0.1 Fringe fitting Preprocessing

Visibility data were processed with fringe fitting software PIMA **?**. The fringe fitting procedure estimates phase delay rate, group delay, and group delay rate of using the spectrum of cross correlation function also known as visibility data. Then the estimates of phase delay rate, group delay, and group delay rate are applied to visibilities, which causes their phase rotation, and averaged over time and frequency within each intermediate frequency (IF). Averaging over time was initially made over intervals of 8.4 s long, but it was further increased for weak sources during consecutive stage of data analysis.

Upon fringe-fitting completion, the data were exported to NASA VLBI analysis software VTD/pSolve. A model that includes source coordinates and the clock function presented as a B-spline of the first degree with one hour stride between knots for all the stations but the one taken as the reference was fitted to X-band and S-band group delays in two separate least square (LSQ) solution. Initially, the data with SNR less than 5.5 were suppressed. The SNR is defined as the ratio of the amplitude averaged over time and frequency of a given observation after applying phase delay rate, group delay, and group delay rate to the mean visibility amplitude. The outliers were eliminated by using a recursive algorithm that starts from the observation with the largest normalized residual. After suppression of each observation, the solution was updated. The iterations were terminated when the largest normalized residuals became less than 6σ. Then the parametric model was extended. Estimation positions of all stations, but the reference one and estimation of path delay in zenith direction presented as a B-spline of the first degree with one hour stride between knots for all the stations. The outlier elimination procedure was repeated till the largest normalized residuals became less than 4.5σ. Then the opposite procedure for restoration of suppressed observations was performed: the suppressed observations with the SNR $\geq$ 5.5 and with normalized residuals less than 4.5σ were restored by the iterative procedure starting with the observations with the smallest normalized residuals.

A source is considered detected if the number of its observations used in the solution, i.e. not suppressed is at least 3. Estimation of right ascension and declination takes two degrees of freedom. Three observations provide a minimum redundancy. Group delays of detected observations have the Gaussian distribution with the standard deviation less than 0.1 ns, while group delays of non-detected observation have the uniform distribution in a range [-4000, 4000] ns. Astrometric LSQ solution provides a power filter of false detections: the probability that a point with the random distribution [-4000, 4000] will be within 0.1 ns of given value is 10^{-5}. Therefore, the probability that a given sources had two detections, but the third group delays was from a non-detection, but by chance appeared within 4.5σ (i.e. in range of approximately [-0.5, 0.5] ns at S-band and [-0.1, 0.1] ns at X band) is $1.2 \cdot 10^{-4}$ at S-band and $2.5 \cdot 10^{-5}$ at X-band respectively.

Then the sources that have more than 2 observations with SNR ≥ 5.5, but with the total number of observations that are not suppressed were evaluated. It may happened that the outlier elimination procedure kept one or more non-detections and eliminated detections. A non-detection may "poison" the least square solution and course large errors in computation of residuals, which prevented elimination of the non-detections. Different combinations of flagging these observations were tried, and if a combination that left 3 or more observations with normalized residuals more less 4.5σ was found, such flags were retained.

Then the SNR cutoff limit was lowered from 5.5 to 5.0 and the procedure for restoration of suppressed observations was repeated. After that all suppressed observations of detected sources (i.e. those with 3 or more retained observations) were re-fringed with a narrow search window. The a posteriori path delay was computed using results of preliminary astrometric solution. The fringe fitting procedure was repeated with the narrow search window for group delays within 3 ns of the a posteriori group delay at S-band and within 1 ns of the a posteriori group delay at X-band. Astrometric solution was repeated and those observations with SNR $\geq$ 4.8 that after re-fringing had normalized residuals less than 4.5σ were un-flagged and used for further analysis.

0.2 Absolute astrometry

Observations of the VLBA Northern Polar Cap survey were also used absolute astrometry. They were processed the same way as VLBA Calibrator survey (**?**). All dual-band geodetic VLBI data from 24-h observing sessions since 1980.04.01 through 2020.03.09, in total 6498 experiments, and three observing sessions of this survey were processed in three least square runs. The first run used X/S band data from the survey, the second run X-band data, and the third run used X-band data. The number of detected target sources from the survey used in these solutions is 104, 109, and 154 respectively. Estimated parameters are split into three categories: global parameter such as station positions, station velocities, and source coordinates; session parameters, such pole coordinates, UT1 angle, their time derivatives, and nutation angle offsets; and segment parameters, such as clock function and atmospheric path delay in zenith direction. The segmented parameters are modeled with a B-spline with time span of 1 hour.

For accounting systematic errors, we computed weights the following way

$$w = \frac{1}{k \cdot \sqrt{\sigma_g^2 + a^2 + b^2(e)}}, \qquad (1)$$

where σ_g is the uncertainty of the group delay path delay, k is the multiplicative factor, a is the elevation-independent additive weight correction and b is the elevation-dependent weight correction. We used $k = 1.3$ base on analysis of VLBI-Gaia offset (**?**). For processing dual-band observations we used $b(e)^2 = \beta(\tau(e_1)^2_{\mathrm{atm},1} + \tau(e_2)^2_{\mathrm{atm},2})$, where $\tau(e_i)_{\mathrm{i,atm}}$ is the atmospheric path delay at the ith station. We used $\beta = 0.02$ in our analysis.

For processing single band observations we computed the ionospheric delay using Total Electron Contents (TEC) maps from analysis Global Navigation Satellite System (GNSS) observations. Specifically, we used CODE TEC time series (**?**)[⋆] with a resolution of $5^\circ \times 2.5^\circ \times 1^h$ ($5^\circ \times 2.5^\circ \times 2^h$ before December 19, 2013). However, the TEC maps accounts

⋆ Available at ftp://ftp.aiub.unibe.ch/CODE only partially for the ionospheric path delay due to coarseness of their spatial and temporarily resolution. In order to account for residual errors, we used the same approach as we used processing single-band Long Baseline Array observations (**?**). We computed variances of the mismodeled contribution of the ionosphere to group delay in zenith direction for the both stations of a baseline, Cov_{11} and Cov_{22}, as well as their covariances Cov_{12}. Then for each observation we computed the predicted rms of the mismodeled ionospheric contribution as

$$b^2_{\mathrm{iono}}(e) = \gamma \left(\mathrm{Cov}^2_{11}\ M^2_1(e) - 2\,\mathrm{Cov}_{12}\ M_1(e)\, M_2(e) + \mathrm{Cov}^2_{22}\ M^2_2(e) \right), \quad (2)$$

where $M_1(e)$ and $M_2(e)$ are the mapping function of the ionospheric path delay. We used $\gamma = 0.5$ in our analysis and added $b^2_{\mathrm{iono}}(e)$ to $b(e)^2$ when processed single-band observations.

Additive parameter a was found by in iterative procedure that makes the ratio weighted sum of post-fit residuals to their of their mathematical expectation close to unity.

We compared positions of 86 sources derived using X-band and S-band only observations that were observed only in the Northern Polar Cap observations with dual-band positions. The position differences normalized over single-band position uncertainties fit to the Gaussian distribution over right ascensions and declination with the zero mean and 2nd moment 0.5 for X-band positions, 0.8 for S-band right ascensions, and have a positive bias of 10 mas and 2nd moment 1.0 for S-band declinations. Since the 2nd moment of the distribution of normalized differences does not exceed 1, we conclude the formal uncertainties correctly accounts for ionosphere-driven systematic errors. The declination bias in S-band positions was applied in the catalogue.