IAG 150 Years
Proceedings of the 2013 IAG Scientific Assembly, Postdam, Germany, 1–6 September, 2013
Simulated VLBI Satellite Tracking of the GNSS Constellation: Observing Strategies ........................................ 85
Lucia Plank, Johannes Böhm, and Harald Schuh

On the Development and Implementation of a Semi-Dynamic Datum for Indonesia ........................................... 91
Hasanuddin Z. Abidin, Susilo Susilo, Irwan Meilano, Cecep Subarya, Kosasih Prijatna, M. Arief Syaﬁ’i, Edwin Hendrayana, Joni Effendi, and Dodi Sukmayadi

Regional Model to Estimate Vertical Deformations Due to Loading Seasonal Changes ........................................ 101
Romina Galván, Mauricio Gende, and Claudio Brunini

Expression of the Local GPS Solution in the Regional Reference Frame ETRF2000 ............................................. 111
Violeta Vasič and Dragan Blagojević

Impact of Antenna Phase Centre Calibrations on Position Time Series: Preliminary Results .................................. 117
D. Sidorov and F.N. Teferle

Optimized Parameterization of VLBI Auxiliary Parameters in Least-Squares Adjustment: Preliminary Results 125
Emine Tanır Kayıkçı, Robert Heinkelmann, Maria Karbon, Tobias Nilsson, Virginia Raposo-Pulido, Benedikt Soja, and Harald Schuh

The Antarctic Regional GPS Network Densification: Status and Results ......................................................... 133

Impact of Celestial Datum Definition on EOP Estimation and CRF Orientation in the Global VLBI Session IYA09 141

A High-Precision Deformation Model to Support Geodetic Datum Modernisation in Australia ................................ 149
R. Stanaway and C. Roberts

Interaction Between Subdaily Earth Rotation Parameters and GPS Orbits ......................................................... 159
Natalia Panafidina, Urs Hugentobler, and Manuela Seitz

A Geocenter Time Series from a Combination of LAGEOS and GRACE Observations ........................................ 169
Rolf König, Christoph Dahle, Margarita Vei, and Karl-Hans Neumayer

DPD2008: A DORIS-Oriented Terrestrial Reference Frame for Precise Orbit Determination .............................. 175
Pascal Willis, Nikita P. Zelensky, John Ries, Laurent Soudarin, Luca Cerri, Guilhem Moreaux, Frank G. Lemoine, Michiel Otten, Donald F. Argus, and Michael B. Heflin

SIRGAS Core Network Stability ......................................................................................................................... 183
L. Sánchez, H. Drewes, C. Brunini, M.V. Mackern, and W. Martínez-Díaz
Optimized Parameterization of VLBI Auxiliary Parameters in Least-Squares Adjustment: Preliminary Results

Emine Tanır Kayıkçı, Robert Heinkelmann, Maria Karbon, Tobias Nilsson, Virginia Raposo-Pulido, Benedikt Soja, and Harald Schuh

Abstract

In a general parameter estimation model, a priori information is used to linearize the system of equations being solved so that just offsets to the a priori values need to be estimated. A priori information used in Very Long Baseline Interferometry (VLBI) data analysis is additionally needed for modeling and constraining the auxiliary parameters, i.e. zenith wet delays, clocks, and troposphere gradients, in order to stabilize the parameter estimation. In our study we investigate the modelling of the auxiliary parameters.

In order to improve the currently used parameterization in the VLBI software VieVS used by many International VLBI Service for Geodesy and Astrometry – IVS Analysis Centers we consider three different approaches. In the first one the choice of the length of the time interval is made relatively to the temporal behavior of parameters (\textit{approach1}), in the second one we do not estimate parameters in gaps in the observation sessions (\textit{approach2}), and in the third one the time interval is choosen relatively to the number of observations (\textit{approach3}). The preliminary results show that \textit{approach2} and \textit{approach3} provide results better than the standard approach (currently used parameterization in VieVS software) for VLBI single session analysis with the least squares solution of the Vienna VLBI Software (VieVS). The impacts of \textit{approach2} and \textit{approach3} on various VLBI solutions with VieVS were assessed by descriptive statistics and remarks for future studies are given. The optimization depending on \textit{approach1} will be investigated in future.

Keywords

Atmospheric gradients • Clock • Parameterization • VLBI • Zenith wet delay (ZWD)

1 Introduction

The adjustment of Very Long Baseline Interferometry (VLBI) data can be carried out using different methods such as Kalman Filter (KF), least-squares method (LSM), and least-squares collocation method (LSCM). The functional model of LSM, based on the Gauss-Markov Model, in the VLBI data analysis contains time delay observations and pseudo-observations (constraints). Within this model, the standard geodetic parameters like station coordinates and Earth orientation parameters can be estimated. In order to avoid numerical problems and to stabilize the estimation, constraints (pseudo observations) for the coefficients of the
continuous piecewise linear functions of the clocks (clk) and the
tropospheric zenith delays (ZWD) have to be included
(Kutterer 2003). These parameters are defined as piecewise
linear offsets and the offsets are estimated at certain time
intervals, e.g. every 60 min (Titov et al. 2004; Teke et al.
2009). Auxiliary parameters like the coefficients of the
continuous piecewise linear functions for the clocks (clk),
the tropospheric zenith delays (ZWD), and the north and
east troposphere gradients (NGR, EGR) are usually of little
interest for geodetic purposes. However, it is important to
model them accurately in order to obtain precise results of the
geodetic parameters. The temporal variations of the auxiliary
parameters are restricted to stay within predefined limits. In
addition, the gradients are sometimes directly constrained,
i.e. constrained to be close to their a priori values. Due to
the direct constraints, precise VLBI solutions depend on the
exact knowledge and application of a priori gradients.

The auxiliary parameters in space geodetic least-squares
analysis are not standardized as several reduction models
are recommended by the IERS Conventions (2010). Yet,
the parameterization can have a significant effect on the
results; sometimes it can even be the largest effect causing
significant differences between various VLBI data analyses
of the same data set (c.f. Heinkelmann et al. 2011). Most
VLBI analysts apply a kind of standard parameterization
(called standard approach later on) to the auxiliary param-
eters with empirically assessed numerical values for time
intervals and constraints. In principle, it would be possible
to determine these numerical values by analyzing the
physics of the processes modeled by the various auxiliary
parameters. However, apart from the physics there are also
mathematical restrictions given by the equation system, for
example the number of observations per time. In prac-
tice the mathematical restrictions are much more stringent
than the ones derivable through physical models. Hence, in
this work we propose three different methods (approach1,
approach2, approach3) for choosing the time intervals of the
auxiliary parameters. In the entire article the constraints
are kept constant, i.e. if the interval length of an auxiliary
parameter is changed the size of its constraint is changed
accordingly so that the constraining effect remains constant
over time. This performance of two of them (approach2, approach3) was investigated by analyzing
VLBI data with the Vienna VLBI Software (VieVS) (Böhm
et al. 2012) and the results were presented. The evaluation of
approach1 will be performed in ongoing investigations.

2 Methods

The current version of VieVS applies in its standard
approach the least-squares method weighting the observa-
tions with their formal errors from the correlations plus
a noise floor of 1 cm. A standard parameterization for
the auxiliary parameters is used, i.e. a piece-wise linear
representation with a default temporal resolution of 60 min
for clocks and ZWD and 6 h for the gradients. Loose
relative constraints are applied to all these parameters.
From the physical point of view, the interval length should
be as short as possible to optimally represent the high
frequency variations of the underlying processes. From the
mathematical point of view, however, the interval length
should be long enough to achieve an appropriate redundancy
required to estimate stable parameters. In the subsections
below, two of the new approaches (approach2, approach3)
for achieving optimized parameterizations of the auxiliary
parameters for each station and session are described
and investigated. The general idea and determination of
approach1 is presented in section of Conclusions and
Future Work. The approach1 realizes the idea of a flexible
parameter definition interval depending on the variability of
the parameters determined with a priori estimation featuring
an equally spaced standard parameterization.

2.1 Solution Intervals Considering Data
Gaps

A significant number of VLBI sessions show gaps between
successive observations at a certain station. Figures 1 shows
the time differences between successive observations at sta-
tion WETTZELL during the session 08AUG24 (CONT08-
Continuous VLBI Campaign 2008). For example, during the
CONT08 session WETTZELL stopped and performed an
intensive VLBI session of about one hour duration together
with another network station. Before and after the intensive
session additional time was needed for test and the antenna
system reset until the station could again join the CONT08
schedule. Since the intensive observations are not included
in the CONT08 database, an observational gap is found
within the CONT08 data (Fig. 1). Currently, VLBI group
delay observations are based on a few minutes of coherent
integration. Consequently, between successive observations
there is always a time difference usually of several minutes
or more. Thus, it is necessary to define a data gap based on a
minimal time difference between successive observations.
As empirically assessed in this study, we define a time difference
of greater or equal 45 min between successive observations
at a station as a data gap.

With our second approach (approach2) we want to define
the auxiliary parameters strictly outside of data gaps. A
parameter defined inside a data gap is determined by the
soft constraint (the non-singularity of the equation system is
ensured by the constraint) and probably only a few observa-
tions will contribute to its determination. This ‘unsupported’
parameter does not improve the solution but decreases the
redundancy and thus might degrade the solution. To be more specific, in case of a data gap between observations, the node within the gap is removed and replaced by one at beginning and one at the end of the gap.

2.2 Consideration of the Time Interval Relatively to the Number of Observations

With our third approach (approach3) we want to realize the largest possible flexibility for the definition of auxiliary parameter interval lengths. Therefore, we define the interval lengths solely depending on the number of supporting observations. With this approach it is possible to obtain an equal partial redundancy for each auxiliary parameter, i.e. each parameter is determined by the same number of observations. Figure 2 shows how much the total number of observations supporting an auxiliary parameter will vary if the auxiliary parameter time intervals are defined as equally spaced by the standard parameterization. Because the parameterization is identical for ZWD and clk as well as for NGR and EGR, only the number of observations used to estimate clk and NGR parameters are displayed in Fig. 2 at a variety of VLBI stations during session 02NOV05.

From Fig. 3 it is obvious that there is a significant relation between the formal error of an estimated parameter and the corresponding total number of observations supporting this parameter. However, since we are not interested in the auxiliary parameters themselves, we will not take care about their formal errors. Nevertheless, we will further investigate this issue making sure that it does not cause numerical problems.

3 Results

The approach2, in Fig. 4, slightly decreases the resulting formal errors of the auxiliary parameters around the gaps and the estimated values of parameters with approach2 agree with the results of the standard approach (currently used for the parameterization in the VieVS software providing the standard VLBI least-squares solution), at station OHIGGINS. Further comparisons for this method can be performed on the basis of baseline length repeatability for multi-session analysis in future studies.

Different parameterization options (presented as par.1, par.2, par.3, par.4, and par.5, in Table 1) were used applying VieVS to investigate the effect of approach3 on the resulting parameter estimation. The different parameterization options differ in the total number of supporting observations (column 2 of Table 1) at each parameter estimation interval.

Table 1 shows that using shorter time intervals for the ZWD/clk/NGR/EGR parameters results in a smaller chi-square calculated for the constraints and the observations. The corresponding loss of redundancy does obviously not play a significant role for the quality of the solution. It should be mentioned that in this session one of the stations has a
large diurnal clock variation, what is not well modelled by a piece-wise linear function if the interval length is too large. The significant improvement of chi-square of the overall solution (a posteriori variance factor) is thus expected. For other sessions, the improvement may not be as large as for this session.

Figure 5 shows that options par 2 and par 5 provide almost equivalent results.

4 Conclusions and Future Work

In this article we presented two ideas on how to improve the parameterization of auxiliary parameters zenith delays, clocks, and north and east troposphere gradients.

- Our preliminary results show that approach2 and approach3 provide results better than the standard
Fig. 3 The total number of observations (nobs) supporting the specific parameter and the formal errors (mx in cm) of the auxiliary parameters ZWD, clock, and egr (top down) at station KOKKE during session 02NOV05.

![Graphs showing estimated parameters for ZWD, CLK, and EGR at station KOKKE.](image)

Fig. 4 The impact of approach2 on formal errors (mx in cm) of the estimated parameters.

approach for VLBI single session analysis with smaller chi-square statistics by least-squares solution of VieVS software.

- The next step will be to practically assess approach1, i.e. choice of the interval length relatively to the behavior of parameters. In the standard VLBI least-squares solution, the interval lengths of auxiliary parameters are usually set to be evenly spaced in time because there is no a priori information about the variability available. Consequently, our first optimization (approach1) would realize the idea of a flexible parameter definition interval depending on the variability of the parameters determined with a priori.
Table 1 Parameterizations applied in the analysis of session 02NOV05

<table>
<thead>
<tr>
<th>Parameterization</th>
<th>Number of at each interval observations</th>
<th>Chi-square of overall solution (cm²)</th>
<th>Used relative constraints (cm/interval)</th>
</tr>
</thead>
<tbody>
<tr>
<td>par.1</td>
<td>10–20 for zwd and clock</td>
<td>2.0031</td>
<td>zwd: 1.086</td>
</tr>
<tr>
<td></td>
<td>40–50 for gradients</td>
<td></td>
<td>clock: 0.942</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.030</td>
</tr>
<tr>
<td>par.2</td>
<td>5–10 for zwd and clock</td>
<td>0.518</td>
<td>zwd: 0.791</td>
</tr>
<tr>
<td></td>
<td>40–50 for gradients</td>
<td></td>
<td>clock: 0.686</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.030</td>
</tr>
<tr>
<td>par.3</td>
<td>5–10 for zwd and clock</td>
<td>0.5254</td>
<td>zwd: 0.791</td>
</tr>
<tr>
<td></td>
<td>50–60 for gradients</td>
<td></td>
<td>clock: 0.686</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.033</td>
</tr>
<tr>
<td>par.4</td>
<td>10–20 for zwd and clock</td>
<td>2.164</td>
<td>zwd: 1.086</td>
</tr>
<tr>
<td></td>
<td>60–70 for gradients</td>
<td></td>
<td>clock: 0.942</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.037</td>
</tr>
<tr>
<td>par.5</td>
<td>5–10 for zwd and clock</td>
<td>0.5017</td>
<td>zwd: 0.791</td>
</tr>
<tr>
<td></td>
<td>20–30 for gradients</td>
<td></td>
<td>clock: 0.686</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.021</td>
</tr>
<tr>
<td>standard</td>
<td>Changes in each interval</td>
<td>4.0623</td>
<td>zwd: 1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>clock: 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>gradients: 0.05</td>
</tr>
</tbody>
</table>

Fig. 5 Estimates and formal errors (in cm) of parameters with different parameterizations obtained by approach3 at station KOKEE during session 02NOV05
Fig. 6 An example for the time dependent variations of auxiliary parameters: a) egr at FORTLEZA for session 00FEB03 (OHIG-10), b) clock at GILCREEK for session 02NOV05 (APSG-11)

estimation featuring an equally spaced standard parameterization. Thus, if the variation is relatively large, the length of the estimation interval will be shortened allowing for a larger degree of freedom for this specific parameter over this interval. The bottom part of Fig. 6a illustrates this idea. The larger first time derivatives of successive differences for the first three parameters are shown; for the interval between minutes 1,000 and 1,200 of modified Julian date (mj) 51577 more than one parameter is estimated, what is shown in the upper part of Fig. 6a. If the temporal variation of a parameter over a certain interval is relatively small, the interval length of the parameter will be increased for the successive estimation. As shown in Fig. 6b around minutes 1,600 of mj 52583, five estimated parameters have almost the same values and show relatively small time dependent variation of the successive parameter differences. As a consequence of this temporal behavior, only one parameter will be estimated instead of five parameters. Estimating one parameter instead of five immediately increases the redundancy and since the variations over time are relatively small the residuals of the observations supporting this parameter will not increase significantly. At the same time the gained redundancy can be utilized to set up more parameters where larger variations were found. Thus, this will reduce the residuals of observations where bigger variations are present.

With this approach it is possible to flexibly handle the parameter definition time interval according to a first standard solution while keeping the overall number of parameters constant. It would also be possible to repeat the application of approach 1 in an iterative way whenever the session is reanalyzed. This iterative optimization will be investigated in future.

Furthermore, it remains to study the size of the constraints. We plan to develop an automatic optimized parameterization for auxiliary parameters in VLBI single session least-squares analyses probably combining all three approaches.

Acknowledgements The authors thank the International VLBI Service for Geodesy and Astrometry - IVS (Schuh and Behrend 2012) for scheduling, observing, correlating, and providing the VLBI data used in this work. The first author, Emine TANIR KAYIKCI, acknowledges the Council of Higher Education of Turkey (YOK) for the financial support of her research stay at GFZ.

References


