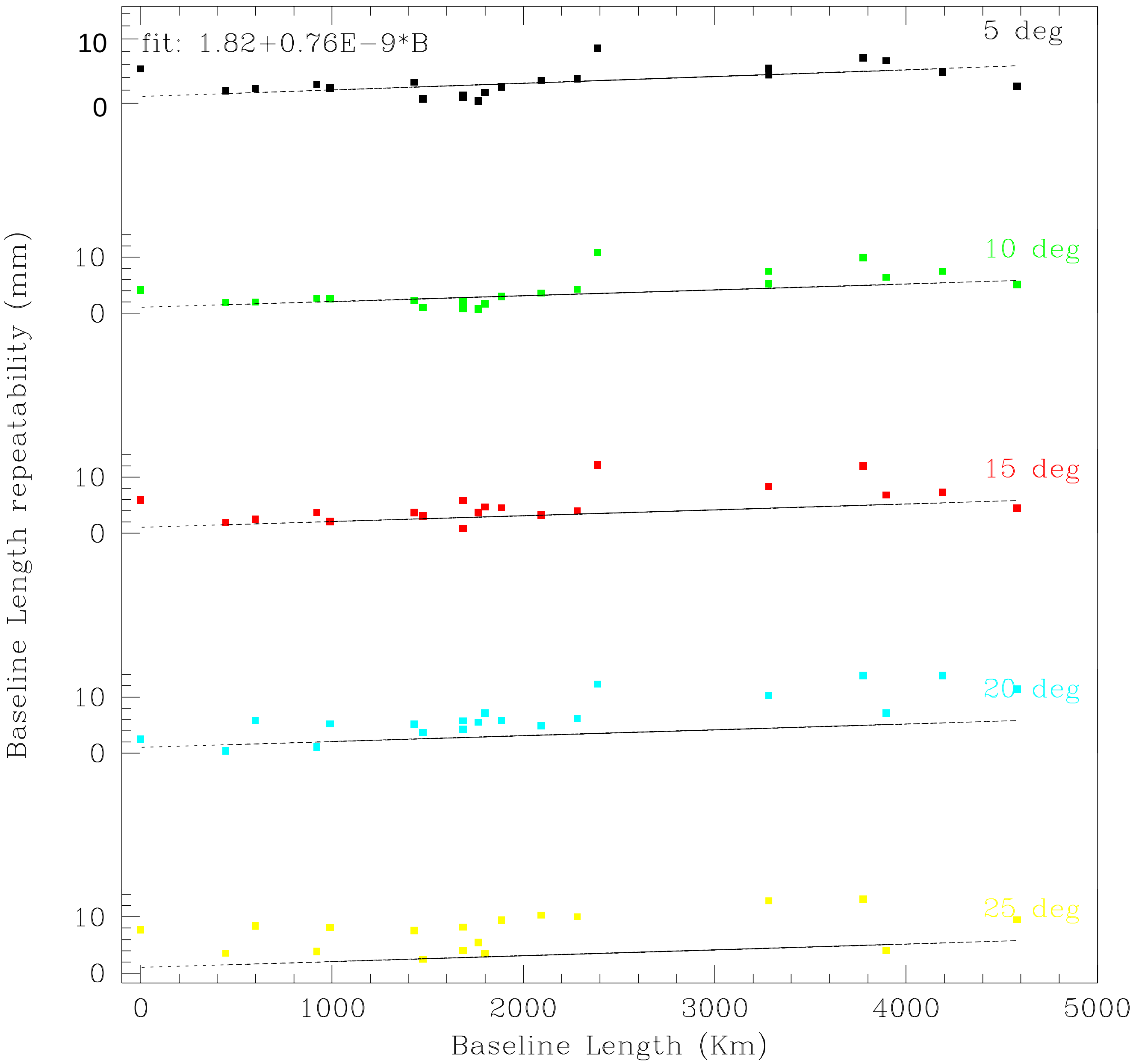

Figure 1: Repeatability of the baseline length estimates, using a 's-tandard route' in the analysis of 4 24-hours european VLBI sessions in 1998, with different cutoff elevation angles in SOLVE (see upper right corner of each plot). The solid line represents the best-fit with the minimum slope, corresponding to a cutoff elevation angle of 5^0. It is inserted in all subplots for visual cross-checking. The fitted coefficients appear written above the 5^0 plot.

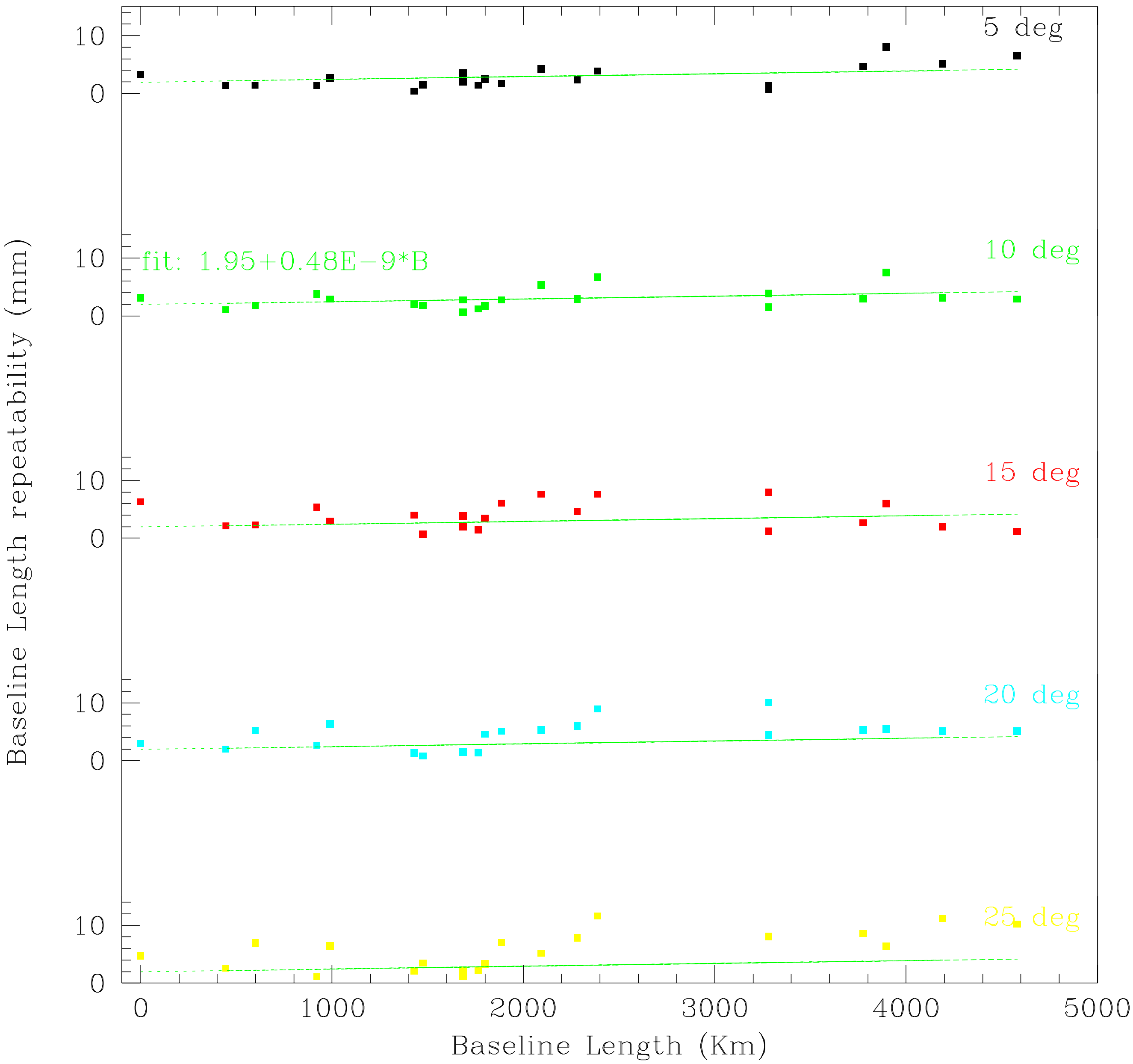

Figure 2: Repeatability of the baseline length estimates, using a 'hybrid route' in the analysis of 4 24-hours european VLBI sessions in 1998, with different cutoff elevation angles in SOLVE (see upper right corner of each plot). The solid line represents the best-fit with the minimum slope, corresponding to a cutoff elevation angle of 10^0. It is inserted in all subplots for visual cross-checking. The fitted coefficients appear written above the 10^0 plot.

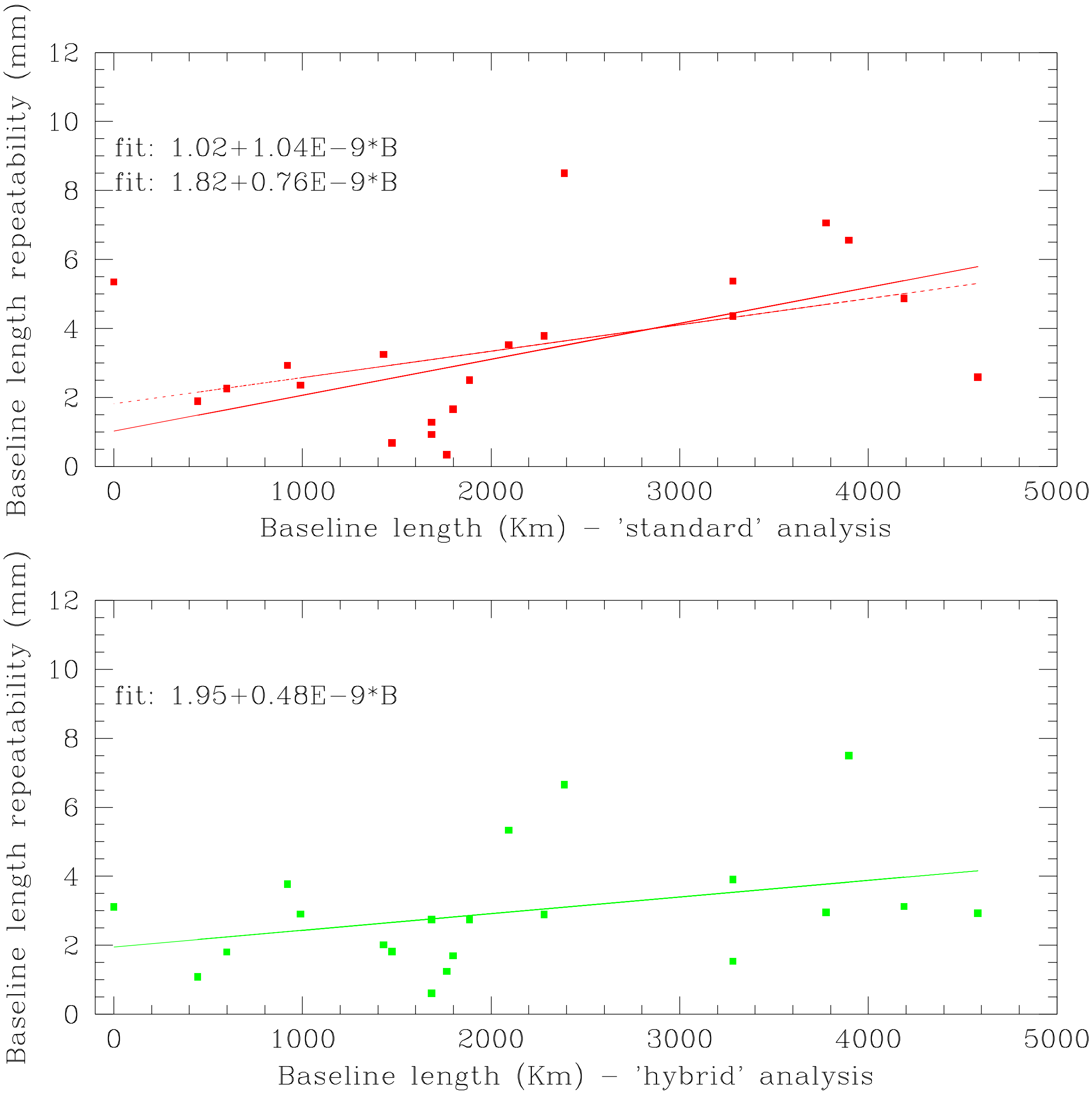

Figure 3: Repeatability of the baseline length estimates, using an 'standard' analysis (upper), and a 'hybrid' analysis (lower) of 4 24-hours european VLBI sessions in 1998, with cutoff elevation angles of 5^0 and 10^0, respectively, in SOLVE. Solid lines are best linear fits. The 2 fits in the upper plot differ in the inclusion in the fit of the shortest baseline (Tigo-Wettzell). See text for explanation of 'standard' and 'hybrid' nomenclature.

bias between the estimates of both techniques, the VLBI values always smaller than the GPS values, variable with time. Figure 4 shows a comparison of the tropospheric total zenith delays from VLBI (our analysis) and GPS (IGS product) techniques for the station of Wettzell, at 3 epochs.

Exploiting the temporal span of our database along 1 year, we have also attempted to investigate the impact of potential "seasonal" aspects onto the geodetic parameters. We have carried on comparative analysis using different cutoff elevation angles, at 10 and 5 degrees. Figure 5 shows the differences between baseline length estimates from individual 'standard' analysis of 4 VLBI observations in 1998. The plots corresponding to the observations from June and August show larger differences for the longest baselines, instead, in February and April, there is no significant dependence with baseline length. This can be explained in terms of the wet component of the troposphere being most difficult to model in summer periods.

At present, we are trying to make a sensible comparison of the vertical estimates derived from the 2 analysis routes considered in this presentation. Figure 6 showes repeatability plots for the vertical components of the baselines, as estimated from the 'standard' and 'hybrid' analysis routes. The configuration of the parameters involved in both analysis is identical to the one corresponding to the results presented in figure 3.

4. Conclusions and Future work

We have established a working interface that integrates external tropospheric data in the analysis of VLBI observations with SOLVE. Our goal is to make a sistematic comparison between the results obtained from an standard VLBI analysis and those from a 'hybrid route' which implement simultaneous GPS tropospheric estimates. The results presented here are preliminary and constitute a progress report on that project. Nevertheless, we want to point out some interesting facts that are worth mentioning. We confirm the evidence found by other authors too, that the inferred wet delay contributions estimated from GPS and VLBI techniques exhibit similar short term variations, but with an apparent long term bias. Our results from repeatability tests and cutoff elevantion angle tests indicate a promising perspective for the combination of both geodetic techniques. In fact it is the first time such a clear evidence is found. Inferring from the improvement found in VLBI, we believe that a reduction of the current 10 deg cutoff elevation angle in GPS observations, might be a non-negligible factor for further improvement of results.

We intend to extend our analysis to include the 2 remaining 24-hours sessions of European VLBI observations from 1998. There are many interesting aspects that remain to be understood and investigated, just to mention here a few of them: the effect of decreasing the solution interval of tropospheric estimates, try new strategies in the analysis, understanding the sistematic bias between estimates from both techniques...

5. References

Carlsson T.R., Elgered, G., and Johansson, J., 1995, *Proc. 10th Working Meeting on European VLBI for Geodesy and Astrometry*, Eds. R. Lanotte and G. Bianco, pp. 148-153

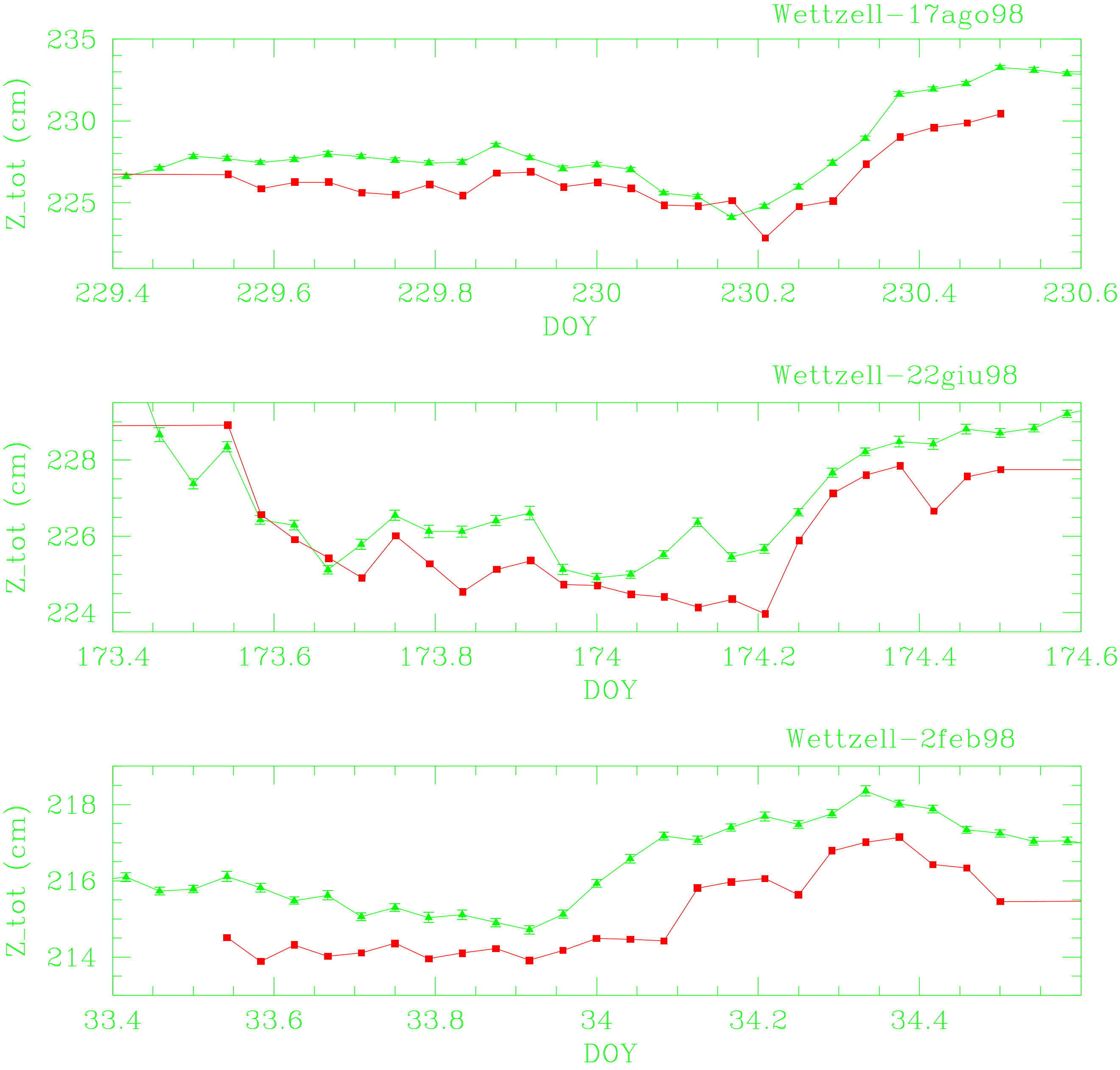

Figure 4: Comparison of 1-hourly tropospheric zenith delay estimates for Wettzell, along 3 days in 1998, using VLBI (filled squares) and GPS (filled triangles) techniques.

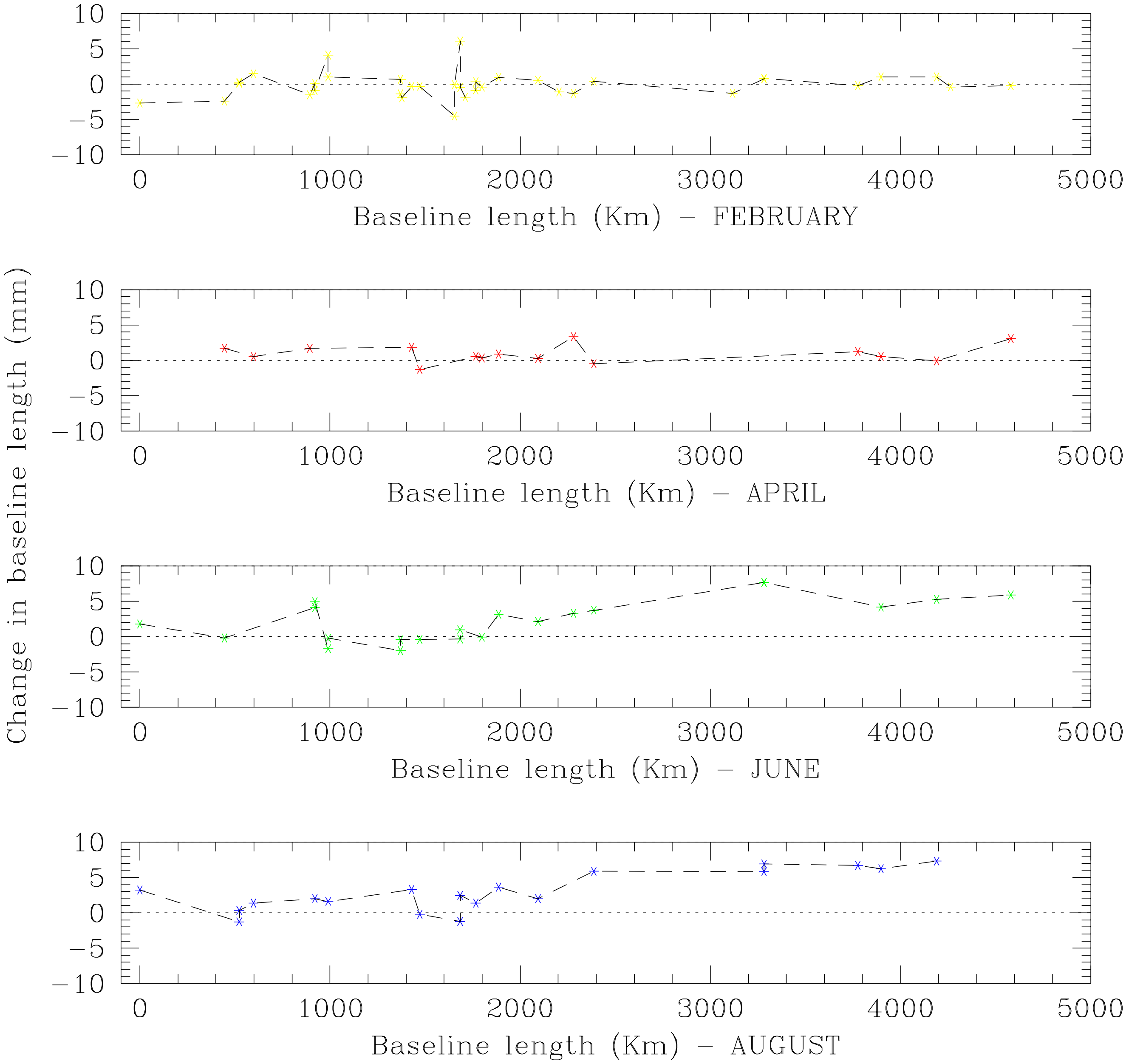

Figure 5: Differences in the baseline length estimates with SOLVE, using two different cutoff angles, 10 and 5 deg. Some sort of "seasonal" dependence is visible.

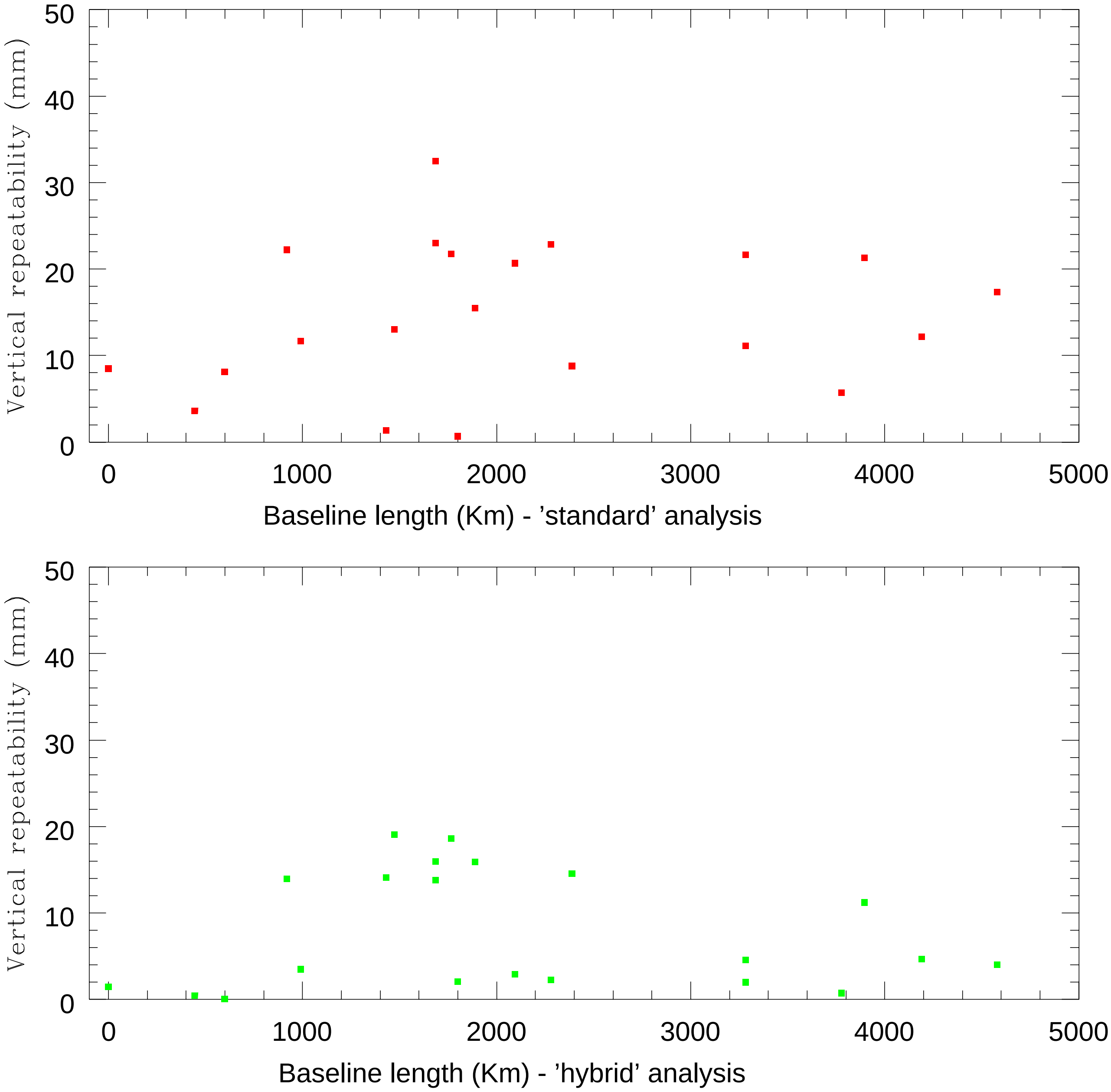

Figure 6: Repeatability of the baseline vertical component estimates, using a 'standard route' analysis (upper), and a 'hybrid route' analysis (lower) of 3 24-hours european VLBI sessions in 1998, with cutoff elevation angles of 5^0 and 10^0, respectively, in SOLVE. See text for explanation of 'standard route' and 'hybrid route' nomenclature.