# Estimation

In the tab *Estimation*, parameters for the estimation process can be selected. The current version supports parameter estimations with the least squares adjustment (LSM). One of our aims is to develop a Kalman Filter as second parameter estimation algorithm. It has not been implemented yet. For the estimation of a global solution the $N$ matrix has to be prepared with the LSM module (menu item *Global parameters*). The corresponding source code can be found in VIE_LSM. It should be mentioned there that the weighted of the observations are derived by taking the standard deviation of the observations as provided in the NGS files (there are NGS files with different standard deviations available!) plus adding 1 cm quadratically.

## Overview of VIE_LSM

The VIE_LSM module was designed by Kamil Teke in the course of his Ph.D. thesis. This section provides a brief discussion of the module and its implementation into VieVS. For further detail see (Teke, 2011). The VIE_LSM module takes care of the parameter estimation process with the least squares method. All the parameters can be estimated as continuous piece-wise linear offsets (CPWLO) in sub-daily and daily temporal resolution. Pseudo observations (constraints) can be introduced to the estimation process. We distinguish between two types of constraints, namely relative and absolute. Relative constraints are used to fill gaps where two parameters have no observation in an estimation interval. Additionally they provide supplementary observations which keep the normal equation matrix $N$ regular. Absolute constraints are used if the preferred value of the parameter is known (e.g. fixing it to the a priori value). A detailed description of the theory can be found in the chapter about Least-squares adjustment in VLBI.

The design matrix $A_{ro}$ is formed by 15 sub-matrices, $$ A_{ro} = [A_1 \; A_2 \ldots A_{15}]. $$

The used models are:

- CPWLO of clocks ($A_1$),
- rate and quadratic terms of polynomials of clocks ($A_2$),
- CPWLO of zenith wet delay ($A_3$),
- CPWLO of troposphere north gradients ($A_4$),
- CPWLO of troposphere east gradients ($A_5$),
- CPWLO of polar motion coordinates in TRF along the Greenwich meridian ($xpol$) ($A_6$),
- CPWLO of polar motion coordinates in TRF along $270^{\circ}$ east meridian ($ypol$) ($A_7$),
- CPWLO of Earth's rotation phase (dUT1) ($A_8$),
- CPWLO of celestial intermediate pole (CIP) coordinate in CRF (X) ($A_9$),
- CPWLO of celestial intermediate pole (CIP) coordinate in CRF (Y) ($A_{10}$),
- CPWLO of right ascensions of source in CRF ($A_{11}$),
- CPWLO of declinations of sources in CRF ($A_{12}$),
- CPWLO or one offset (optional) of VLBI antenna X coordinate in TRF ($A_{13}$),
- CPWLO or one offset (optional) of VLBI antenna Y coordinate in TRF ($A_{14}$),
- CPWLO or one offset (optional) of VLBI antenna Z coordinate in TRF ($A_{15}$).

# Troposphere

The estimation settings for the troposphere can be found in *Estimation - Least squares - Troposphere*, a screen shot of the GUI is depicted in Figure below. We usually estimate the zenith wet delay and north and east gradients. Both are estimated as CPWLO, intervals and constraints can be selected in the GUI. If nothing is changed the predefined default values are used.
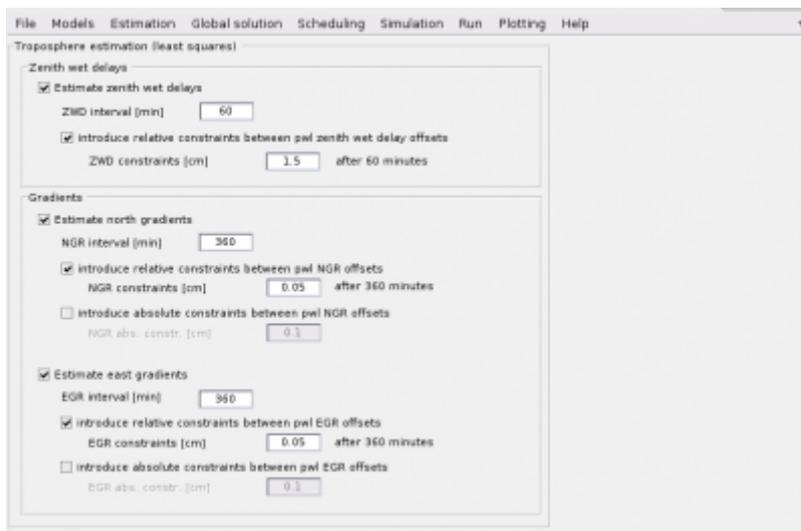


# Clock

Estimation settings for clock parameters can be found in *Estimation - Least squares - Clock*. A screen shot of the GUI is depicted in the Figure below. One can specify if clock breaks from an OPT file should be used.

In order to estimate clock errors a reference clock has to be selected. The clock of the first station in the *_antenna* file is chosen as default. One can specify any other clock as reference in the OPT file. The deviation of the other clocks w. r. t. the reference clock is then modeled according to the selection of the user. The CPWLO for each clock at each UTC integer hour or any other user defined interval ($t_1$ and $t_2$) is modeled according to:

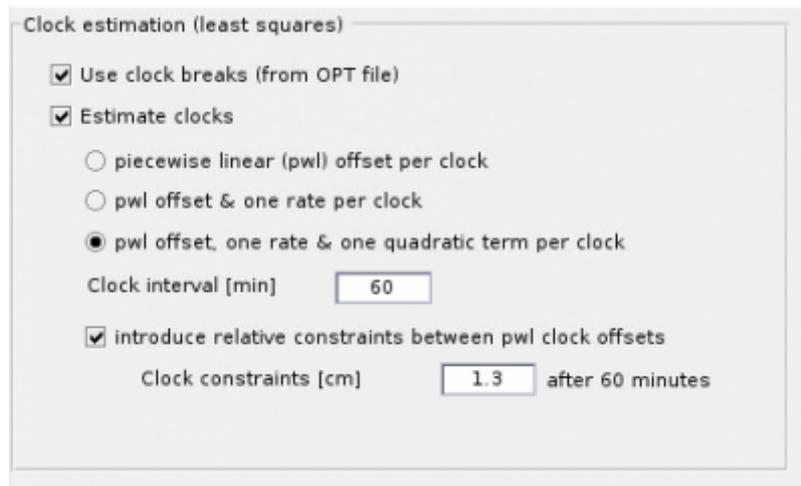$$ \Delta\tau_{clk}^{CPWLO}(t) = x_1 + \frac{t-t_1}{t_2-t_1}(x_2-x_1) $$

and the quadratic polynomial term is estimated with:

$$ \Delta\tau_{clk}^{poly}(t) = \beta_0 + \beta_1(t-t_0) + \beta_2(t-t_0)^2. $$

The total clock error at the epoch $t$ is the summation of the CPWLO for each clock and the quadratic polynomial term for each clock:

$$ \Delta\tau_{clk}(t) = \Delta\tau_{clk}^{CPWLO}(t) + \Delta\tau_{clk}^{poly}(t). $$

Relative constraints can be introduced by the user.

# Earth orientation parameters

The settings of the EOP estimation can be changed in *Estimation - Least squares - EOP*. A screen shot of the GUI is depicted in Figure below. It is possible to estimate EOP (with the CPWLO method) in any given interval with specified constraints. One can fix the EOP to the a priori values by ticking off the parameters respectively.
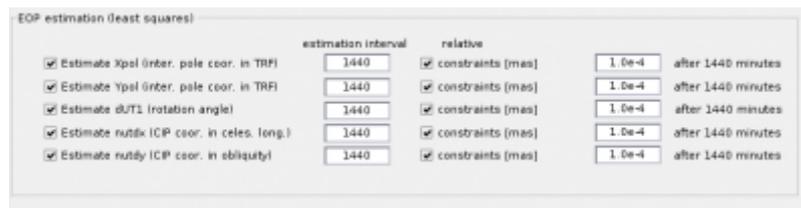


# Station coordinates

The settings for station coordinate estimation can be found in *Estimation - Least squares - Station coordinates*.

To specify the datum of the network one has to define the origin and orientation of the coordinate system. This can either be done by fixing station coordinates to their a priori (TRF) values or by introducing the no-net-translation (NNT) and no-net-rotation (NNR) conditions. To fulfill the NNT condition the three translations are constrained to zero. The NNR condition is fulfilled when all three rotations are constraint to zero. The common approach for VLBI estimation is to use the NNR and NNT approach, as depicted in the Figure below. The no-net-scale (NNS) condition (constraining the scale to 1) is usually not used for VLBI parameter estimation.
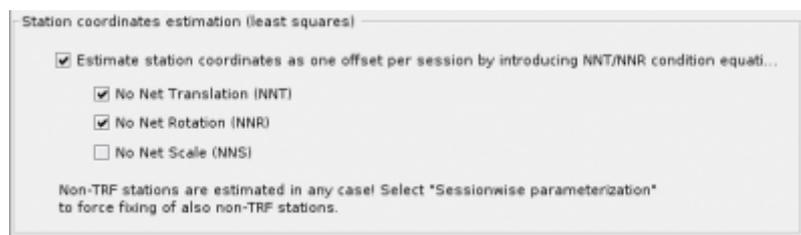


Coordinates are estimated daily. The Estimation of sub-daily antenna TRF CPWLO coordinates with

NNR/NNT conditions is not yet implements in VIE_LSM.

# Source coordinates

VieVS is able to estimate source coordinates. The settings can be found in *Estimation - Least squares - Source coordinates*. Source coordinates can be estimated as pwl offsets (estimation interval and relative constraints are selected in the GUI), or with NNR condition. If you ticked the pwl offset estimation, only non-CRF sources are estimated (the respective sources can be changed in the "Sessionwise parameterization"). The NNR option estimates all sources with a loose constraint (can be specified in the GUI) applied on all sources. In the NNR condition only sources in the chosen catalogue are included by default, if not specified otherwise by the checkbox (only use the defining sources for the datum definition). By default the NNR is selected for the estimation ofsource coordinates. From Version 3.0 sources observed less than 3 times are automatically excluded from the NNR condition, or in case the pwl offset estimation is applied they are fixed to their a priori coordinates.
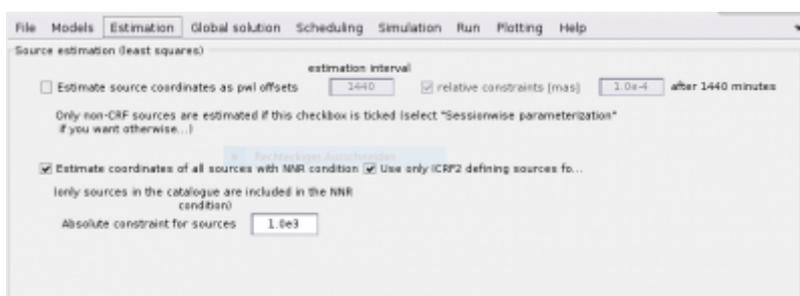


# Weight matrix

### Default settings

Weight matrix of observations $P$ is a diagonal matrix. The main diagonal contains 1/m_ni^2, where m_ni^2 is a sum between the squared formal error reported by the correlator (stored in the NGS file) and squared one centimeter error (33ps) for each observation.

$$ P = diag \frac{1}{n_{mi\_observ}^2 \cdot c^2 \cdot 100^2} [1/cm^2]$$ $$ n_{mi\_observ} = \sqrt{(mi\_observ)^2 + \Big(\frac{0.01}{c}\Big)^2} [seconds] $$

There is a possibility to down-weight certain stations in the OPT file. Added to VieVS by Monika Tercjak.
# STATIONS TO BE DOWN-WEIGHTED (NOISE IN [m]): 1
# MATERA 0.040

$$ n_{mi\_observ} = \sqrt{(mi\_observ)^2 + \Big(\frac{0.01}{c}\Big)^2 + \Big(\frac{an\_weight}{c}\Big)^2} [seconds] $$

### Baseline dependent weights

Another option is to use the baseline dependent weights. The least square adjustment is run iteratively in two steps. In the first run the $v$ vector with residuals for each observation is obtained (using the default settings), in the second run the new $P$ matrix is created where the mean value over same baselines is added. You can choose this option in GUI *Run - VieVS estimation settings* under "Apply baseline dependent weights". The creation of the baseline dependent $P$ matrix was

coded by Minttu Uunila.

$$ n_{mi\_observ} = \sqrt{(mi\_observ)^2 + \frac{\sum v_{bas}^2}{n} \cdot \Big(\frac{0.01}{c}\Big)^2} [seconds] $$

### Elevation dependent noise

When choosing the elevation dependent noise, terms dependent on the elevation of the antennas for the respective observation are added to the squared formal error reported by the correlator, instead of the squared one centimeter error:

$$ n_{mi\_observ} = \sqrt{(mi\_observ)^2 + \Big(\frac{6\cdot10^{-12}}{\sin e_1}\Big)^2 + \Big(\frac{6\cdot10^{-12}}{\sin e_2}\Big)^2} [seconds] $$

You can choose this option in GUI *Run - VieVS estimation settings* under "Introduce elevation dependent noise".

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