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Statistical Assessment of Subdiurnal Earth Orientation Parameters from VLBI

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Abstract

Very Long Baseline Interferometry (VLBI) permits the direct determination of Earth orientation parameters (EOP) in subdiurnal resolution. For this reason, it enables monitoring of regular geophysical effects on this time scale such as EOP variations due to subdiurnal ocean tides. The question is if singular effects on the Earth rotation can also be detected which are, e.g., excited by earthquakes. Since the EOP are determined by means of a least-squares adjustment, the statistical properties of highly resolved EOP are of particular interest. Besides the analysis of VLBI session configurations, statistical hypothesis tests can be performed to assess the significance of the estimated EOP.

In this paper, eleven parallel NEOS-A and CORE-A sessions are considered. The data are processed using the software package OCCAM 5.0 LSM. The estimated EOP of each session and their variance-covariance matrices show a clear dependency of the precision and the correlations of the estimated EOP on the chosen temporal resolution. In addition, there is a strong relevance of the representation of the terrestrial and celestial reference frame by the VLBI antennas and the radio sources. The statistical significance of the highly resolved EOP decreases with increasing resolution. For this reason there is a limit for the magnitude of detectable geophysical causes.

1. Introduction

One expectation concerning the very high resolution of Earth orientation parameters (EOP) reads as: The signals in the EOP on the subdiurnal scale which are induced by geophysical processes are revealed more and more clearly with increasing resolution. This is true for regular events if the considered time span is sufficiently long to reduce the noise level and to separate neighbouring frequencies. However, in case of singular events this procedure can obviously not be applied. The noise which is caused by the observation and evaluation process as well as configuration weaknesses have to be considered in the quality assessment of highly resolved EOP (hr-EOP).

Therefore it is worthwhile to study the estimated hr-EOP series and their variance-covariance matrices (vcm) from an algebraic and statistical point of view regarding their ability to indicate effects caused by singular events. For this purpose a set of eleven parallel CORE-A and NEOS-A sessions is discussed in the following with respect to the particularities of the configurations and the significance of the estimated signals. Formal details are omitted; they can be found in [1].

2. Considered Sessions and Data Processing Specifications

The station-date matrices of the considered sessions are given in Figure 1, the numbers of observed sources in Figure 2 and the numbers of observations in Figure 3. The sessions were chosen representatively from the time interval between 1997 and 2000. In the CORE-A program the participating stations vary significantly whereas in the NEOS-A program the configuration is stable. On average, the number of sources of NEOS-A is higher than of CORE-A but the number of observations is similar for both programs. Note that the average number of observations per station is higher for NEOS-A. CORE-A shows a typical geographical coverage of more or less the complete northern hemisphere including the South African HARTRAO and the Australian HOBART26. The NEOS-A stations represent only the northern quartersphere east of the Greenwich meridian.

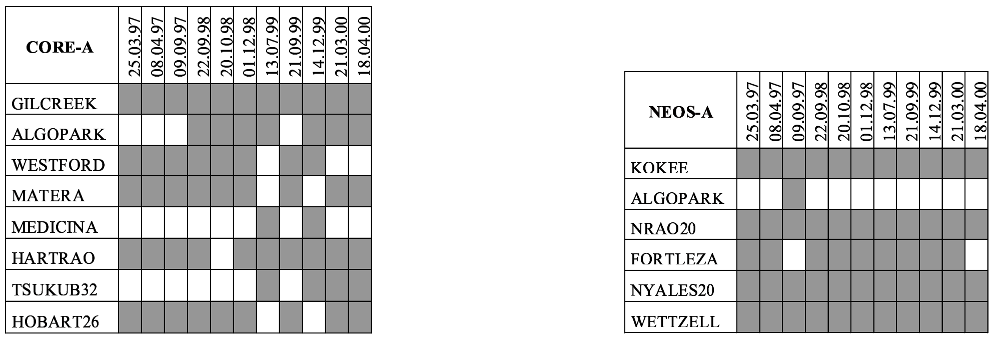

Figure 1. Station-date matrices for the considered CORE-A (left) and NEOS-A (right) sessions.

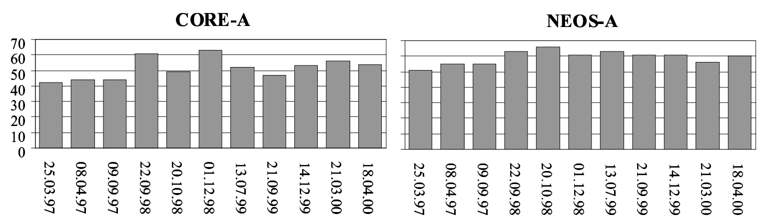

Figure 2. Numbers of sources in the considered sessions.

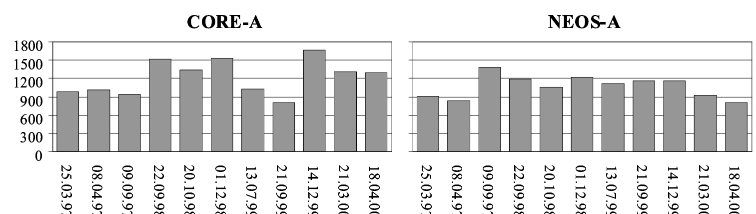

Figure 3. Numbers of observations in the considered sessions.

The offsets of the EOP with respect to the IERS C04 series were estimated for each network. Corrections due to diurnal and semidiurnal variations of the EOP were applied to the observations by means of the Ray model [2]. Different temporal resolutions were studied by halving the time intervals successively starting with a length of 24 hours and ending with 0.75 hours. The VLBI data were processed at the DGFI in Munich, Germany, using the OCCAM 5.0 LSM software. The positions of the VLBI antennas were fixed to their respective ITRF 2000 positions and the positions of the radio sources to the ICRF Ext. 1. The nutation parameters were fixed to the MHB 2000 model according to the IERS Conventions 2000 [3]. The coordinates of the pole as well as ΔUT1 were treated without constraints.

3. Average Precision of the hr-EOP

The average mean errors of the estimated ΔUT1 parameters are given in Figure 4 as precision measures session by session and resolution by resolution. Three results are important to mention. First of all, the precision of the CORE-A sessions is significantly better than the precision of the NEOS-A sessions. This holds for each temporal resolution. For a standard diurnal EOP resolution the obtained precision is in both cases better than 5 μs. Second, in both programs the precision decreases with increasing resolution. Third, as a rule of thumb it holds that the higher the number of stations in the session and the more global their distribution, the better is the precision of the estimated EOP. However, exceptions from this rule are given: The CORE-A session of 08.04.97 shows considerably good results although there are only five participating stations and relatively few observations and sources (see Figures 1-3). On average, the precisions of the NEOS-A sessions of 01.12.98 and 14.12.99 are obviously better than the precisions of the NEOS-A sessions of 08.04.97 and 20.10.98 despite the homogeneity of the NEOS-A session configurations.

Some further results are briefly mentioned. The precisions of the hr-EOP within the same session are inhomogeneous which means that temporally successive EOP estimates have different standard deviations. The higher the temporal resolution the more dominant is the effect of the observation configuration (including the scheduling) on the precision. Actually, the available number of observations per time interval is of secondary importance. Please note that the results obtained for the position of the pole are similar to the ones presented here.

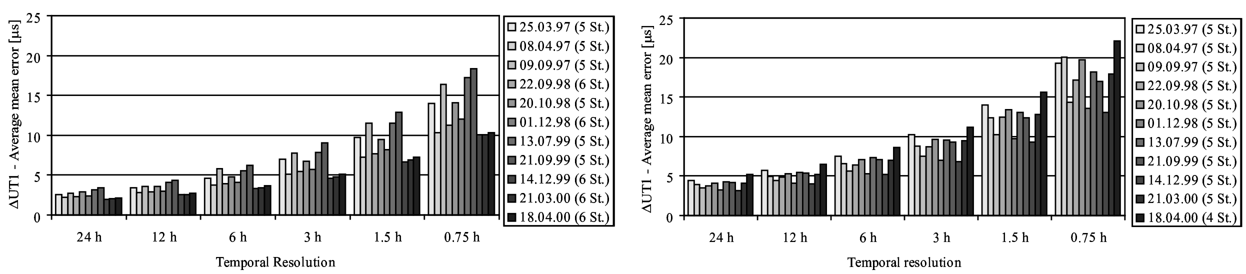

Figure 4. Average mean error of ΔUT1 for the considered CORE-A and NEOS-A sessions.

4. Correlation of the hr-EOP

Besides the mean errors, the correlations of the estimated hr-EOP reflect the quality of the configuration and scheduling. In Figure 5 two correlation scenarios are given representatively. The correlation coefficients are derived from the theoretical vcm of the estimated EOP. The CORE-A session of 21.03.00 yields nearly optimum results as there are neither significant inter-type nor intra-type (i.e. temporal) correlations of the estimated hr-EOP. This is in contrast to the results of the NEOS-A session of 09.09.97 with a negative inter-type correlation between x_{pole} and ΔUT1 and strong positive intra-type correlation, most prominent for x_{pole}, but also for y_{pole} and ΔUT1. The analysis of the precision and of the correlation of the hr-EOP indicates that the common white-noise assumption for the estimated values (mainly equal variances and uncorrelatedness) does not hold from a theoretical point of view. As the inter-type correlation does not depend on the temporal resolution, it is probably caused by the geographical distribution of the participating stations.

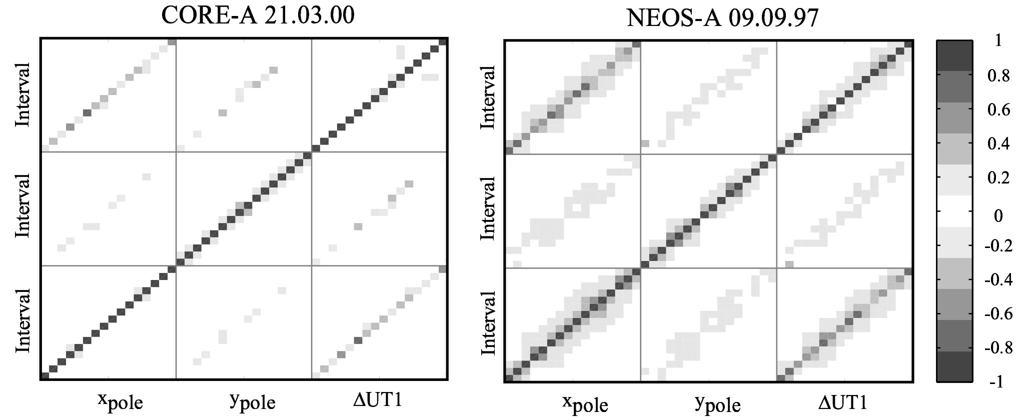

Figure 5. Correlation matrices of the estimated EOP in case of 1.5 h resolution. The main diagonals are plotted from bottom left to top right. The values are given type by type in chronological order.

5. Significance Test of the Higher Resolution

In order to check the benefit of an increased temporal resolution of the EOP, the corresponding reduction of the sum of squared residuals can be tested for significance by means of an F-test. The results are given in Figure 6 for the transitions between the different temporal resolutions both for the CORE-A and NEOS-A sessions. There is a weak significance in case of CORE-A sessions down to a temporal resolution of about 1.5 h. The significance is even weaker for the NEOS-A sessions. As the denominator of the test statistics is controlled by the variances of the observations, the significance would be reduced in its most parts if the observation variances were increased by a factor of 2. It would even vanish if a factor of 5 was applied.

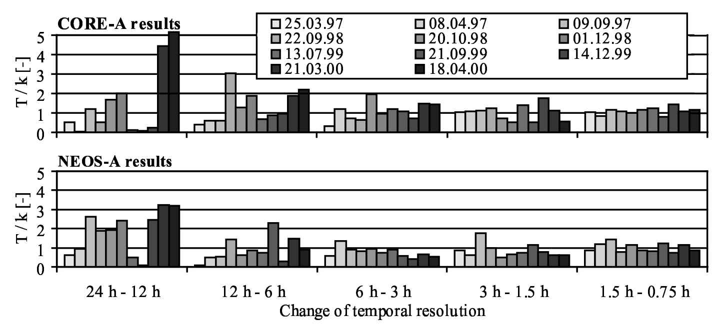

Figure 6. Significance of an increased temporal resolution of the EOP (pole coordinates and ΔUT1): The values of the test statistics T divided by the 0.99 fractile value k of the respective F-distribution are plotted; values greater than 1 are significant. Please note that diurnal and semidiurnal tidal signals according to the Ray model [2] were removed from the estimated EOP before the test.

6. Test of the Differences Between Parallel CORE-A and NEOS-A Sessions

A second significance test was performed to check the difference between the estimated hr-EOP from parallel CORE-A and NEOS-A sessions. The results are shown in Figure 7. Nearly all values are less than 2. Thus, they are very weakly significant. As it was stated in the previous section, the increase of the observation variances by a certain factor would eliminate the significance. If one regards the difference between CORE-A and NEOS-A as accuracy measure, the application of the factor 2 would do the job. Note however that this argument is purely qualitative just to give an idea of the problems associated with the statistical significance of estimated hr-EOP. In addition, there is no dependency of the presented values on the temporal resolution.

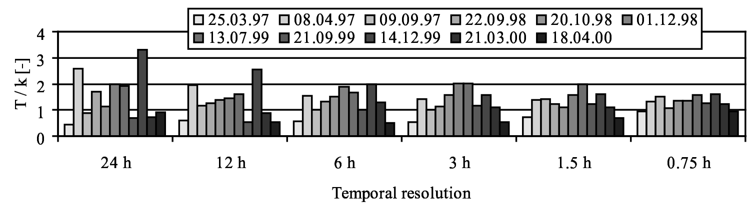

Figure 7. Significance of the differences of EOP from parallel CORE-A and NEOS-A sessions (pole coordinates and ΔUT1): The values of the test statistics T divided by the 0.99 fractile value k of the respective F-distribution are plotted; values greater than 1 are significant. Please note that diurnal and semidiurnal tidal signals according to the Ray model [2] were removed from the estimated EOP before the test.

7. Conclusions

The statistical quality of highly resolved EOP depends mostly on the particular configuration and scheduling of the sessions comprising the involved stations and sources as well as the number of observations. Inhomogeneities of the precision as well as considerable inter-type and intra-type correlations of the hr-EOP are found in the considered sessions. Taking the weak statistical significance of the estimated values and the surely too optimistic stochastic model of the VLBI observations into account, it is at present not likely to detect effects of singular geophysical events in the Earth rotation variations. For this reason it is recommended to develop and to apply a dedicated scheduling for the determination of hr-EOP to increase their precision and to decrease their correlation. As the present efforts of the International VLBI Service for Geodesy and Astrometry aim at globally distributed networks observing 24 hour sessions at short time intervals the situation will probably improve in the near future. Nevertheless it is recommended to study the new sessions as presented here. Further studies should also focus on the refinement of the stochastic model for the VLBI parameter estimation towards a more realistic formulation and on the benefit of VLBI-GPS combined determination of hr-EOP.

References

[1] Kutterer, H., V. Tesmer, Subdiurnal earth orientation parameters from VLBI-networks - determinability and significance, In: Proceedings of the IAG 2001 Scientific Assembly "Vistas for Geodesy in the New Millenium", Springer, Berlin (in print), 2002.

[2] McCarthy, D.D., IERS Conventions (1996), IERS Technical Note 21, Obs. de Paris, 1996.

[3] McCarthy, D.D., IERS Conventions (2000), Draft Version, 2001.