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Simulation Analysis of the Geodetic Performance of Networks of VLBI2010 Stations

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Abstract. The IVS is performing simulations of networks of new-generation VLBI2010 stations to find optimal antenna specifications and network site locations for the VLBI2010 observing system. To determine the precision (repeatability) of estimated geodetic parameters, I performed Monte Carlo simulations with input simulated tropospheric, clock, and observation noise, where the troposphere noise is based on a realistic model of atmospheric turbulence. I investigated the dependence of station position precision on antenna slew rate. I determined the improvement in reference frame scale and EOP precision resulting from an increase in the number of network sites.

1. Introduction

The IVS (International VLBI Service for Geodesy and Astrometry) is designing a new observing system called VLBI2010 [1], which will consist of a global network of small (at least 12-m diameter) fast-slewing antennas. One of the VLBI2010 goals is to choose antennas that are both mechanically reliable and cost effective enough to be reproduced economically so that more international groups can afford to install antennas. The global network of new VLBI stations will provide much better global coverage compared to the current network of antennas that is dominated by Northern Hemisphere sites. A critical specification for VLBI2010 is the antenna slew rate which will determine the observation rate at each station. I used a Monte Carlo procedure for simulating the performance of antennas with different slew rates and global observing networks of increasing size. The results of the simulations are estimates of the geodetic precision of the system.

2. Models and Simulation Procedure

To determine the WRMS precision (repeatability) of estimated geodetic parameters for a given scenario, I performed a Monte Carlo simulation by making repeated (typically 25 times) VLBI analysis solutions with the same 24-hour observation file but with different input simulated noise. The simulated noise consists of tropospheric, clock, and observation noise delay contributions. The current model used for the input simulated noise of an observation on the baseline between station 1 and station 2 is

$$O - C = [m_w(elev_2)\tau_{wz2} + clk_2] - [m_w(elev_1)\tau_{wz1} + clk_1] + \sigma_{obs} \qquad (1)$$

Here, m_w is the wet troposphere mapping function and $elev_1$ and $elev_2$ are the observation elevation angles at station 1 and 2. The τ_{wz} and clk terms are the wet zenith and clock delays at the two sites. The observation uncertainty is given by the white noise contribution σ_{obs}. The wet zenith delays are either a random walk series or the equivalent zenith delays derived from a turbulent troposphere model. Clock delays are the sum of a random walk and an integrated random walk to match the performance level (Allan Standard Deviation) of the maser that is modeled. The turbulence model is based on the analysis of Treuhaft and Lanyi [3], which assumes that the refractivity of wet tropospheric refractivity spatial fluctuations is described by Kolmogorov turbulence theory. It is assumed that temporal fluctuations are caused by the "frozen flow" of spatial fluctuations that are carried horizontally past a site by the wind. Nilsson [2] describes the procedure used here for generating turbulent delays for a 24-hour schedule that are correlated according to Kolmogorov turbulence. The parameters of the turbulence model are the strength C (refractive index structure constant), the wind velocity, and the effective troposphere height.

3. Comparisons Between Simulation and Observed Scatter

To see how simulations compare with observed results, I performed tests by running simulated noise through observing schedules that were used for actual VLBI experiments. The first comparison is for the CONT05 series of 15 continuous days of VLBI observing. These R&D experiments represent the best level of VLBI precision. Clocks were modeled as a random walk plus integrated random walk corresponding to an Allan standard derivation of $2{\cdot}10^{-14}$ at 50 minutes. I used turbulent delays derived using a latitude-dependent structure constant model and wind velocities and effective atmosphere height derived from ECMWF data for the CONT05 period [2]. On average, the simulated CONT05 Weighted Root Mean Square (WRMS) baseline length repeatabilities in Fig. 1 are 72% of the observed repeatabilities.

In a second comparison, I looked at the RDV (Research and Development VLBA) network experiments. These are run approximately every two months with an 18-20 site network consisting of the 10 VLBA (Very Long Baseline Array) antennas (operated by the National Radio Astronomy Observatory) plus 8 to 10 of the IVS geodetic antennas. Fig. 2 shows the observed length WRMS from a several year series of RDV experiments compared with a simulation (25 repetitions) for a recent RDV experiment (January 2007) using turbulent delays generated with the parameters given in [3].

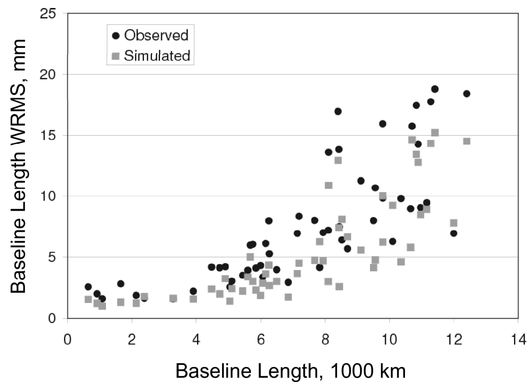

Figure 1. Comparison of observed (solid circles) and simulated (gray squares) WRMS length repeatabilities from the CONT05 series

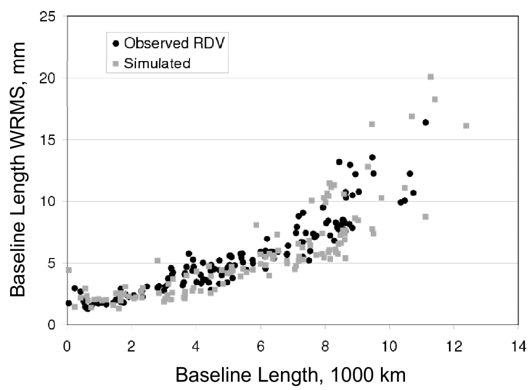

Figure 2. Comparison of observed RDV length repeatabilities over several years (solid circles) with a single RDV session (January 2007) simulation (gray squares)

4. VLBI2020 Antenna Slew Rate Specification

A critical antenna design choice for the VLBI2010 antennas is the antenna slew rate. Higher slew rates allow an antenna to move across the sky faster and make more observations. As part of the work of the IVS VLBI2010 committee, I investigated the effect of antenna slew rate on geodetic precision using observing schedules for a 16-site globally-distributed subset of the network shown in Fig. 3. Turbulent delays were generated with a site-dependent turbulence model where the C_n were based on a latitude-dependent model derived from high-resolution radiosonde data [2] and winds and troposphere heights were from ECMWF data. Two types of schedules were analyzed: 1) schedules made with the operational VLBI scheduling program SKED and 2) uniform

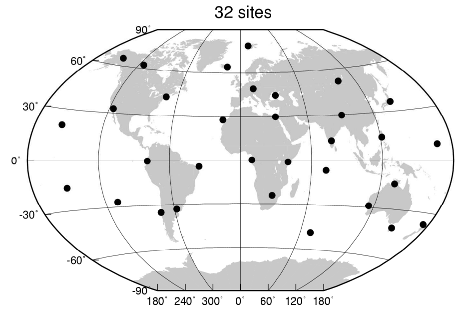

Figure 3. Global 32-site simulation network

sky schedules designed by B. Petrachenko [4] to have uniform site sky coverage every consecutive 12 observations. Fig. 4 for the uniform sky schedules shows that the 3D position WRMS repeatability improves significantly when the azimuth slew rate for an azimuth/elevation antenna is increased from 2 deg/s to 5 deg/s, but not signficantly for larger rates. Analysis using the observing schedules generated with SKED yielded a similar conclusion.

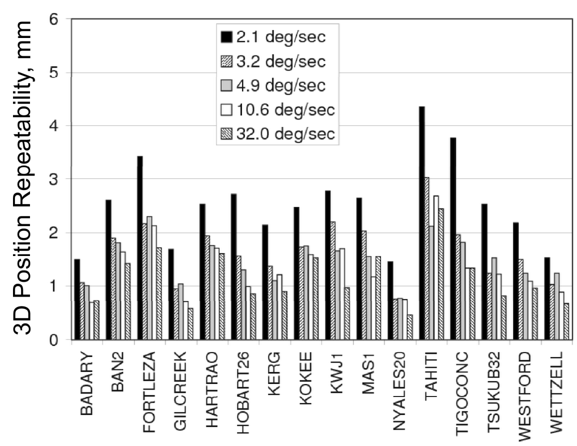

Figure 4. Improvement of 3D position repeatability versus antenna azimuth slew rate for uniform sky schedules. The median 3D repeatabilities were: 2.53 mm (2.1 deg/s), 1.64 mm (3.2 deg/s), 1.53 mm (4.9 deg/s), 1.21 mm (10.6 deg/s), 0.96 mm (32 deg/s)

5. Network Simulations

I investigated the dependence of scale and Earth Orientation Parameters (EOP) precision (repeatability) for the network in Fig. 3 and for subset networks of 24, 16, and 8 sites. Troposphere delay contributions were generated from a turbulence model with Treuhaft-Lanyi parameters [3]. Fig. 5, 6 show the improvement in precision (repeatability) of the reference frame scale and EOP estimates as network size increases. The observing schedules were uniform sky schedules [4]. Stations observed about 70 scans/hour compared to current operational schedules, where stations typically observe 10 scans/hour.

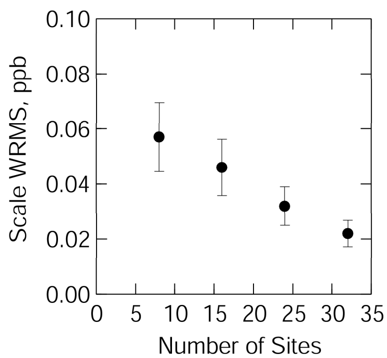

Figure 5. Scale precision

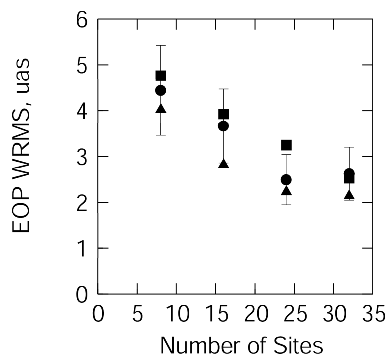

Figure 6. EOP precision: x-pole (circle), y-pole (square), UT1 (triangle)

6. Conclusions

Monte Carlo simulations show that increasing the antenna azimuth slew rate beyond 5-6 deg/s does not significantly improve site position 3D precision. Reference frame scale and EOP precision (repeatability) are improved by about a factor of 2 as VLBI2010 network size increases from 8 to 32 sites.

References

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