TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

Vie_LSM and Vie_LSM_scan (version 2.1)

Kamil Teke and Johannes Böhm

VieVS User Workshop

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Vienna

VieVS
Vienna VLBI Software

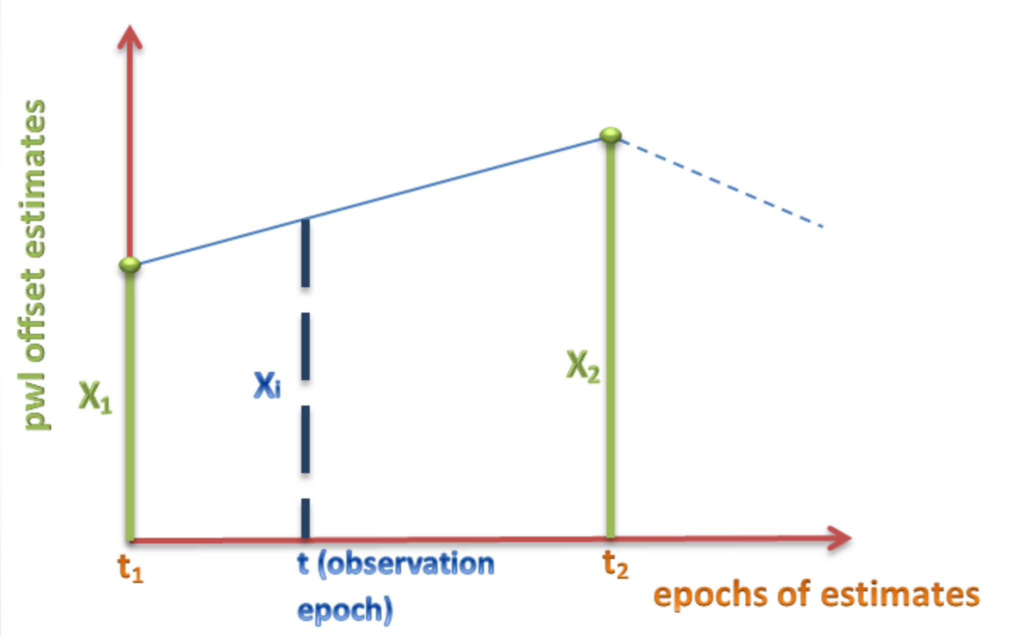
Introduction

- “vie_lsm” is a module of “VieVS”, which estimates geodetic parameters with least squares adjustment from VLBI observations.
- All the parameters can be estimated as continuous piece-wise linear offsets (CPWLO) in sub-daily and daily temporal resolution.

Estimated parameters are:

- Clocks (offset (cm), rate (cm/day), quadratic term (cm/day^2), CPWLO (cm)),
- Zenith wet delays (cm) as CPWLO,
- Troposphere gradients (cm) as CPWLO,
- EOP (mas and ms) as CPWLO,
- Antenna coordinates in TRF (cm) as one offset per session or as CPWLO,
- Source coordinates in CRF (declinations in mas and right ascensions in ms) as CPWLO.

continuous piece-wise linear offsets (CPWLO)



$$x_i = x_1 + \frac{t - t_1}{t_2 - t_1}(x_2 - x_1)$$

Partial derivatives of the delay model w.r.t. a sub-daily parameter

$$\frac{\partial \tau(t)}{\partial x_1} = \frac{\partial \tau(t)}{\partial x_i} \cdot \frac{\partial x_i}{\partial x_1} \rightarrow \frac{\partial x_i}{\partial x_1} = 1 - \frac{t - t_j}{t_{j+1} - t_j}$$

$$\frac{\partial \tau(t)}{\partial x_2} = \frac{\partial \tau(t)}{\partial x_i} \cdot \frac{\partial x_i}{\partial x_2} \rightarrow \frac{\partial x_i}{\partial x_2} = \frac{t - t_j}{t_{j+1} - t_j}$$

$$t_j < t < t_{j+1}$$

$$A = \left[A(1).sm \quad \cdots \quad A(15).sm \right]$$

design matrix of real observation equations

$$H = \begin{bmatrix} H(1).sm & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & H(15).sm \end{bmatrix}$$

design matrix of pseudo-observation equations (constraints)

$$N = \begin{bmatrix} A^T PA + H^T P_H H & C^T \\ C & 0 \end{bmatrix} \qquad b = \begin{bmatrix} A^T Poc + H^T P_H och \\ b_c \end{bmatrix}$$

bc is a zero vector (due to NNT and NNR conditions

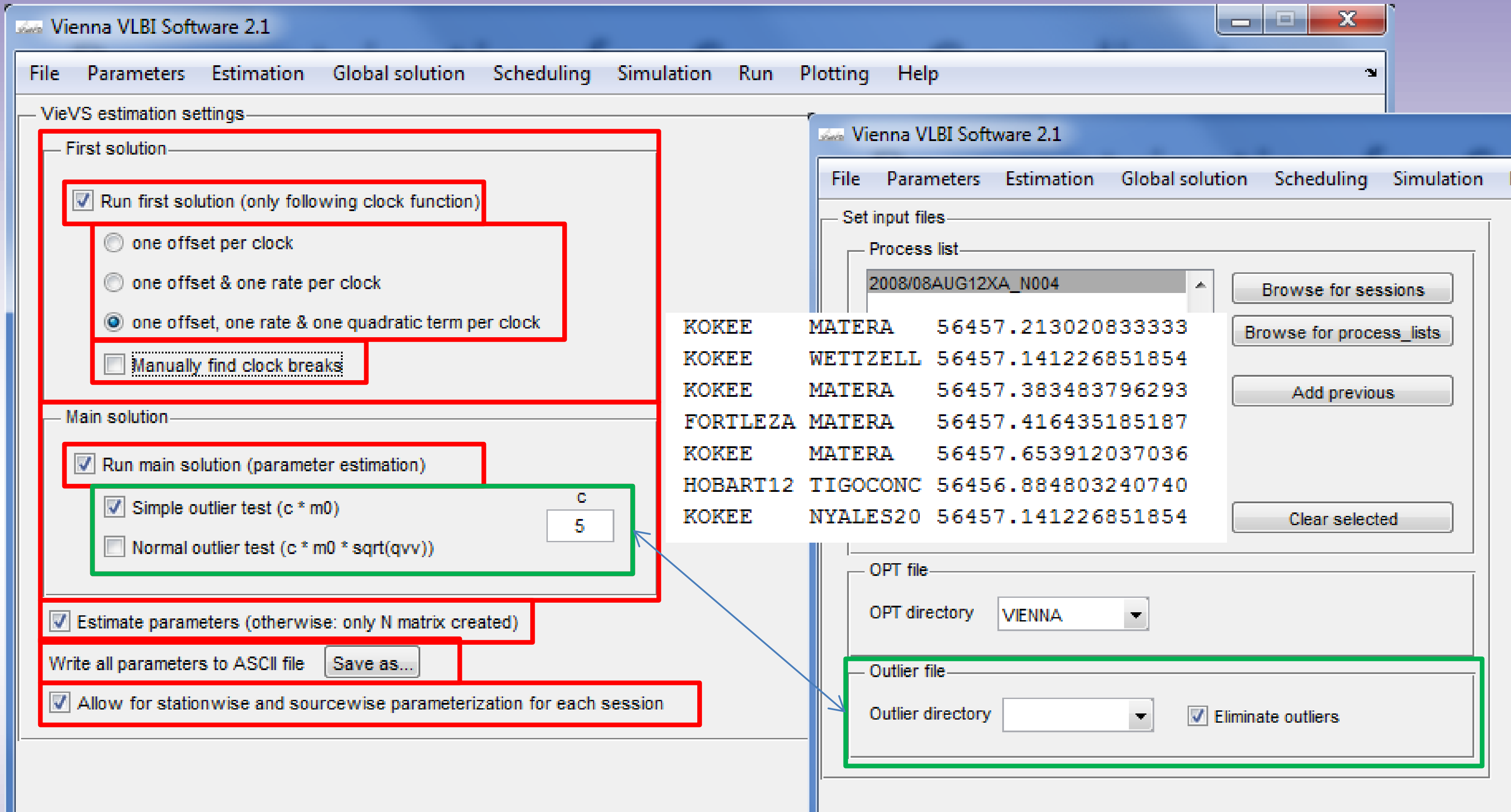
parameter vector (estimates)

$$x = N^- b \qquad m_0 = (v^T Pv + v_H^T P_H v_H) / (n_{obs} + n_{constr} - n_{unk})$$

$$K_x = m_0 N^-$$

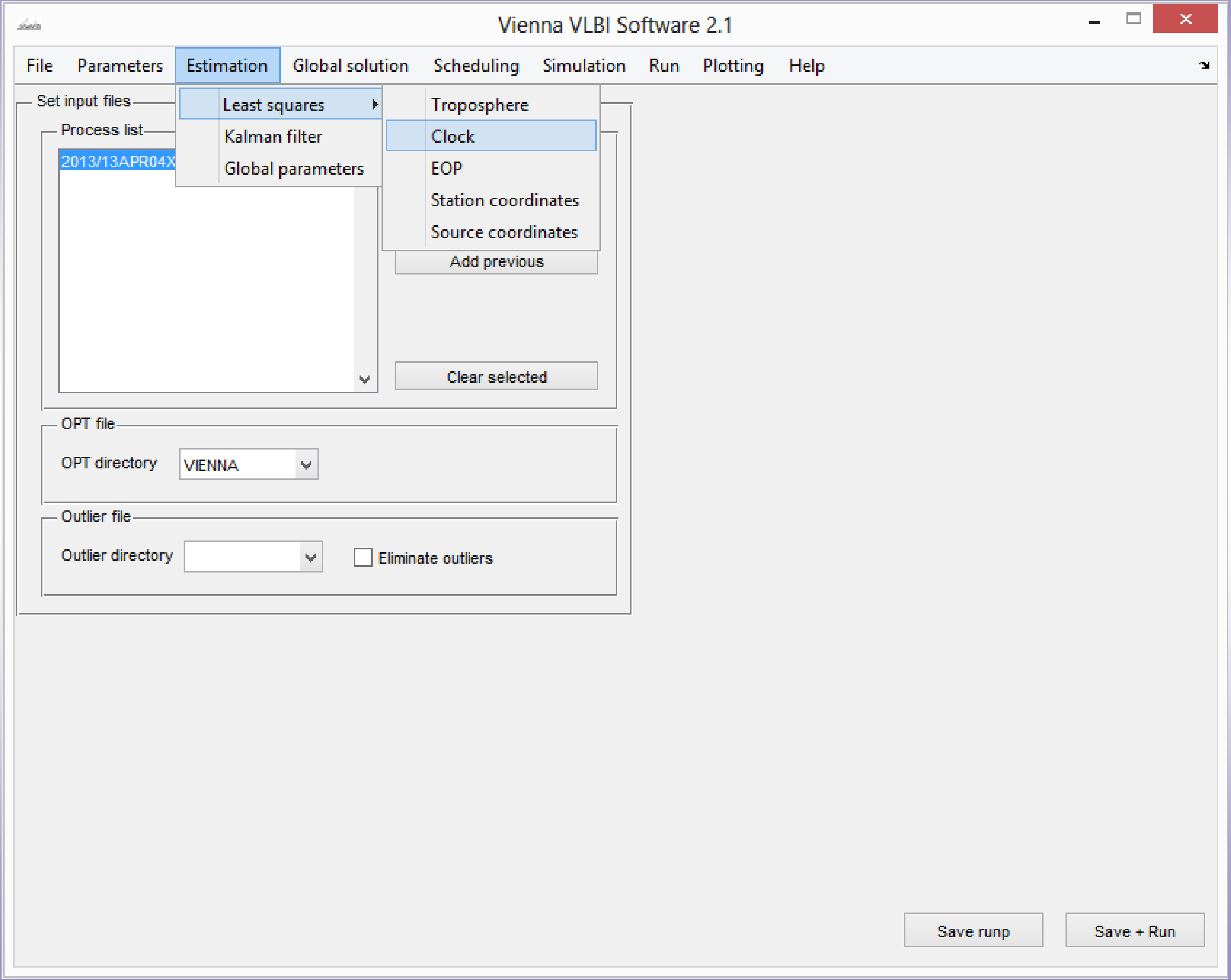
variance-covariance matrix of the estimates

Estimation Settings



The first solution is meant to remove large clock offsets (and rates and quadratic terms) for numerical reasons. (Clock offsets can be several kilometers.)

Parametrization for least squares



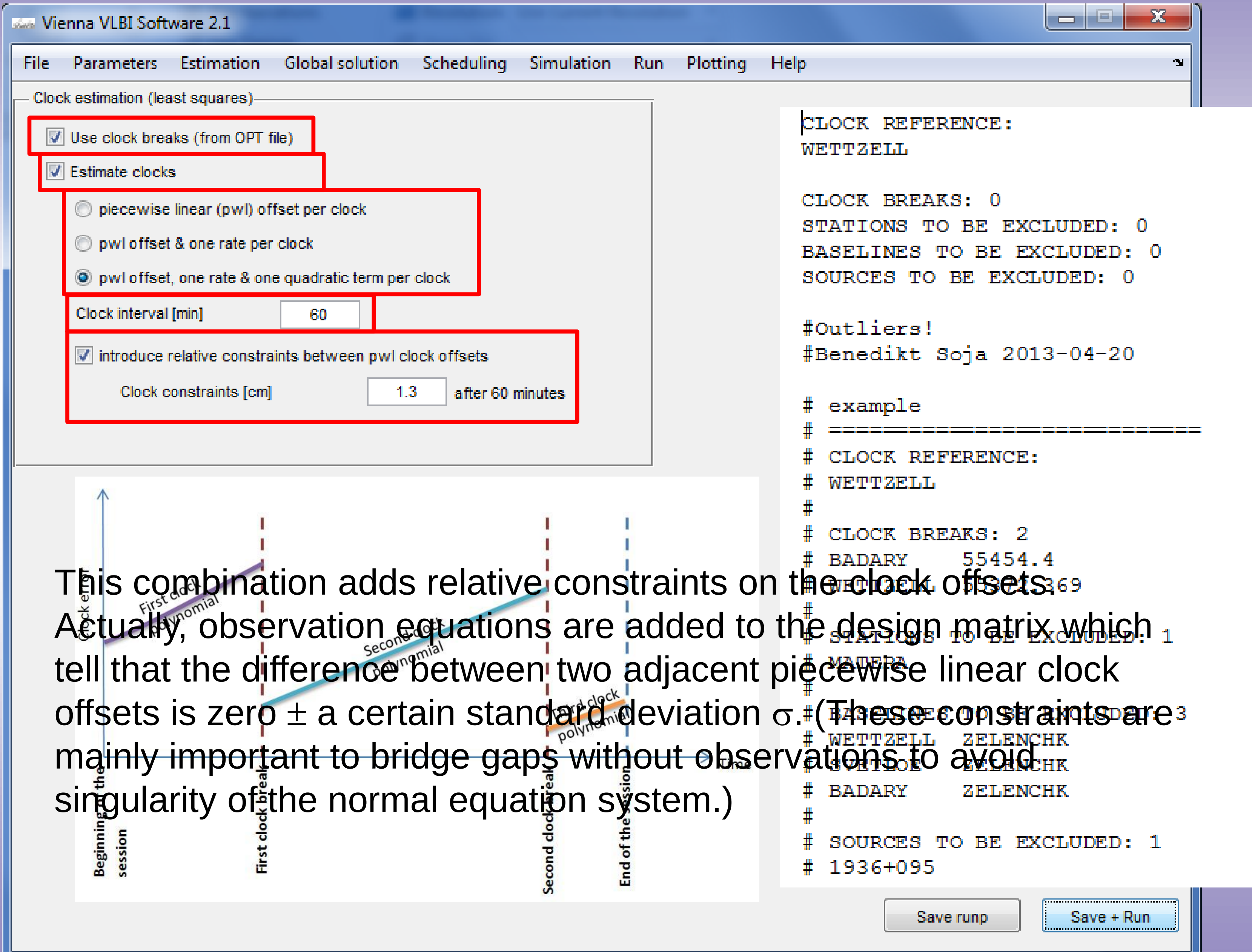
VLBI clock error

$$\Delta\tau_{clk}^{poly}(t) = \beta_0 + \beta_1(t - t_0) + \beta_2(t - t_0)^2$$ ➡ quadratic polynomial for each clock

$$\Delta\tau_{clk}^{CPWLO}(t) = x_1 + \frac{t - t_1}{t_2 - t_1}(x_2 - x_1)$$ ➡ CPWLO for each clock e.g. at each UTC integer hour (t_1 and t_2)

$$\Delta\tau_{clk}(t) = \Delta\tau_{clk}^{poly}(t) + \Delta\tau_{clk}^{CPWLO}(t)$$ ➡ total clock error at epoch t

Parametrization for relative clock errors



This combination adds relative constraints on the clock offsets. Actually, observation equations are added to the design matrix which tell that the difference between two adjacent piecewise linear clock offsets is zero ± a certain standard deviation σ. (These constraints are mainly important to bridge gaps without observations to avoid singularity of the normal equation system.)

Troposphere delay

$$\Delta\tau_{trop} = 10^{-6} \int_0^{H_{trop}} \left[N_h(s) + N_w(s)\right] ds$$

$$\Delta\tau_{trop}(\alpha,\varepsilon) = ZHD\, m_h(\varepsilon) + ZWD\, m_w(\varepsilon) + m_w(\varepsilon)\cot(\varepsilon)\left[G_n \cos(\alpha) + G_e \sin(\alpha)\right]$$

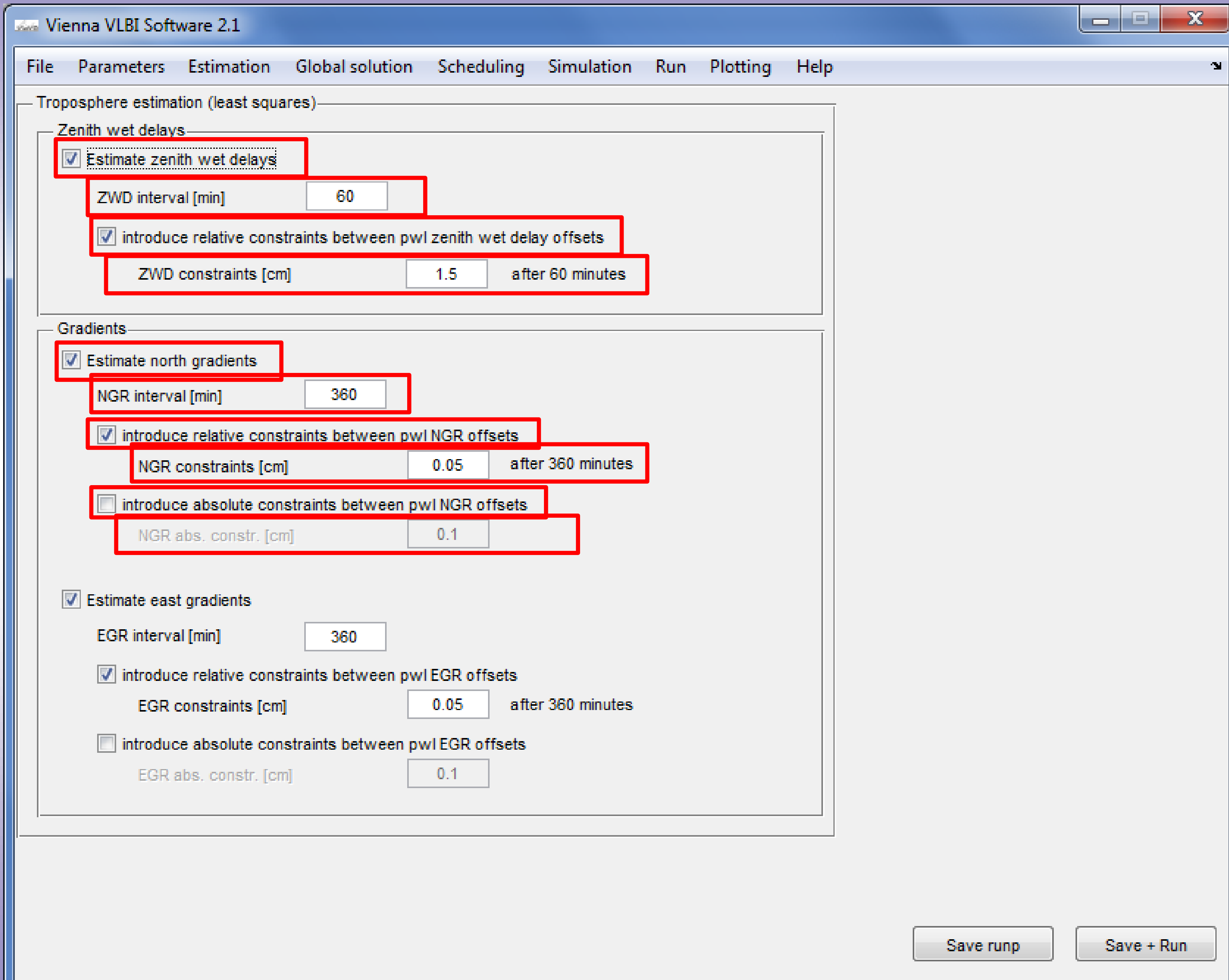
reduced from observations a priori to the adjustment

estimated

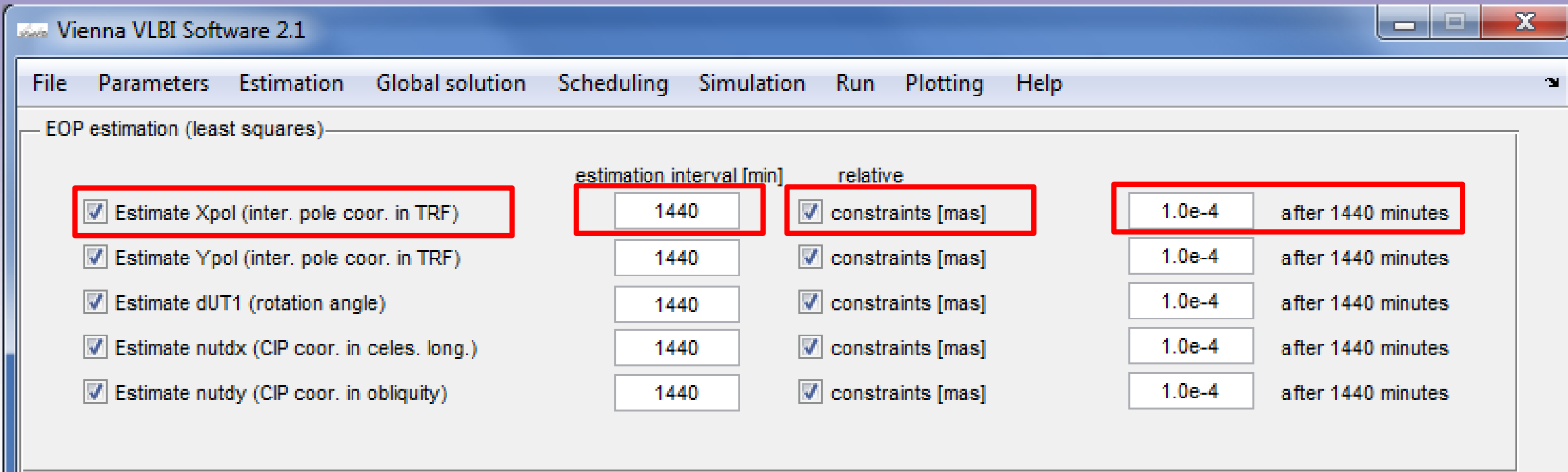
estimated

estimated

Parametrization for ZWD and gradients



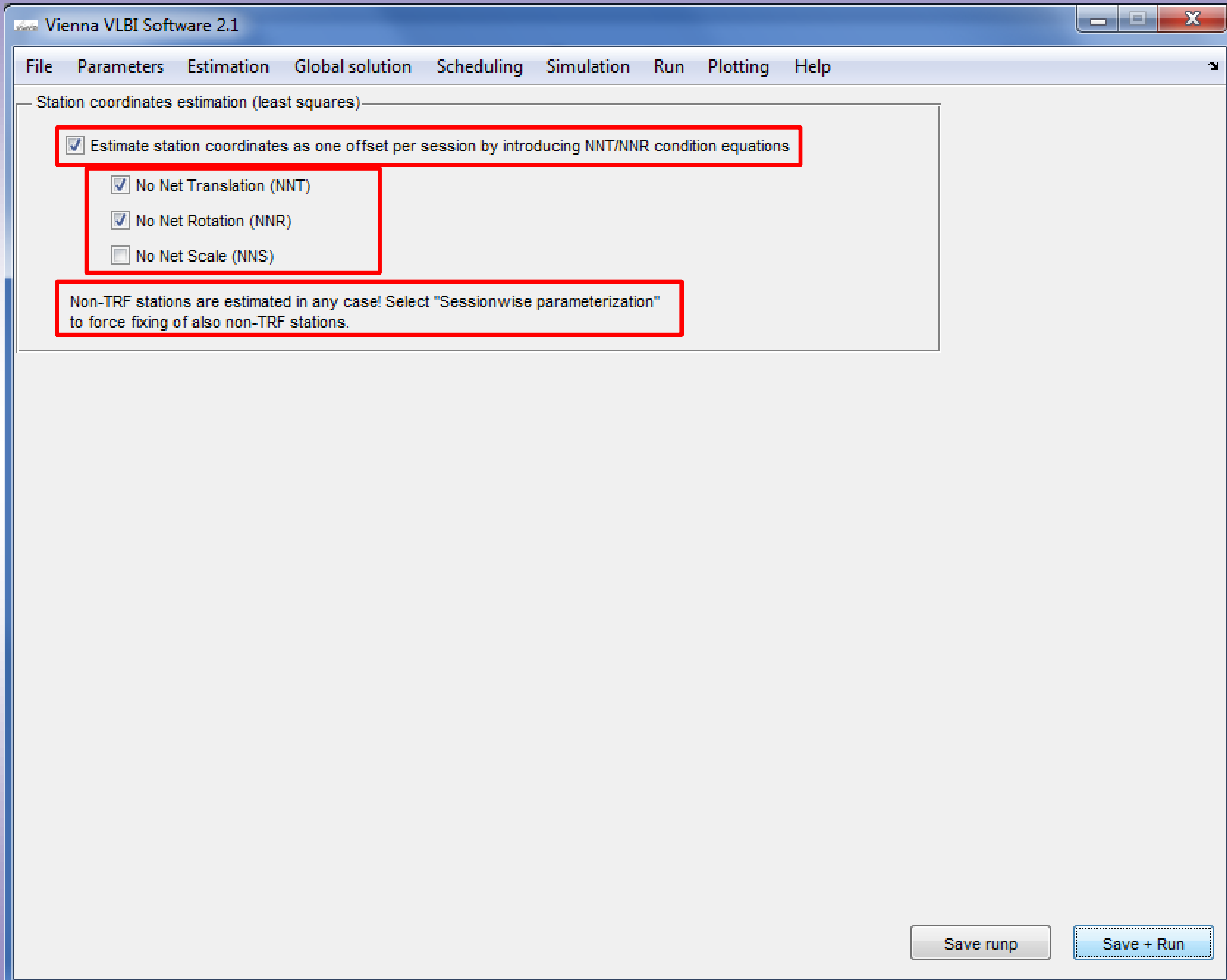
Parametrization for EOP



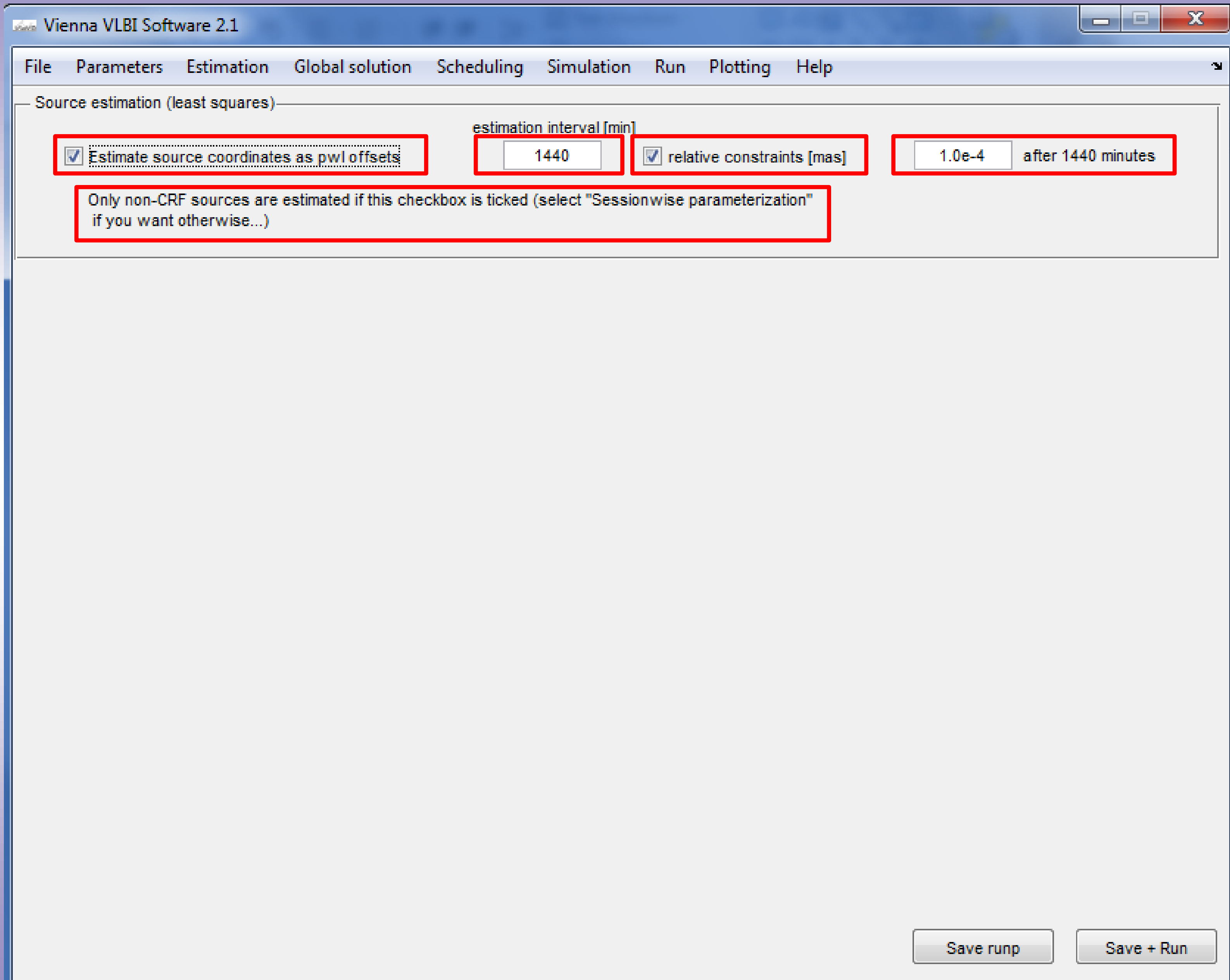
If you want to estimate one constant value per session, the recommendation is to set the parameterization as shown above. Very strong relative constraints of 1e-4 m(a)s/day take care that the estimates are the same over the session.

Example: The session is from 18 UT to 18 UT. Then, three piecewise linear offsets are set up for each EOP. (They are set up a midnight before the session, at midnight during the session, and at midnight after the session.) The strong constraints take care that all three estimates per session are the same.

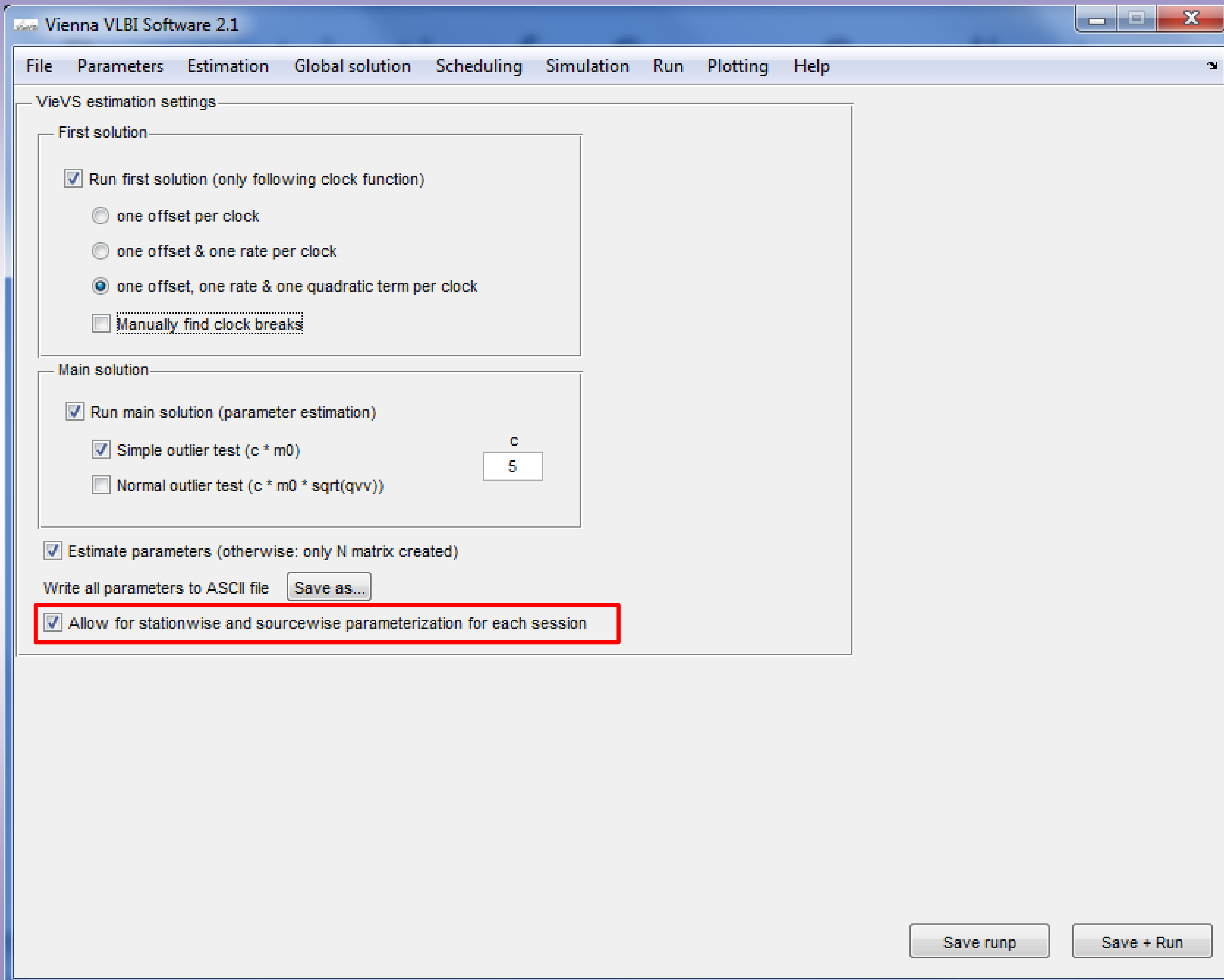
Parametrization for Station Coordinates



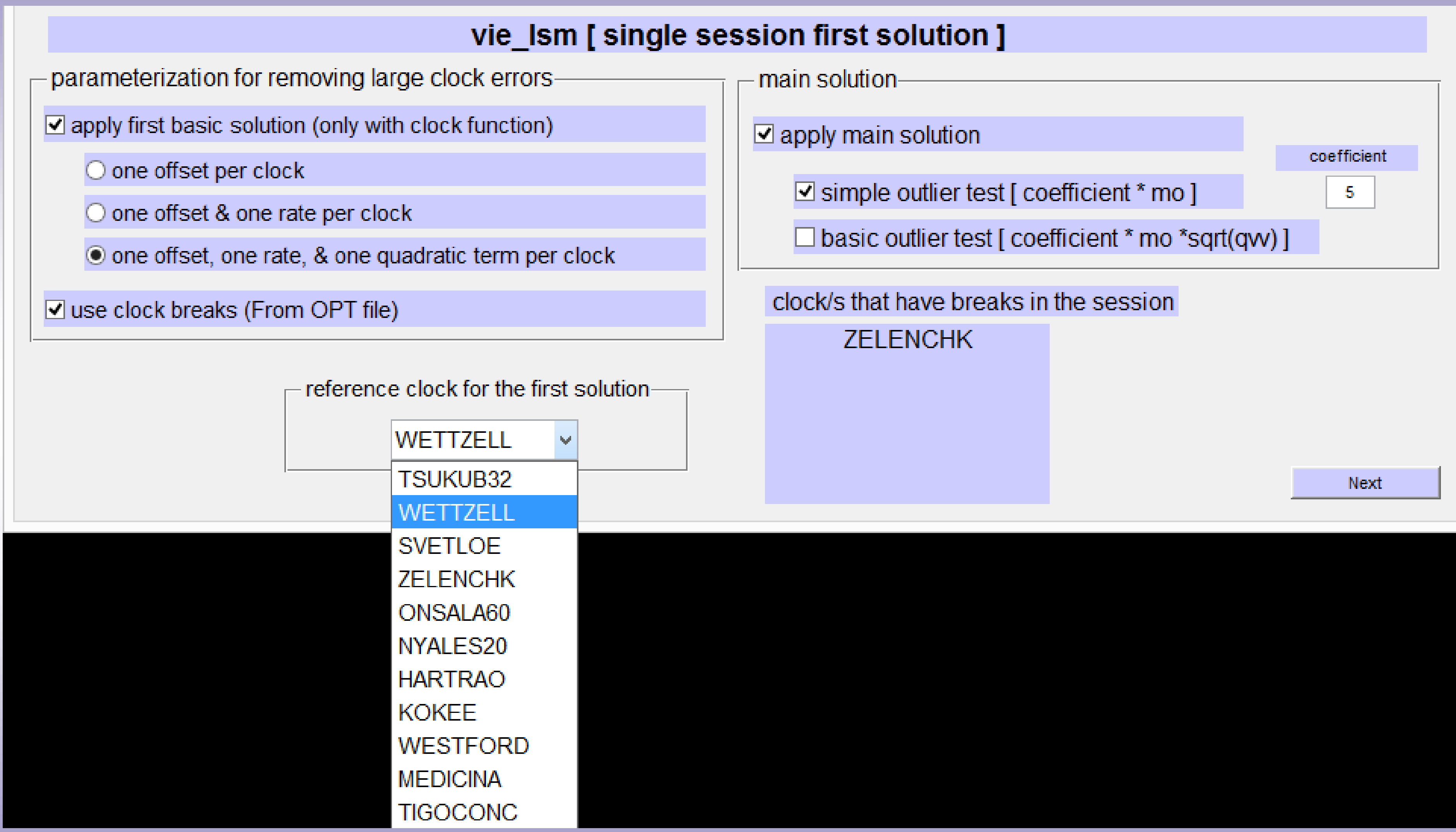
Parametrization for Source Coordinates



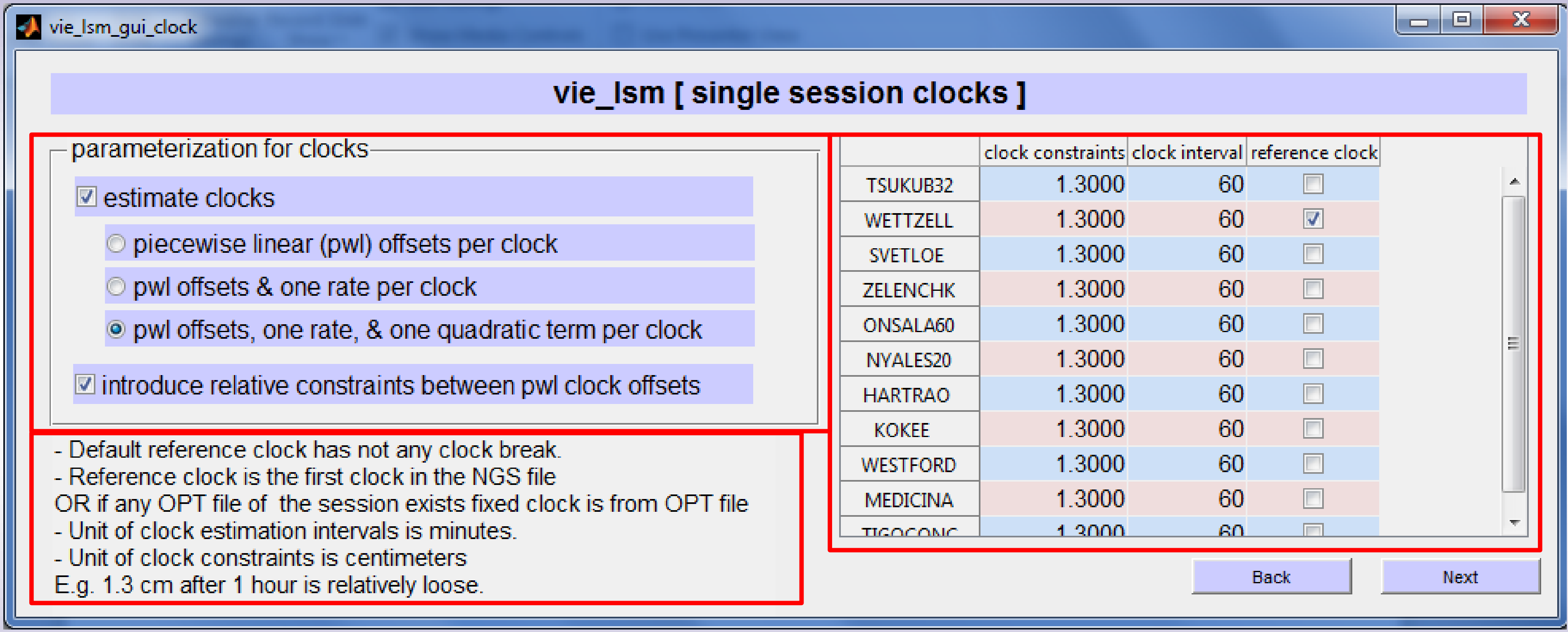
Session-wise parameterization



Session-wise parameterization



Session-wise parameterization



Session-wise parameterization

vie_lsm_gui_tropo

vie_lsm [single session troposphere]

apply relative constraints between tropospheric offset estimates

- [x] introduce RELATIVE CONSTRAINTS between pwl ZENITH WET DELAY offsets
- [x] introduce REALTIVE CONSTRAINTS between pwl tropo. NORTH GRADIENT offsets
- [x] introduce RELATIVE CONSTRAINTS between pwl tropo. EAST GRADIENT offsets
- [ ] introduce ABSOLUTE CONSTRAINTS between pwl tropo. NORTH GRADIENT offsets
- [ ] introduce ABSOLUTE CONSTRAINTS between pwl tropo. EAST GRADIENT offsets

- unit of estimation intervals is minute.

- unit of ZWD relative constraints is cm e.g. 1.5 cm after 1 hour is relatively loose.

- unit of NGR & EGR relative constraints is cm, e.g. 0.05 cm after 6 hours is relatively loose.

- unit of NGR & EGR absolute constraints is cm, e.g. 0.1 cm absolutely loose.

	ZWD coef.	NGR rel. coef.	EGR rel. coef.	NGR abs. coef.	EGR abs. coef.	ZWD int.	NGR int.	EGR int.	est. ZWD	est. NGR	est. EGR
TSUKUB32	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
WETTZELL	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
SVETLOE	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
ZELENCHK	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
ONSALA60	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
NYALES20	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
HARTRAO	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
KOKEE	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
WESTFORD	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]
MEDICINA	1.5000	0.0500	0.0500	0.1000	0.1000	60	360	360	[x]	[x]	[x]

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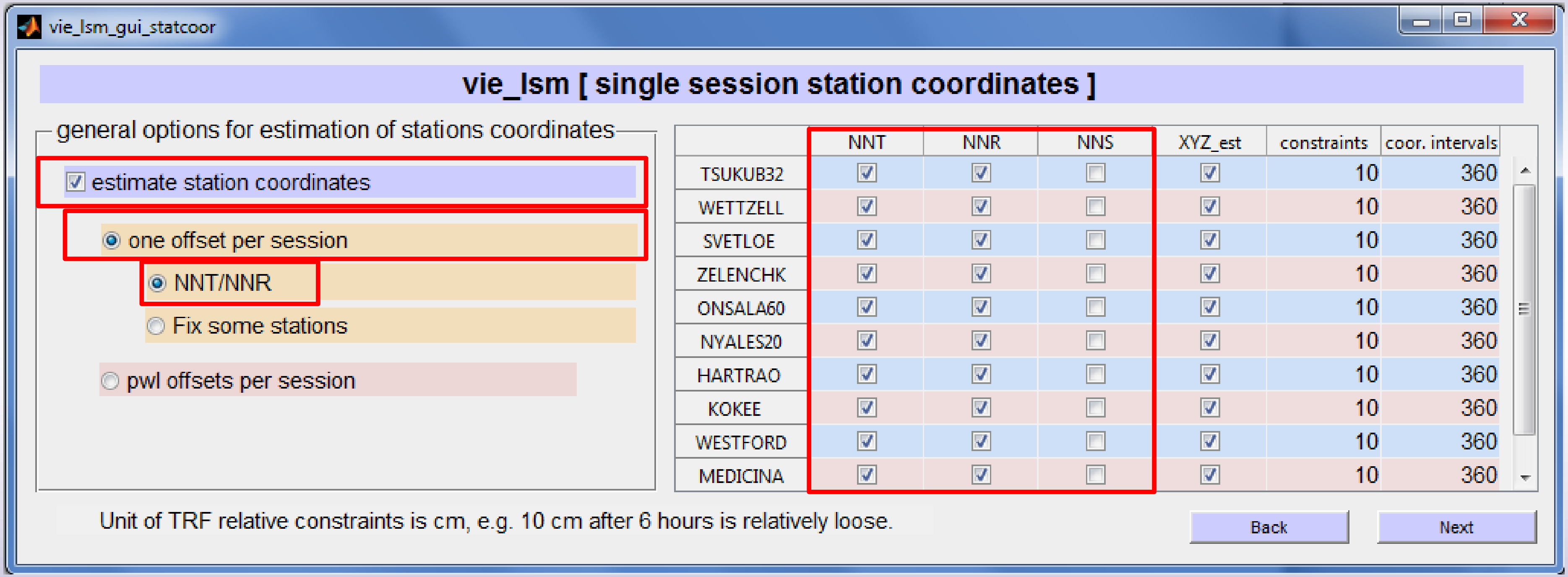
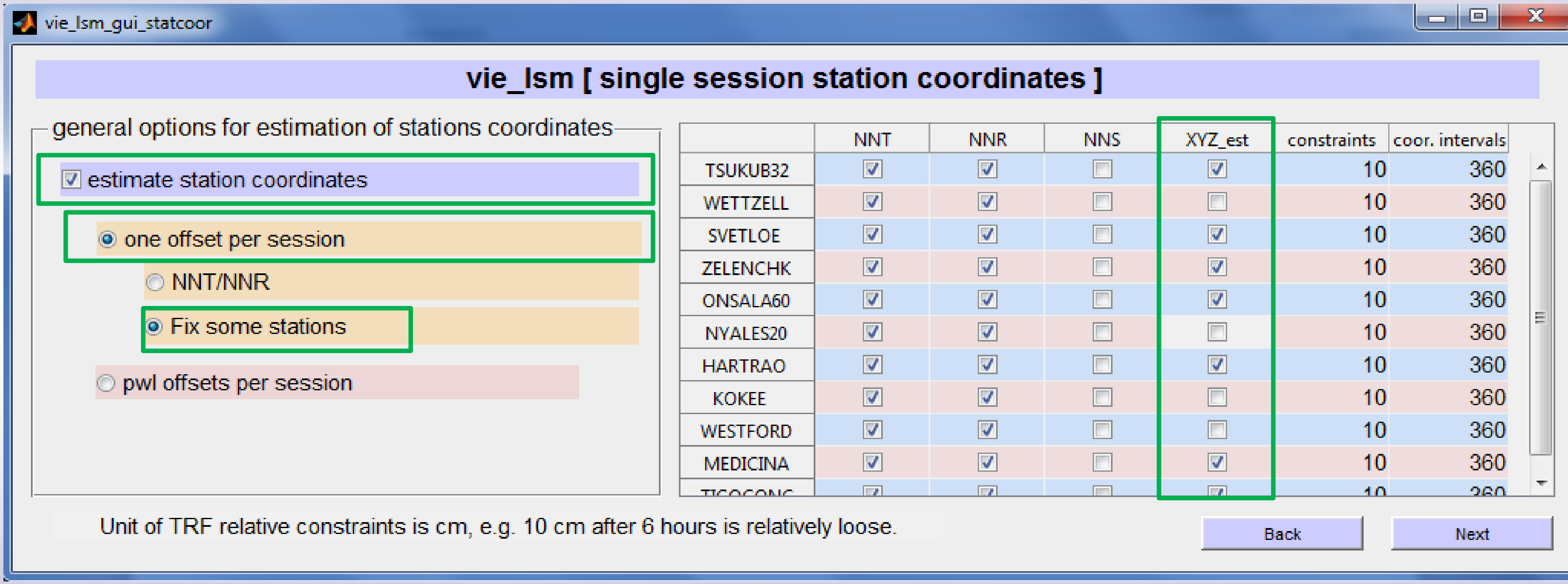
Session-wise parameterization

Case 1: NNT/NNR
(one coordinate offset per session)



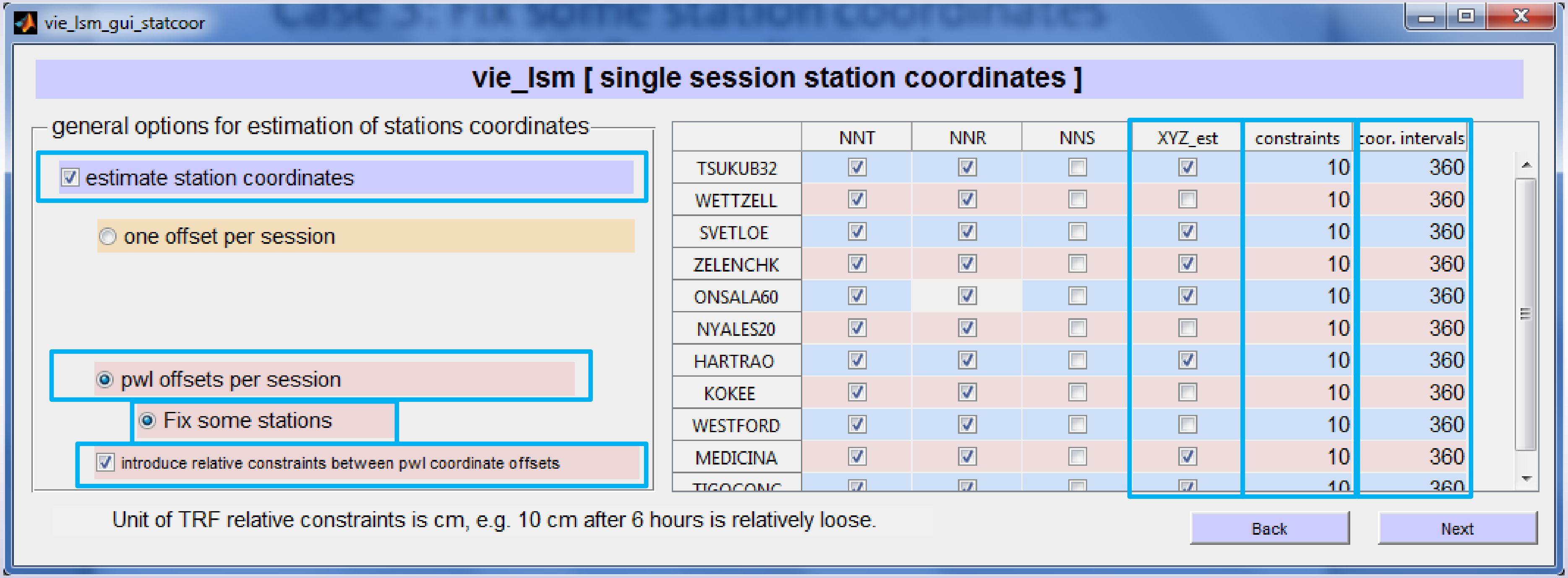
Session-wise parameterization

Case 2: Fix some station coordinates (one coordinate offset per session)



Session-wise parameterization

Case 3: Fix some station coordinates (CPWLO coordinates)



Session-wise parameterization

vie_lsm_gui_eop

vie_lsm [single session EOP]

Earth Orientation Parameter (EOP) pwl offsets estimation options

	include model	estimation interval	use constraints	constraints
Xpol (inter. pole coor. in TRF)	☑	1440	☑	1.0000e-04
Ypol (inter. pole coor. in TRF)	☑	1440	☑	1.0000e-04
dUT1 (rotation angle)	☑	1440	☑	1.0000e-04
nutdx (CIP coor. in celes. long.)	☑	1440	☑	1.0000e-04
nutdy (CIP coor. in obliquity)	☑	1440	☑	1.0000e-04

- unit of estimation intervals is minute
- constraints are mas for EOP
- 2 mas after 1 hour is relatively loose constraints for EOP

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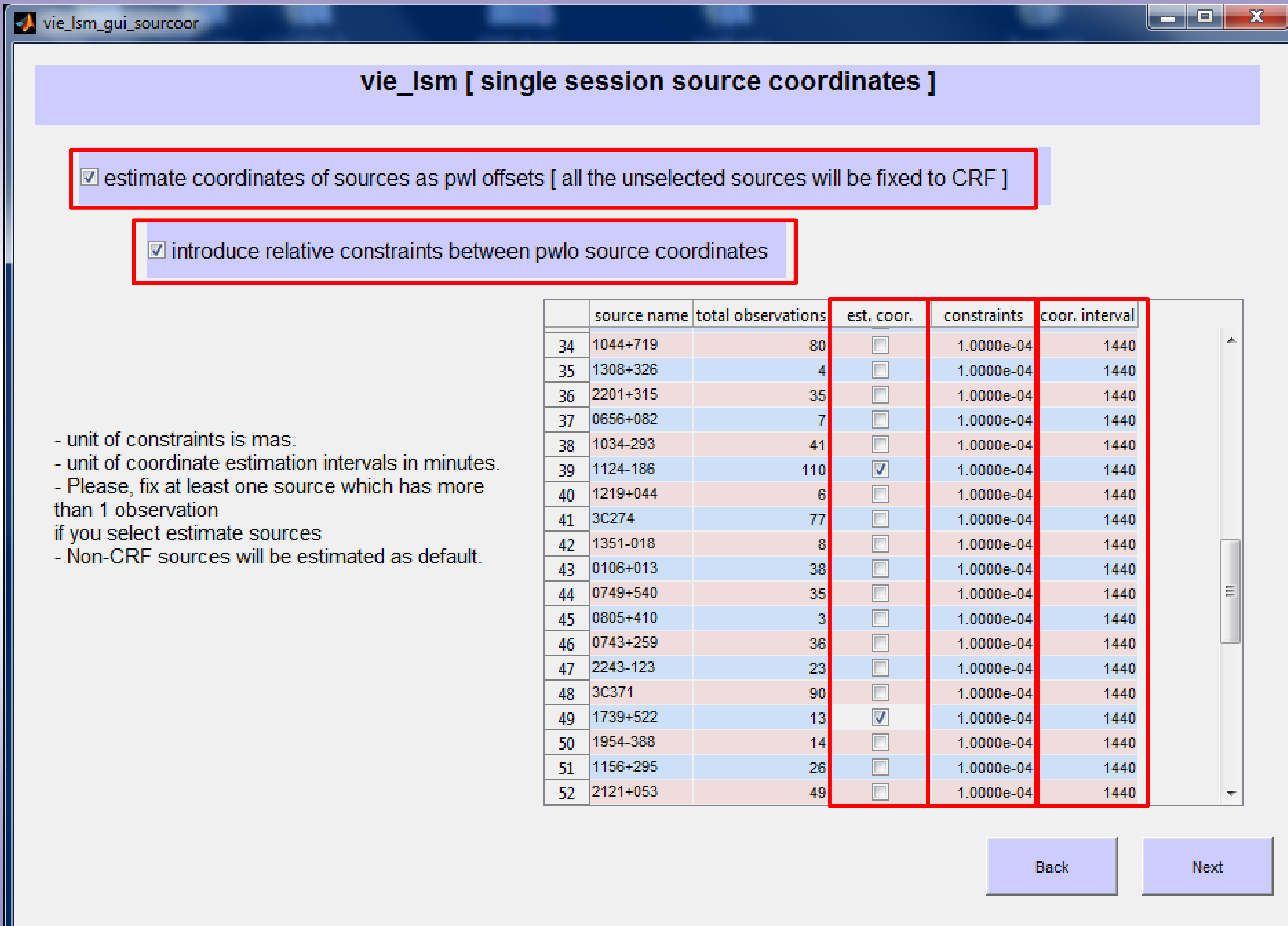
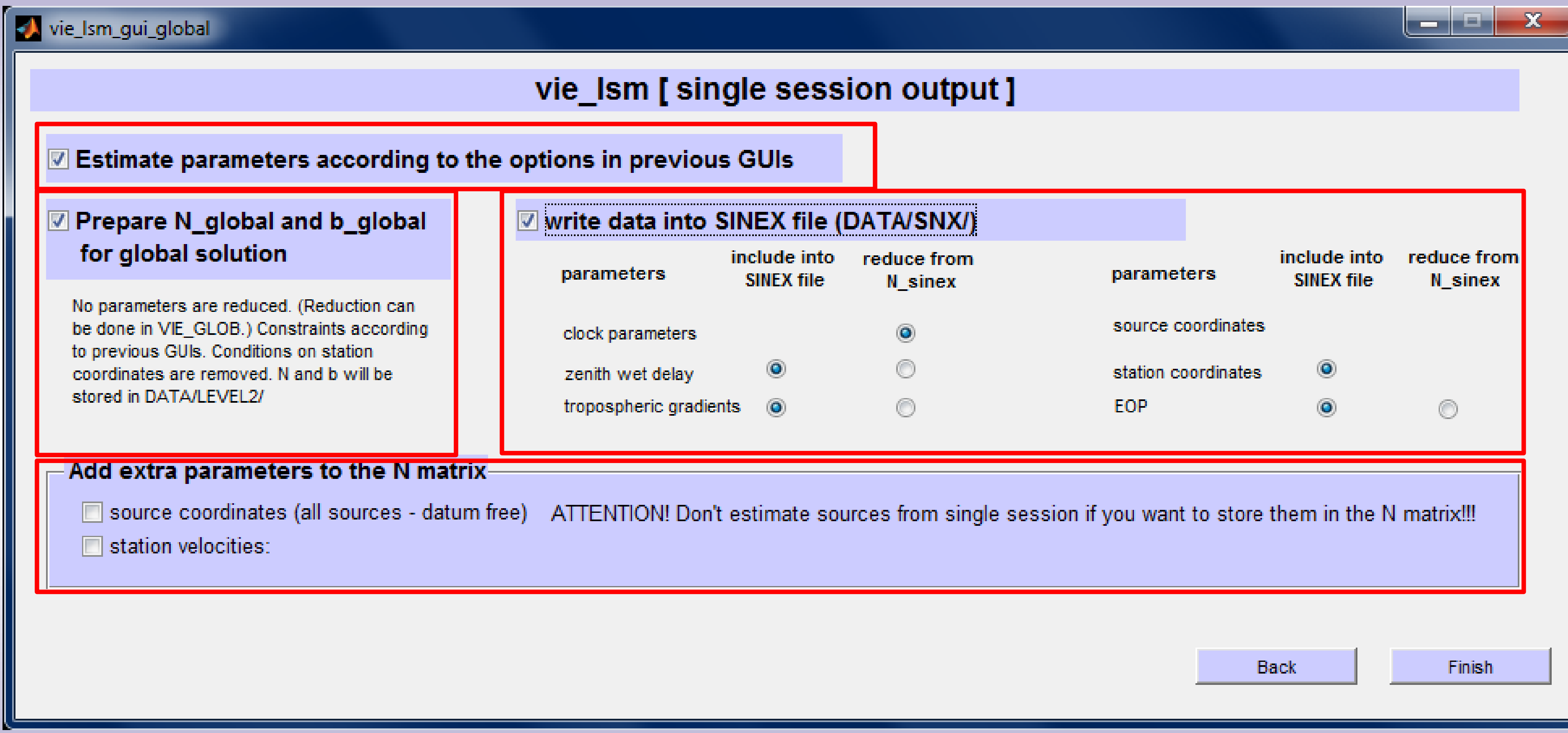
Session-wise parameterization

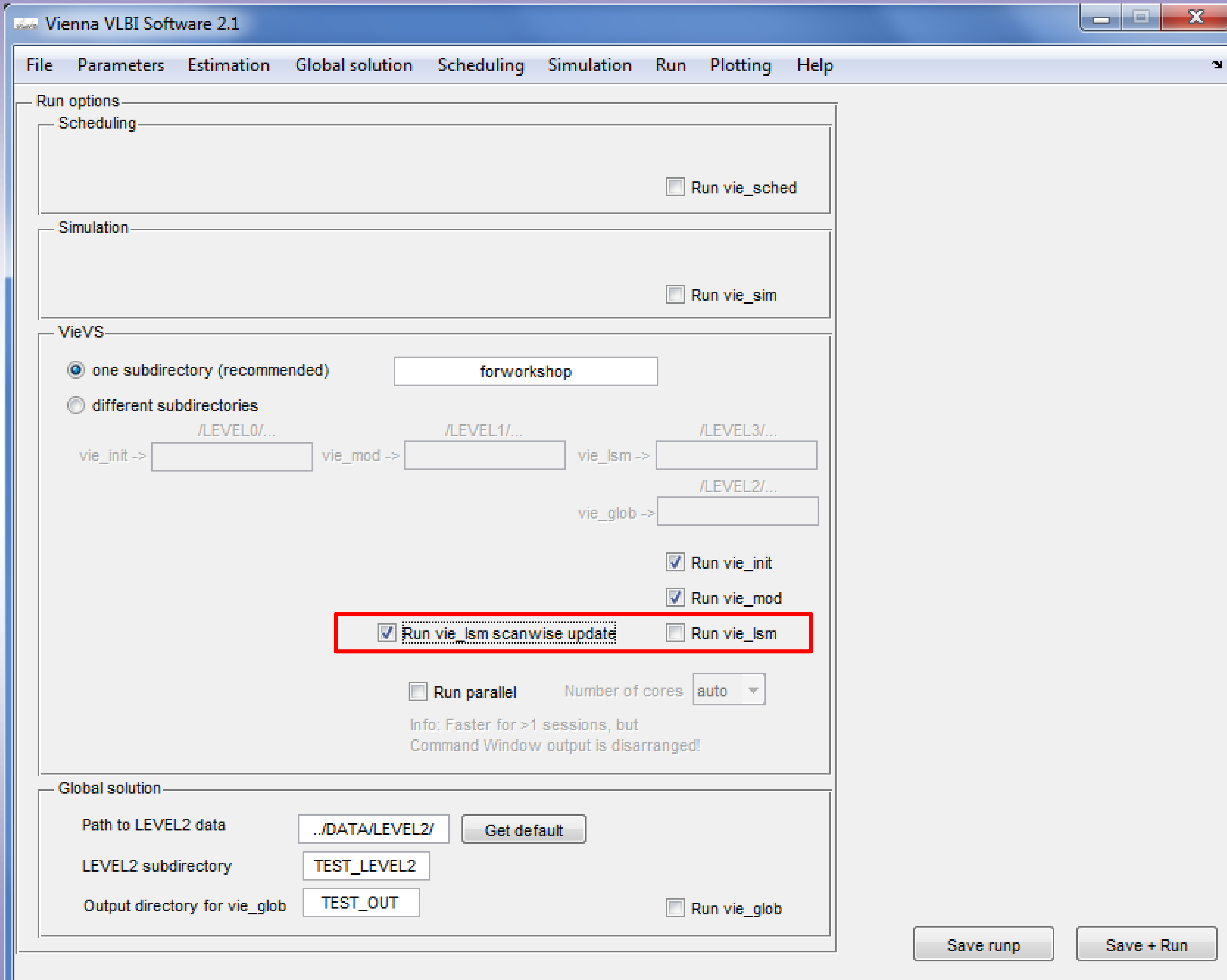


	source name	total observations	est. coor.	constraints	coor. interval
34	1044+719	80	☐	1.0000e-04	1440
35	1308+326	4	☐	1.0000e-04	1440
36	2201+315	35	☐	1.0000e-04	1440
37	0656+082	7	☐	1.0000e-04	1440
38	1034-293	41	☐	1.0000e-04	1440
39	1124-186	110	☑	1.0000e-04	1440
40	1219+044	6	☐	1.0000e-04	1440
41	3C274	77	☐	1.0000e-04	1440
42	1351-018	8	☐	1.0000e-04	1440
43	0106+013	38	☐	1.0000e-04	1440
44	0749+540	35	☐	1.0000e-04	1440
45	0805+410	3	☐	1.0000e-04	1440
46	0743+259	36	☐	1.0000e-04	1440
47	2243-123	23	☐	1.0000e-04	1440
48	3C371	90	☐	1.0000e-04	1440
49	1739+522	13	☑	1.0000e-04	1440
50	1954-388	14	☐	1.0000e-04	1440
51	1156+295	26	☐	1.0000e-04	1440
52	2121+053	49	☐	1.0000e-04	1440

Session-wise parameterization

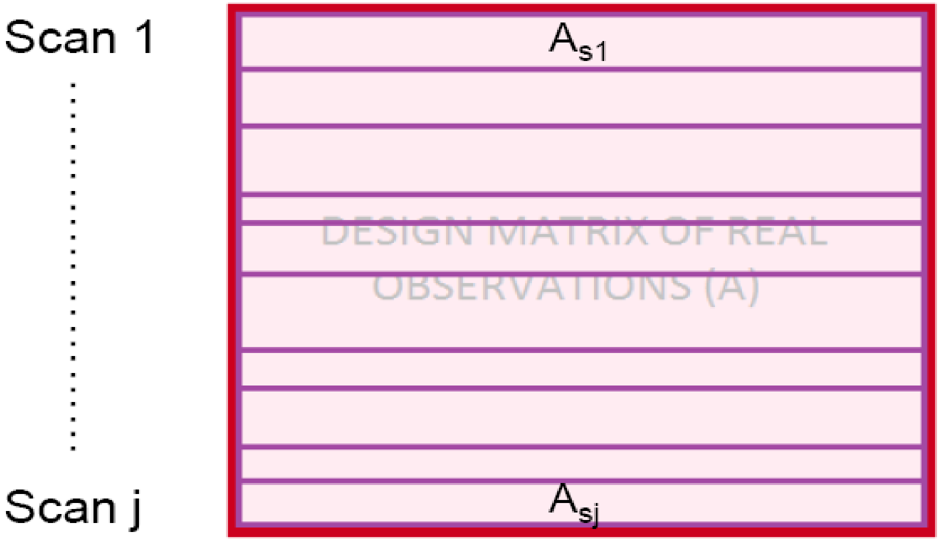


vie_lsm scan-wise update



Scan-wise update of normal equation system

1 A-matrix per scan



$$N_{s1} = A_{s1}^{T} \cdot P_{s1} \cdot A_{s1}$$

$$N_A = N_{s1} + N_{s2} + \ldots + N_{sj}$$

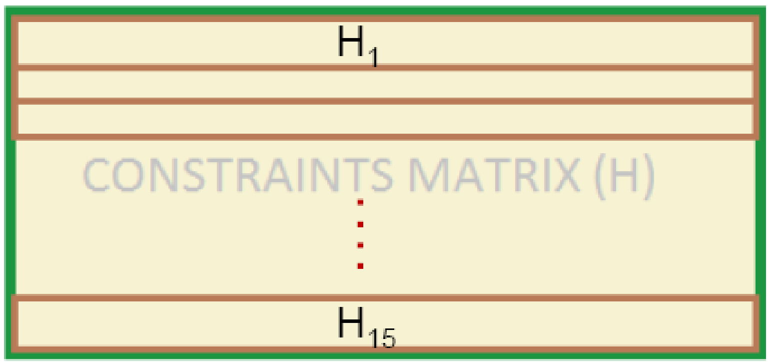
$$b_{s1} = A_{s1}^{T} \cdot P_{s1} \cdot oc_{s1}$$

$$b_A = b_{s1} + b_{s2} + \ldots + b_{sj}$$

j : number of scans in the session

Scan-wise update of normal equation system

Same procedure with H matrix: 15 H-matrixes



$$N_1 = H_1^T \cdot Ph \cdot H_1$$

$$N_H = N_1 + N_2 + \ldots + N_{15}$$

$$b_1 = H_1^T \cdot Ph_1 \cdot oc_1$$

$$b_H = b_1 + b_2 + \ldots + b_{15}$$

$$N = A^T \cdot P \cdot A \quad \rightarrow \quad N = N_A + N_H$$

$$b = A^T \cdot P \cdot oc \quad \rightarrow \quad b = b_A + b_H$$

$$x = N^{-1} \cdot b$$

Command window – vie_lsm

```
vie_mod successfully finished!
---------------------------------------------------------------
|                    Welcome to VIE_LSM!!!!!                  |
---------------------------------------------------------------

number of scans : 1151
number of antennas : 11
number of sources :  76
number of obs. :  9917
2. CREATING DEFAULT OPTIONS
3. FORMING THE WEIGHT MATRIX OF THE OBSERVATIONS "Pobserv"
apriori std. dev. of unit weight. : 1.1217
obs. of the antenna TSUKUB32 : 1957
obs. of the antenna WETTZELL : 2326
obs. of the antenna SVETLOE  : 2457
obs. of the antenna ZELENCHK : 1420
obs. of the antenna ONSALA60 : 2465
obs. of the antenna NYALES20 : 2354
obs. of the antenna HARTRAO  : 1073
obs. of the antenna KOKEE    : 1456
obs. of the antenna WESTFORD : 1769
obs. of the antenna MEDICINA : 2269
obs. of the antenna TIGOCONC :  288
4. FORMING THE REDUCED OBSERVATION VECTOR "oc_observ"
clock WETTZELL is selected as the ref. clock for the first solution
chi-squared of first solution: 23.3393
5. FORMING THE DESIGN MATRICES "A(i).sm" ...
6. FORMING THE CONSTRAIN MATRIX and WEIGHT MATRIX OF CONSTRAINTS
7. ESTIMATING THE PARAMETERS WITH LEAST SQUARES
!!! some or all station coordinates are not estimated (selected as fixed)!!!
clock WETTZELL is selected as the ref. clock for the main solution

chi-squared of main solution vTPv/degOfFreedom: 1.2136
```

Command window – vie_lsm

```
----------
detecting outliers
num. of outliers :  2
writing outliers to file ../DATA/OUTLIER/2008/08AUG12XA_N004.OUT
total  2 outlier observations are found but NOT eleminated
----------
total number of estimated parameters:  735
total clock offsets:  238
total rate and quad. terms of clock funct.:   20
total zenith wet delay offsets:  263
total tropo. north gradients:   53
total tropo. east gradients:   53
total pole coor. (x-pol) offsets:    2
total pole coor. (y-pol) offsets:    2
total dUT1 offsets:    2
total celestial pole (nutation dx) offsets:    2
total celestial pole (nutation dy) offsets:    2
total right ascension offsets of sources :    4
total declination offsets of sources :    4
antenna coor. dx offsets:   30
antenna coor. dy offsets:   30
antenna coor. dz offsets:   30
----------
estimated parameters are saved as ../VieVS/DATA/LEVEL3/forworkshop/x_08AUG12XA_N004.mat
estimation options are saved as ../VieVS/DATA/LEVEL3/forworkshop/opt_08AUG12XA_N004.mat
normal equation matrix is saved as ../VieVS/DATA/LEVEL3/forworkshop/atpa_08AUG12XA_N004.mat
right hand side vector is saved as ../VieVS/DATA/LEVEL3/forworkshop/atpl_08AUG12XA_N004.mat
residuals are saved as ../VieVS/DATA/LEVEL3/forworkshop/res_08AUG12XA_N004.mat
Data for GLOBAL SOLUTION is saved as ../VieVS/DATA/LEVEL2/forworkshop/08AUG12XA_N004_an_glob.mat
Data for GLOBAL SOLUTION is saved as ../VieVS/DATA/LEVEL2/forworkshop/08AUG12XA_N004_par_glob.mat
Data for GLOBAL SOLUTION is saved as ../VieVS/DATA/LEVEL2/forworkshop/08AUG12XA_N004_Nb_glob.mat

Reduced N and b for SINEX output are saved in ../VieVS/DATA/LEVEL3/forworkshop/SINEX/
```

Conclusions

- vie_lsm corrects clock breaks and detects outlier observations.
- vie_lsm provides SINEX input and datum free normal equations for global solutions (vie_glob).
- CPWLO estimates of VieVS are in a good agreement with those derived from other space geodetic techniques.
- Scan-wise update of normal equation system ensures a successful process of the future sessions with lots of observations.

Thank you so much
for your attention!