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Simulations for VLBI2010

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Abstract

In October 2003 the International VLBI Service for Geodesy and Astrometry (IVS) installed Working Group 3 (WG3) 'VLBI2010' to examine current and future requirements for geodetic VLBI systems. A clear demand was stated by WG3 that thorough and systematic simulation studies should be done. At the Institute of Geodesy and Geophysics of the Vienna University of Technology different simulations are carried out to propose new observing strategies and schedules, to improve troposphere and clock modeling, to find the best antenna configuration and to optimize the network geometry. The software packages used for the simulations are described and first results are presented.

1. Introduction

There has been a lot of discussion in recent years how VLBI could exploit its present resources more efficiently and how future VLBI networks should look like. In October 2003 the International VLBI Service for Geodesy and Astrometry (IVS) installed Working Group 3 (WG3) 'VLBI2010' to examine current and future requirements for geodetic VLBI systems. Based on its report (Niell et al., 2005 [2]) the VLBI2010 Committee was set up to promote and guide research into the improvement of the 'technique' of geodetic VLBI. The Institute of Geodesy and Geophysics (IGG) of the Vienna University of Technology will support these activities by carrying out thorough simulation studies.

2. Simulation Studies at IGG Vienna

The simulation studies are realized by a sequence of three software programs. After scheduling the observations with SKED (Vandenberg, 1999 [3]), the artificial observations are transformed to databases in NGS format which are input for the VLBI analysis software package OCCAM (Titov et al., 2001 [4]). The covariance and correlation matrices in SINEX format are then entered into a Matlab program called VV-SIM (Vienna VLBI-Simulation), which allows the interpretation of the results with distinct numbers and illustrative figures to deliver objective criteria for comparing the various options.

Figure 1. Flow diagram of the software packages. It is very important to define interfaces (NGS and SINEX) which can be used by other groups, too.

2.1. Program SKED

Simulated schedules are created with the software package SKED (Vandenberg, 1999 [3]). This program is based on catalogue files for observed frequencies, radio sources and stations with certain specifications like diameter and slewing rate. For the simulation studies, the catalogue files need to be extended by virtual stations at different locations and of different quality. The schedule can be optimized in different ways (sky coverage, maximum numbers of observations, etc.), and the output of SKED is transformed to NGS format which can be used as input for OCCAM.

2.2. Program OCCAM

The analysis program OCCAM is using the classical Gauss-Markov model for the least-squares analysis:

Table 1. Gauss-Markov Model.

$v = Ax - l$	observation equations	(1)
$Nx - A^TPl = A^TPAx - A^TPl = 0$	normal equations	(2)
$x = N^{-1}A^TPl$	solution for the unknowns	(3)
$Q_{xx} = \sigma_0^2 N^{-1}$	variance-covariance matrix	(4)
$\sigma_0^2 = \frac{v^TPv}{n-u}$	a posteriori variance factor	(5)
$k_{ij} = \frac{q_{ii}}{\sqrt{q_{ii}^2+q_{jj}^2}}$	correlations between the unknowns	(6)

v is the vector of the residuals to the observations, A the design matrix, l the difference between observed and computed values (o-c), P the weight matrix.

For the simulation studies two different approaches for the l-Vector (observed minus computed) are used.

2.2.1. No Observations

The l-vector (o-c) is disregarded. Supposing that realistic standard deviations are used to set up the weight matrix P for the observations, the a posteriori variance factor σ_0^2 is set to unity, the covariance matrix can be determined with equation (4) and the correlation matrix with equation (6). This has been already realized at IGG, and first results are shown below.

2.2.2. Monte-Carlo Simulation

The l-vector (o-c) is subject to both random errors and systematic errors. Troposphere and clock parameters are subject to stochastic variations (Treuhaft and Lanyi, 1987 [5] and Herring et al., 1990 [1]), i.e., they will be simulated as stochastic processes with realistic variances. On the other hand, extreme weather conditions will be taken from numerical weather models to add systematic variations of the l-vectors. The information of the l-vectors will also be transformed backwards to the databases (NGS format), and thus can be used by other software packages, too.

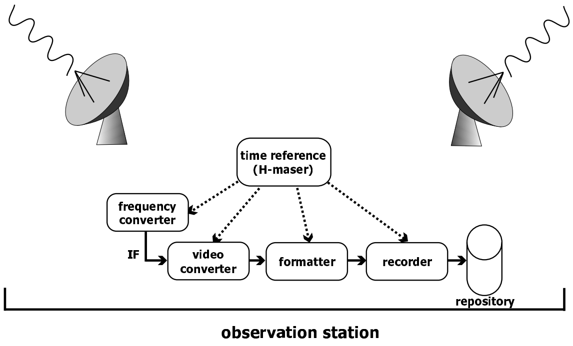

Figure 2. Two antennas at one site.

Additionally, certain modifications will be made with OCCAM, e.g. the introduction of condition equations to account for two co-located VLBI antennas using the same clock (Figure 2). Careful Monte-Carlo simulations have to be carried out to assess the real benefit of this approach.

2.3. VV-SIM

The third program used for the simulations is VV-SIM (Vienna VLBI-Simulation).It is written in Matlab. Its main task is to convey the results of the VLBI analysis in a clear and illustrative form that certain parameters can be extracted easily, e.g. the standard deviations of the unknown parameters or the correlations between the unknowns. The first results and illustrations of VV-SIM are shown below. This software package is based on input data in SINEX format and can be used by other groups, too.

3. First Results of the Simulations

The following network configurations are purely theoretical and only for test purposes. The unusual configuration should help to understand the influence of network configurations and baseline lengths on the cofactors of the Earth orientation parameters (EOP). For all simulations described below the VLBI analysis with the software package OCCAM was realized by setting o-c to zero (Section 2.2.1).

3.1. NET1: Greenwich Network

In the first example, the stations are located on the Greenwich meridian, starting with a latitude of 0° up to 90° North and on the longitude of 180° with a latitude of 0° up to 90° North using a spacing of 30°. The results of the simulation with this 7 station network can be seen in Table 2.

3.2. NET2: Equator Network

The stations are located on the equator, with a spacing of 45°. We get a network with 8 stations. The results of the simulation can be seen in Table 2.

3.3. NET3: CONT05 4^{th} Day

The next simulation was done for the 4^{th} day of CONT05. The o-c vector was set to zero, and realistic relations between the cofactors are expected. The correlations between the parameters give information about the quality of the network. The results of the simulation can be seen in Table 2.

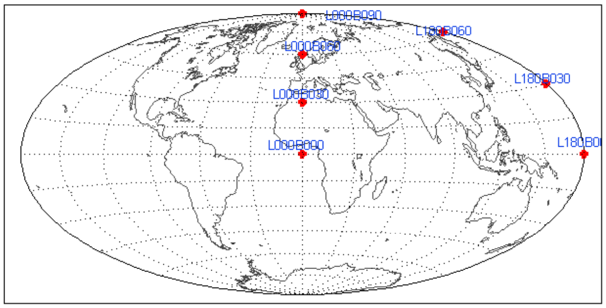

Figure 3. Station distribution Greenwich meridian (NET1).

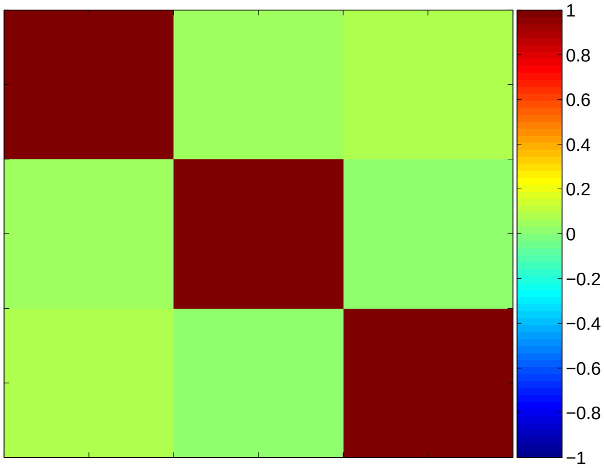

Figure 4. Correlations between xp, yp and dut1 for the station destribution described in Figure 3.

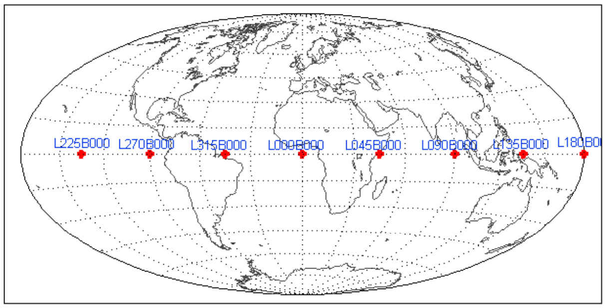

Figure 5. Station distribution equatorial (NET2).

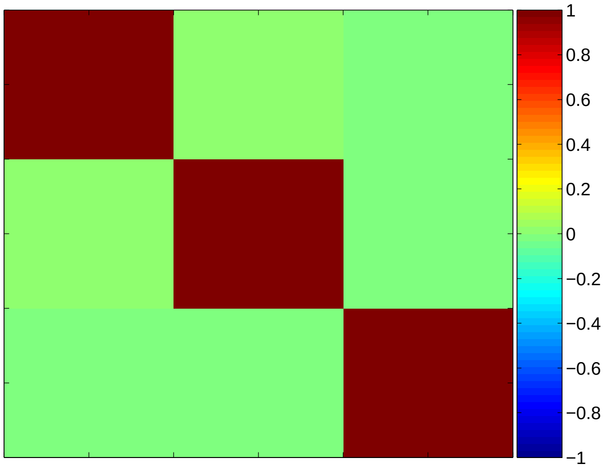

Figure 6. Correlations between xp, yp and dut1 for the station destribution described in Figure 5.

Table 2. Cofactors and Correlations of the EOP (xp, yp and dut1) for the different station distributions NET1, NET2 and NET3.

	Cofactors			*Correlations*		
	xp [μas]	yp [μas]	dut1 [μs]	xp-dut1	yp-dut1	xp-yp
NET 1	33.4	17.3	0.7	0.069	0.024	0.054
NET 2	11.1	10.8	0.3	-0.022	-0.029	0.025
NET 3	12.8	16.0	0.6	-0.369	0.323	0.187

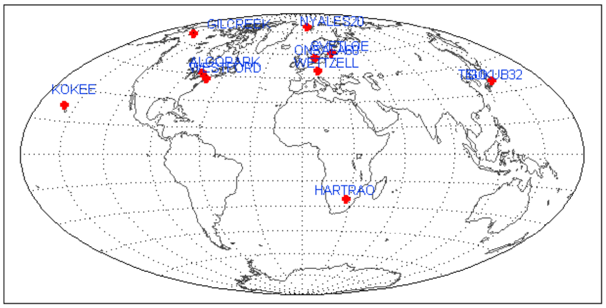

Figure 7. Station distribution CONT05 (NET3).

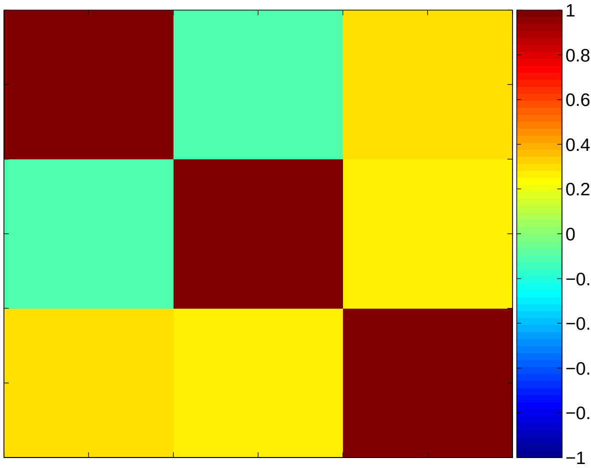

Figure 8. Correlations between xp, yp and dut1 for the station destribution described in Figure 7.

4. Conclusions

Simulation studies play a critical role for the development of a future geodetic VLBI system. Thus, it is important to carry out these studies as realistic as possible, i.e. with the most accurate specifications of future VLBI antennas or sophisticated models for clock and troposphere parameters. Furthermore, it is absolutely necessary to provide as many interfaces to other software packages as possible (SINEX, NGS) to be able to cross-check the results.

5. Acknowledgements

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