Troposphere and Clock Parameterization During Continuous VLBI Campaigns

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Abstract. The Institute of Geodesy and Geophysics of the Vienna University of Technology is developing new software (Vienna VLBI Software, VieVS) for the analysis of Very Long Baseline Interferometry (VLBI) observations. In order to estimate realistic and reliable sub-daily and daily geodetic parameters the basic pre-requisites in the analysis stage are introducing precise a priori geophysical models to the observed minus computed vector. In addition, in the parameter estimation high degrees of freedom, proper selection of estimation intervals and appropriate constraints for each parameter should be ensured. In VieVS, all parameters to be estimated are basically modelled with piecewise linear offsets at integer hours, or at integer fractions or integer multiples of integer hours. In this presentation, we show some outputs of the new software with several plots. These are the piecewise linear offsets of the estimates of clocks, troposphere zenith wet delays, troposphere gradients, Earth orientation parameters, and antenna coordinates with their respective covariance matrices.

Piecewise linear offsets. Clocks, troposphere zenith wet delays, troposphere gradients, Earth orientation parameters, and coordinates of the radio telescopes are estimated as piecewise linear offsets (Equation 1).

$$y(t) = a_{n-1} + \frac{a_n - a_{n-1}}{t_n - t_{n-1}}(t - t_{n-1}) \qquad (1)$$

Estimating piecewise linear offsets with least squares. VLBI parameters can be estimated as piecewise linear offsets with Least Squares (LS) (Titov et al. 2004). Offsets are chosen as the parameters of a continuous piecewise linear function. The partial derivatives of the observation equations are given below.

$$\left.\begin{aligned} \frac{\partial y}{\partial a_n} &= \frac{t - t_{n-1}}{t_n - t_{n-1}} \\ \frac{\partial y}{\partial a_{n-1}} &= 1 - \frac{t - t_{n-1}}{t_n - t_{n-1}} \end{aligned}\right\}$$ partial derivatives of the continuous piecewise linear offset functions which are the elements of the design matrix (2)

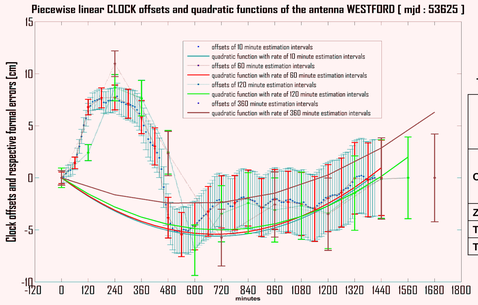

Table 1. Clock parameter estimation options

Estimated Parameters	Estimation Intervals	Constraints over parameters for each estimation interval
Clocks (Fixed clock Gilcreek)	10 minutes 60 minutes 120 minutes 360 minutes	0.1 picosec^2/sec (loose) 0.1 picosec^2/sec (loose) 0.1 picosec^2/sec (loose) 0.1 picosec^2/sec (loose)
Zenith wet delays	5 minutes	0.7 picosec^2/sec (loose)
Troposphere east gradients	60 minutes	2 mm/day (loose)
Troposphere north gradients	60 minutes	2 mm/day (loose)

Figure 1. Piecewise linear clock offsets and quadratic functions of the antenna Westford, for 10, 60, 120, and 360 minutes estimation intervals for the first 24 hour session of CONT05.

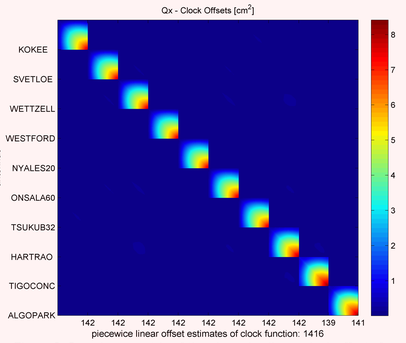

Figure 2. Covariance matrix of the piecewise linear clock offsets for 10 minutes estimation intervals (number of clock offset estimates in total is 1416 for 10 clocks). Gilcreek clock is fixed. The offset errors increase proportionally to the elapsed time from the first scan time (t_0) of the session.

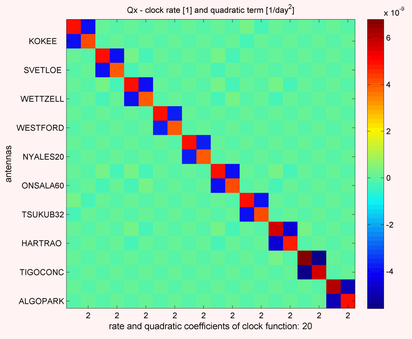

Figure 3. Covariance matrix of the rate and quadratic terms of the clock function (number of estimates in total is 20 for 10 clocks).

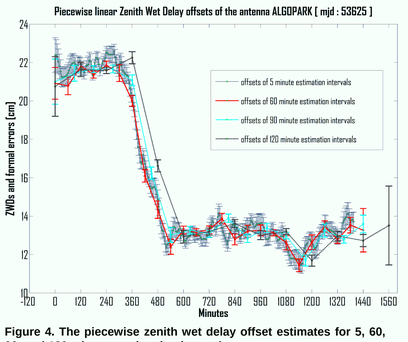

Table 2. Zenith wet delay parameter estimation options

Estimated Parameters	Estimation Intervals	Constraints over parameters for each estimation interval
Clocks (Fixed clock Gilcreek)	60 minutes	0.1 picosec^2/sec (loose)
Zenith wet delays	5 minutes 60 minutes 90 minutes 120 minutes	0.7 picosec^2/sec (loose) 0.7 picosec^2/sec (loose) 0.7 picosec^2/sec (loose) 0.7 picosec^2/sec (loose)
Troposphere east gradients	60 minutes	2 mm/day (loose)
Troposphere north gradients	60 minutes	2 mm/day (loose)

Figure 4. The piecewise zenith wet delay offset estimates for 5, 60, 90, and 120 minutes estimation intervals.

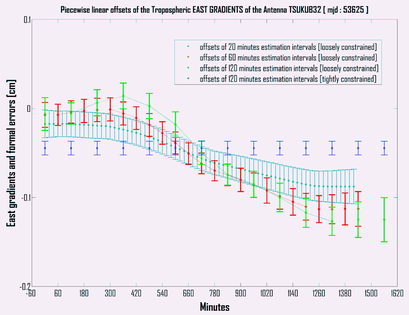

Figure 5. The piecewise troposphere east gradients' offset estimates for 20, 60, and 120 minutes estimation intervals.

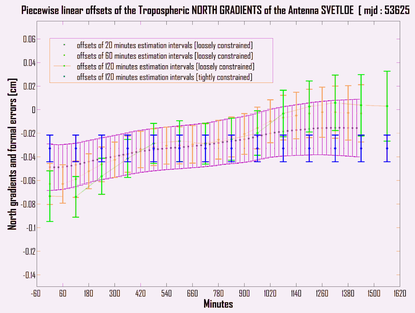

Figure 6. The piecewise troposphere north gradients' offset estimates for 20, 60, and 120 minutes estimation intervals.

Table 3. Tropospheric east and north gradient parameter estimation options

Estimated Parameters	Estimation Intervals	Constraints over parameters for each estimation interval
Clocks (Fixed clock Gilcreek)	60 minutes	0.1 picosec^2/sec (loose)
Zenith wet delays	10 minutes	0.7 picosec^2/sec (loose)
Troposphere east gradients	20 minutes 60 minutes 120 minutes 120 minutes	2 mm/day (loose) 2 mm/day (loose) 2 mm/day (loose) 0.001 mm/day (tight)
Troposphere north gradients	20 minutes 60 minutes 120 minutes 120 minutes	2 mm/day (loose) 2 mm/day (loose) 2 mm/day (loose) 0.001 mm/day (tight)

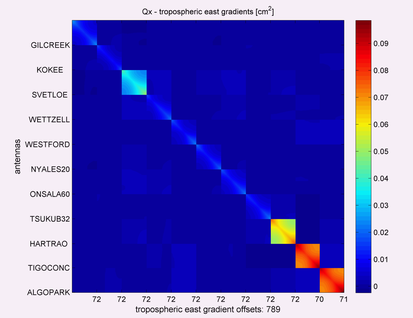

Figure 7. Covariance matrix of the east gradients' offsets for 11 antennas and 20 minutes estimation intervals (number of estimates in total is 789).

Table 4. Antenna coordinates estimation options

Estimated Parameters	Estimation Intervals	Constraints over parameters for each estimation interval
Clocks (Fixed clock Gilcreek)	60 minutes	0.1 picosec2/sec (loose)
Zenith wet delays	10 minutes	0.7 picosec2/sec (loose)
Troposphere east gradients	30 minutes	2 mm/day (loose)
Troposphere north gradients	30 minutes	2 mm/day (loose)
Antenna coordinates (No Net Translation (NNT) and No Net Rotation (NNR) condition equations are introduced to the Normal equation matrix)	30 minutes 60 minutes 120 minutes 360 minutes	100 mm/day (loose) 100 mm/day (loose) 100 mm/day (loose) 0.1 mm/day (tight)

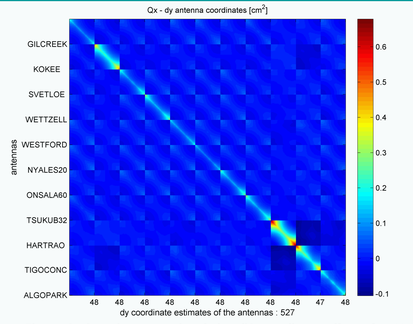

Figure 8. Covariance matrix of the dY coordinate offsets for 11 antennas (30 minutes estimation intervals, number of estimates in total is 527).

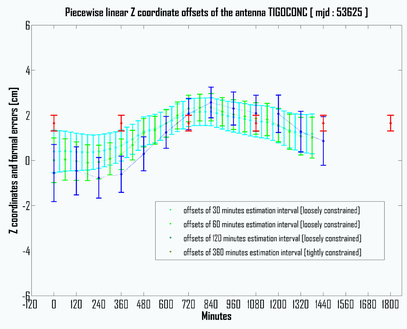

Figure 9. The piecewise Z coordinate offset estimates of the antenna Tigoconc for 30, 60, 120, and 360 minutes estimation intervals.

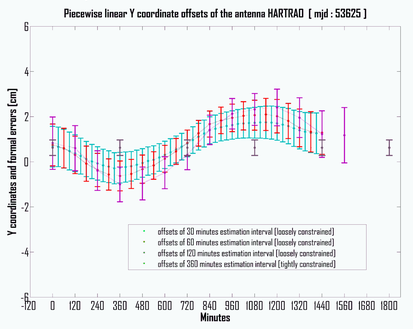

Figure 10. The piecewise Y coordinate offset estimates of the antenna Hartrao for 30, 60, 120, and 360 minutes estimation intervals.

Table 5. Earth orientation parameters (EOPs) estimation options

Estimated Parameters	Estimation Intervals	Constraints over parameters for each estimation interval
Clocks (Fixed clock Gilcreek)	60 minutes	0.1 picosec^2/sec (loose)
Zenith wet delays	20 minutes	0.7 picosec^2/sec (loose)
Troposphere east gradients	120 minutes	2 mm/day (loose)
Troposphere north gradients	120 minutes	2 mm/day (loose)
Xpol (No antenna coordinate is estimated)	20 minutes 20 minutes	3 mas/day (loose) 0.001 mas/day (tight)
Ypol (No antenna coordinate is estimated)	20 minutes 20 minutes	3 mas/day (loose) 0.001 mas/day (tight)
dUT1 (No antenna coordinate is estimated)	20 minutes 20 minutes	0.3 ms/day (loose) 0.001 ms/day (tight)
deps (No antenna coordinate is estimated)	1440 minutes 1440 minutes	0.001 mas/day (tight) 0.001 mas/day (tight)
dpsi (No antenna coordinate is estimated)	1440 minutes 1440 minutes	0.001 mas/day (tight) 0.001 mas/day (tight)

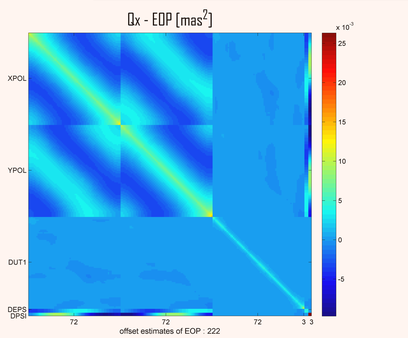

Figure 11. Covariance matrix of the EOP offset estimates for different estimation intervals and for the loosely constrained case (number of estimates in total is 222).

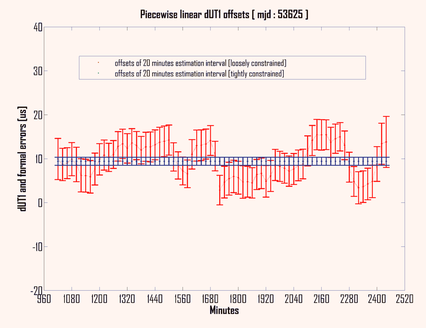

Figure 12. The piecewise dUT1 – Earth rotation angle rate offset estimates for 20 minutes estimation intervals (for the loosely and tightly constrained cases)

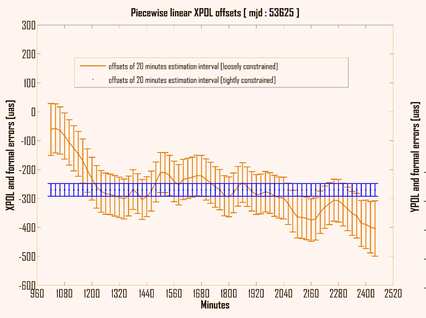

Figure 13. The piecewise Xpol - polar motion coordinate offset estimates for 20 minutes estimation intervals (for the loosely and tightly constrained cases)

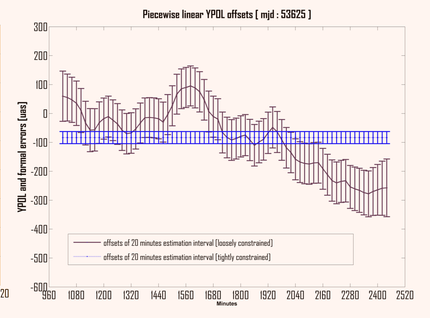

Figure 14. The piecewise Ypol - polar motion coordinate offset estimates for 20 minutes estimation intervals (for the loosely and tightly constrained cases)

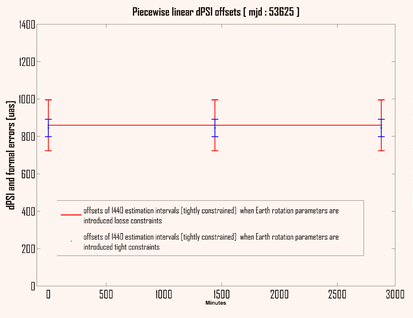

Figure 15. The piecewise dpsi – nutation angle offset estimates for 1440 minutes estimation intervals (tightly constrained)

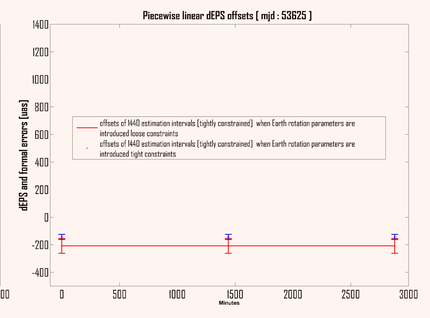

Figure 16. The piecewise deps – nutation angle offset estimates for 1440 minutes estimation intervals (tightly constrained)

Conclusion. From the investigations carried out within this study the following conclusions can be drawn:

- Piecewise linear offsets can be applied for all parameters, i.e. zenith wet delays, troposphere gradients, clocks, Earth orientation parameters, antenna and quasar coordinates.
- The offsets should be determined at integer days, integer hours, or integer fractions of integer hours, respectively.
- The weights of the constraints (pseudo-observations) have to be chosen properly if the usage of the constraints is necessary.
- Troposphere and clock models should be improved in order to increase the accuracies of all estimated parameters.
- More investigations on the magnitude of the amplitudes and respective sub-daily periods of the estimated parameters will be carried out.

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References.

•Titov, O., Tesmer, V., Boehm, J. **OCCAM v. 6.0 software for VLBI data analysis**. In International VLBI Service for Geodesy and Astrometry 2004 General Meeting Proceedings, Ed.; Nancy, R., Vandenberg and Karen D. Baver, NASA/CP-2004-212255, pp. 267-271, 2004.