

# Vie\_LSM V2.2 (part 1: basics)

Kamil Teke and Johannes Böhm



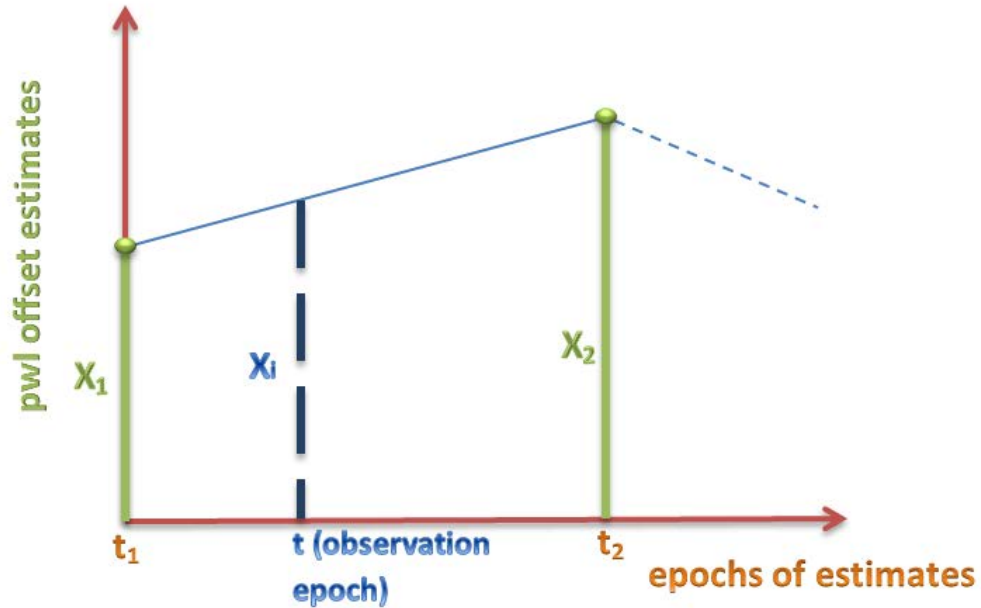
# Introduction

- “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 piece-wise linear offsets (PWLO) in sub-daily and daily temporal resolution.

## Estimated parameters per session are:

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

# CPWLO function



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

# Partial derivatives of the delay model w.r.t. a parameter's first and second offset

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

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

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

# Least-Squares Adjustment in vie\_lsm\_v22

$$A = [A(1).sm \quad \dots \quad A(15).sm] \quad \rightarrow \quad \text{design matrix of real observation equations}$$

$$H = \begin{bmatrix} H(1).sm & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & H(15).sm \end{bmatrix} \quad \rightarrow \quad \text{design matrix of pseudo-observation equations (constraints)}$$

$$N = \begin{bmatrix} A^T P A + H^T P_H H & C^T \\ C & 0 \end{bmatrix} \quad b = \begin{bmatrix} A^T P o c + H^T P_H o c h \\ b_c \end{bmatrix} \quad \begin{array}{l} bc \text{ is a zero} \\ \text{vector} \\ \text{(due to NNT} \\ \text{and NNR} \\ \text{conditions)} \end{array}$$

parameter vector  
(estimates)

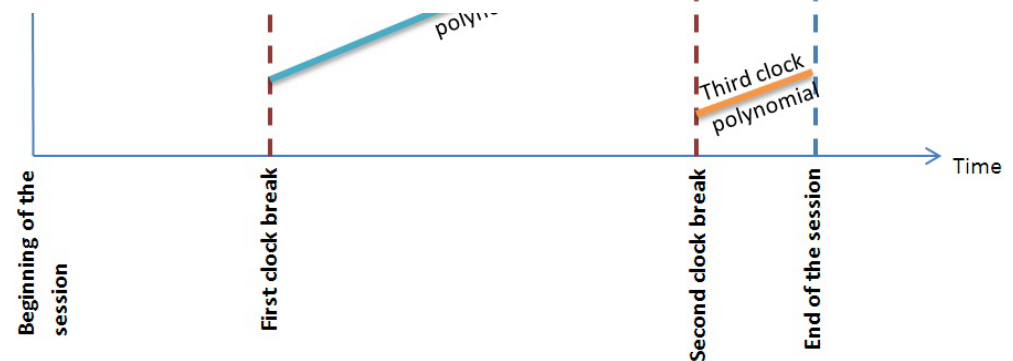
$$x = N^{-1} b \quad m_0 = (v^T P v + v_H^T P_H v_H) / (n_{obs} + n_{constr} - n_{unk})$$

$$K_x = m_0 N^{-1} \quad \rightarrow \quad \text{variance-covariance matrix of the estimates}$$

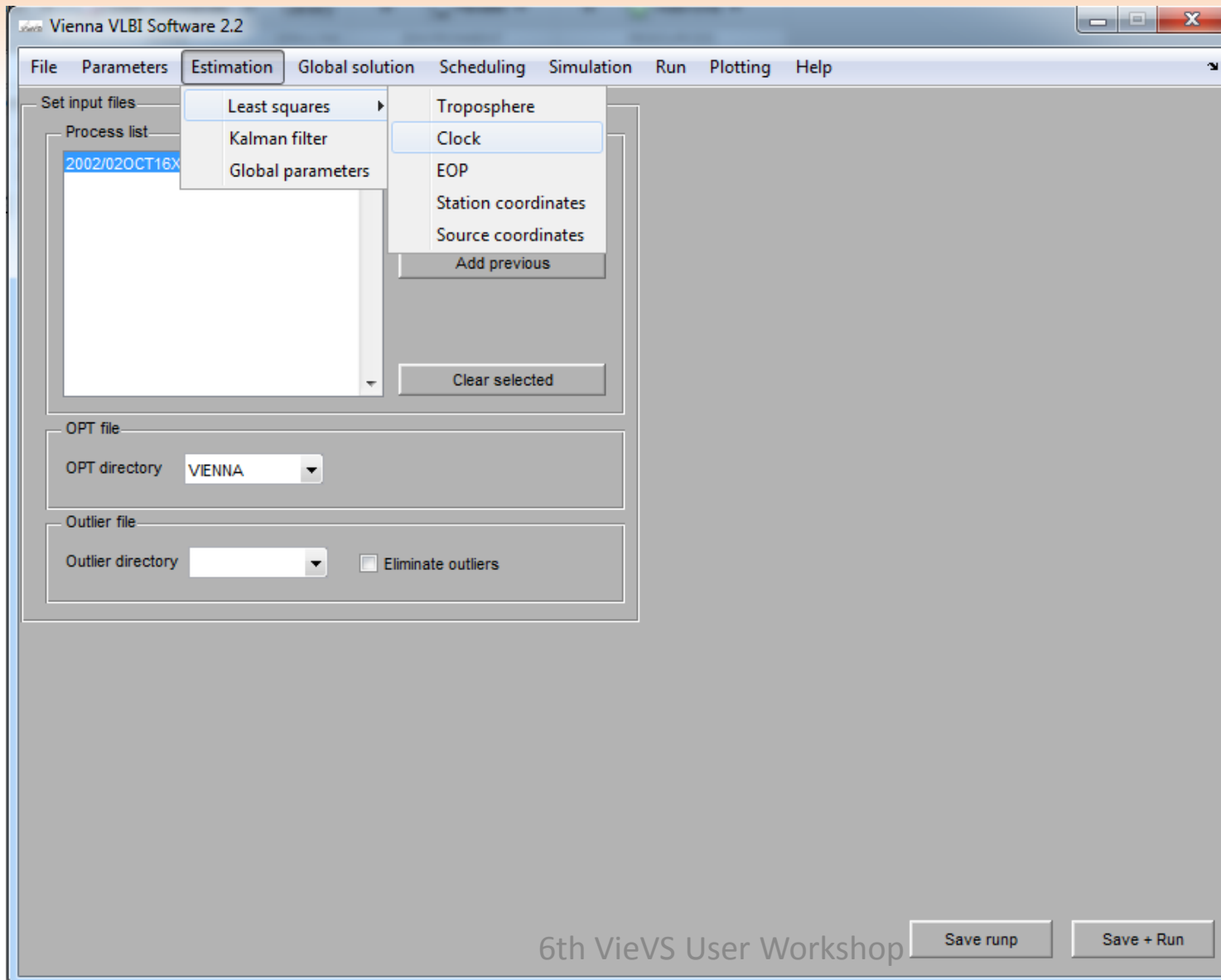
# Reducing large clock errors and correcting clock breaks in a first least-squares solution

A first LS solution is done for reducing large clock errors. New outlier observations are detected and written to text files `VIEWS/ DATA/ OUTLIER/ YOURDIR/ YEAR/ SESSNAME. OUT` breaks

KOKEE	MATERA	56457.213020833333
KOKEE	WETTZELL	56457.141226851854
KOKEE	MATERA	56457.383483796293
FORTLEZA	MATERA	56457.416435185187
KOKEE	MATERA	56457.653912037036
HOBART12	TIGOCONC	56456.884803240740
KOKEE	NYALES20	56457.141226851854



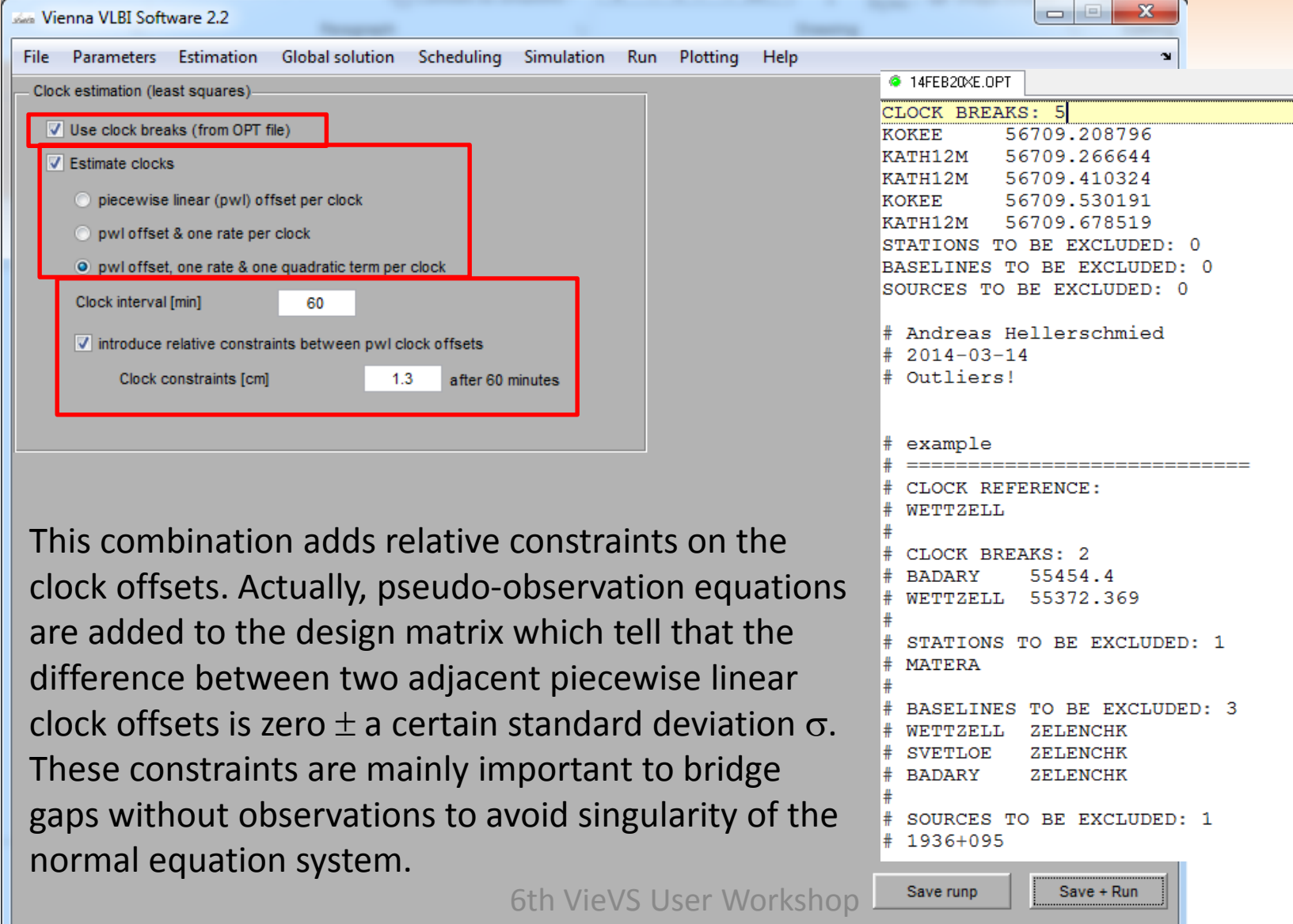
# Parameterisation of Least-Squares Adjustment in VieVS





# Clocks

(Coefficients of a quadratic function and PWLO)



The screenshot shows the Vienna VLBI Software 2.2 interface. The 'Clock estimation (least squares)' panel is active, with several options checked and highlighted by red boxes:

- Use clock breaks (from OPT file)
- Estimate clocks
  - piecewise linear (pwl) offset per clock
  - pwl offset & one rate per clock
  - pwl offset, one rate & one quadratic term per clock
- Clock interval [min]: 60
- introduce relative constraints between pwl clock offsets
  - Clock constraints [cm]: 1.3 after 60 minutes

The log window on the right shows the output for file 14FEB20XE.OPT:

```
CLOCK BREAKS: 5
ROKEE      56709.208796
KATH12M    56709.266644
KATH12M    56709.410324
ROKEE      56709.530191
KATH12M    56709.678519
STATIONS TO BE EXCLUDED: 0
BASELINES TO BE EXCLUDED: 0
SOURCES TO BE EXCLUDED: 0

# Andreas Hellerschmied
# 2014-03-14
# Outliers!

# example
# =====
# CLOCK REFERENCE:
# WETTZELL
#
# CLOCK BREAKS: 2
# BADARY    55454.4
# WETTZELL  55372.369
#
# STATIONS TO BE EXCLUDED: 1
# MATERA
#
# BASELINES TO BE EXCLUDED: 3
# WETTZELL  ZELENCHK
# SVETLOE   ZELENCHK
# BADARY    ZELENCHK
#
# SOURCES TO BE EXCLUDED: 1
# 1936+095
```

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

# Troposphere delays

## (Zenith wet delays, north and east gradients)

The screenshot shows the 'Troposphere estimation (least squares)' window in Vienna VLBI Software 2.2. The window is divided into two main sections: 'Zenith wet delays' and 'Gradients'. Both sections are highlighted with a red border.

**Zenith wet delays:**

- Estimate zenith wet delays
- ZWD interval [min]: 60
- introduce relative constraints between pwl zenith wet delay offsets
- ZWD constraints [cm]: 1.5 after 60 minutes

**Gradients:**

- Estimate north gradients
- NGR interval [min]: 360
- introduce relative constraints between pwl NGR offsets
- NGR constraints [cm]: 0.05 after 360 minutes
- introduce absolute constraints between pwl NGR offsets
- NGR abs. constr. [cm]: 0.1
- Estimate east gradients
- EGR interval [min]: 360
- introduce relative constraints between pwl EGR offsets
- EGR constraints [cm]: 0.05 after 360 minutes
- introduce absolute constraints between pwl EGR offsets
- EGR abs. constr. [cm]: 0.1

At the bottom of the window, there are buttons for 'Save runp' and 'Save + Run'.

reduced from observations a priori to the adjustment

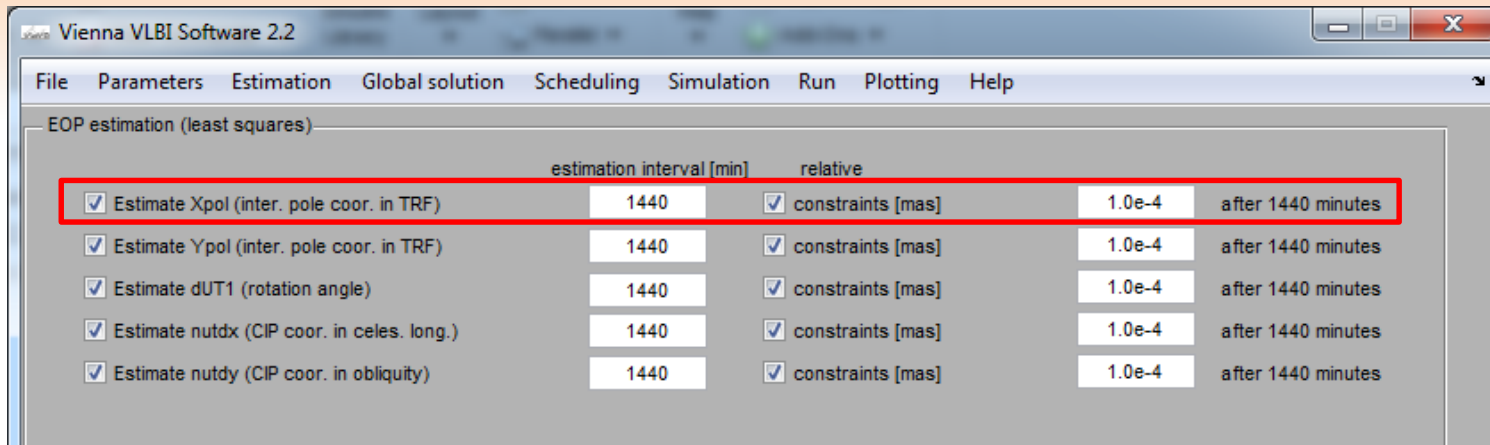
$$\Delta \tau_{trop}(\alpha, \varepsilon) = ZHD m_h(\varepsilon) + ZWD m_w(\varepsilon) + m_w(\varepsilon) \cot(\varepsilon) [G_n \cos(\alpha) + G_e \sin(\alpha)]$$

estimated

estimated

estimated

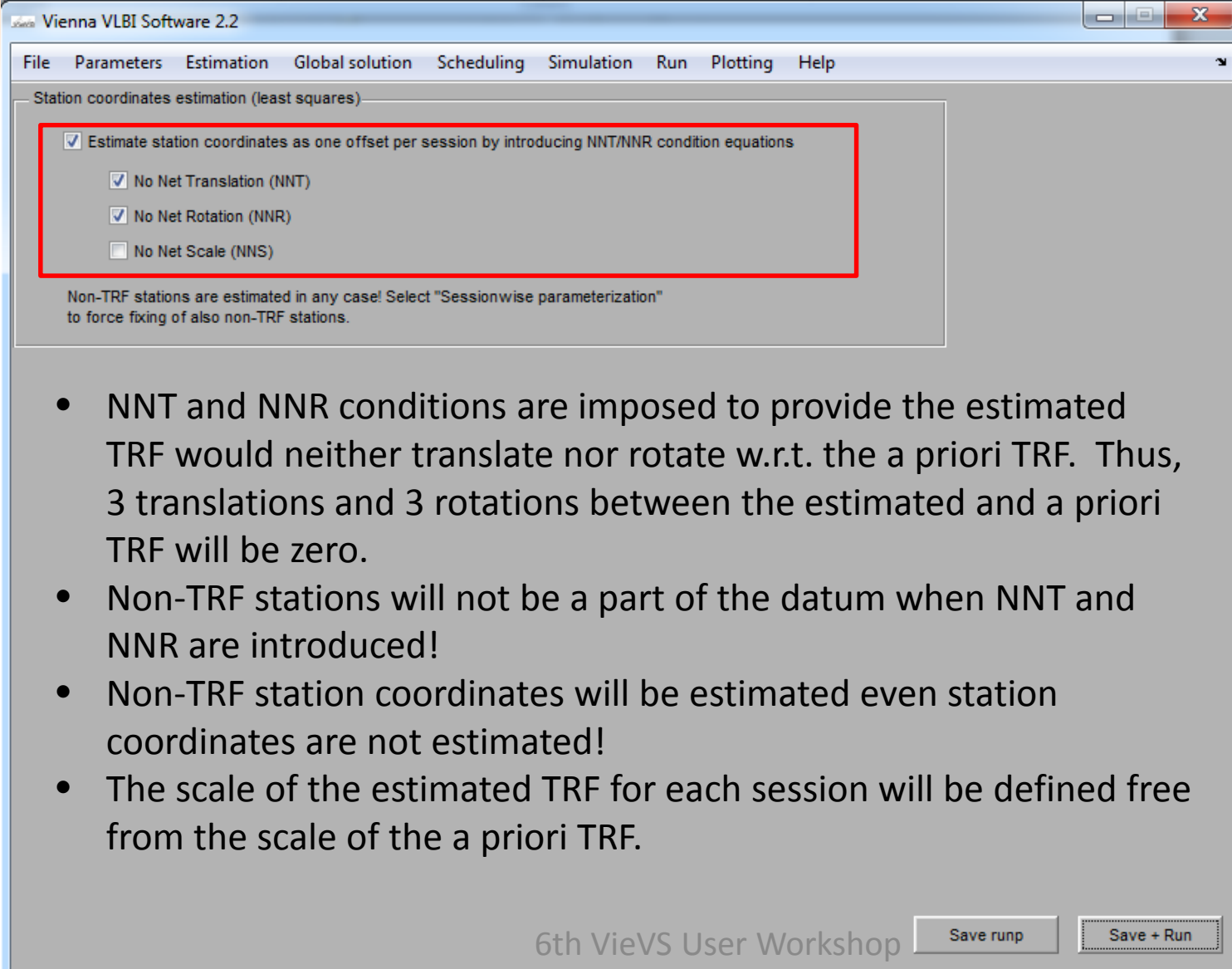
# Earth Orientation Parameters



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.

# Antenna TRF coordinates



The screenshot shows the 'Station coordinates estimation (least squares)' dialog box in Vienna VLBI Software 2.2. The dialog has a menu bar with 'File', 'Parameters', 'Estimation', 'Global solution', 'Scheduling', 'Simulation', 'Run', 'Plotting', and 'Help'. The main area contains a red-bordered box with the following options:

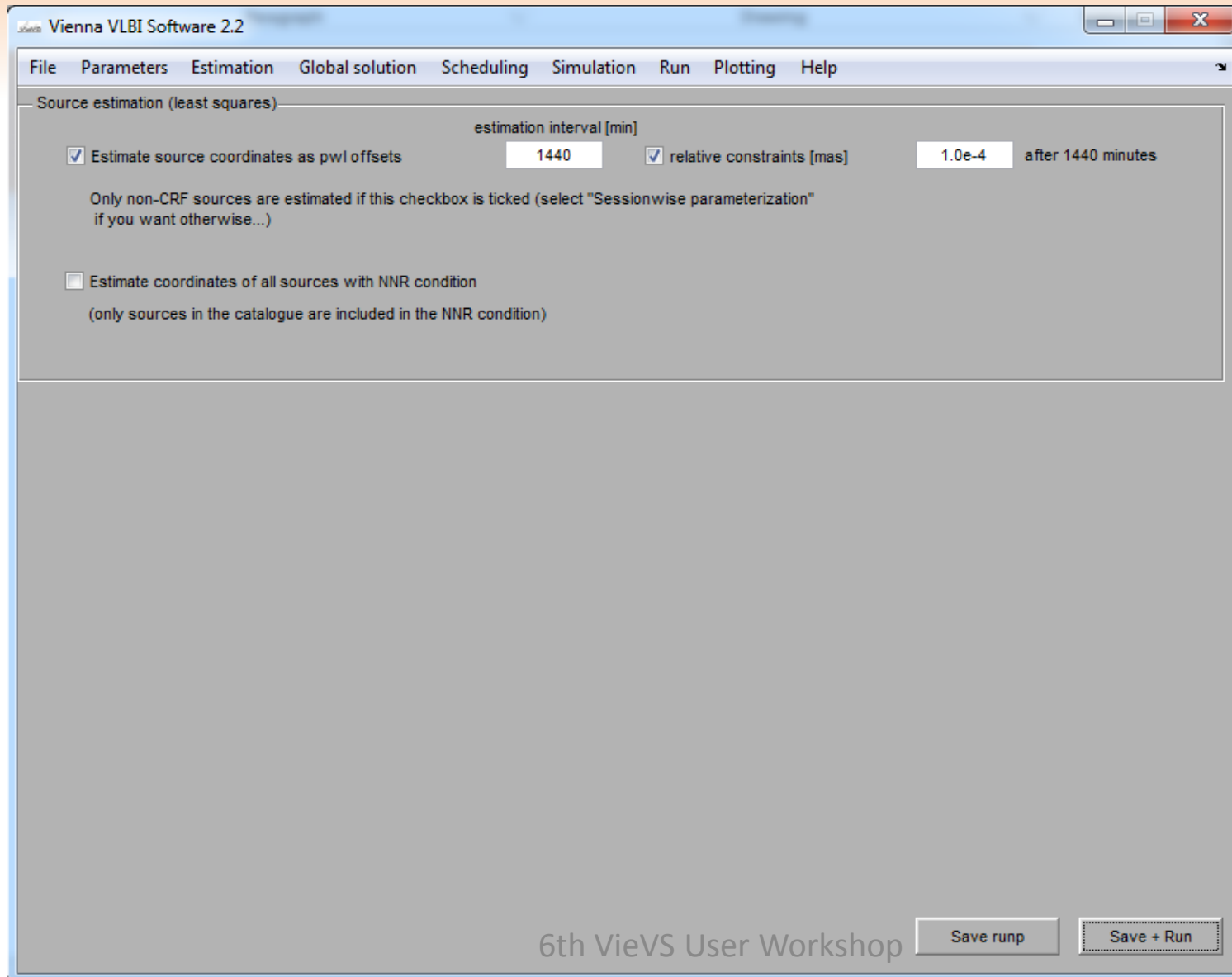
- Estimate station coordinates as one offset per session by introducing NNT/NNR condition equations
  - No Net Translation (NNT)
  - No Net Rotation (NNR)
  - No Net Scale (NNS)

Below the red box, a note states: 'Non-TRF stations are estimated in any case! Select "Sessionwise parameterization" to force fixing of also non-TRF stations.'

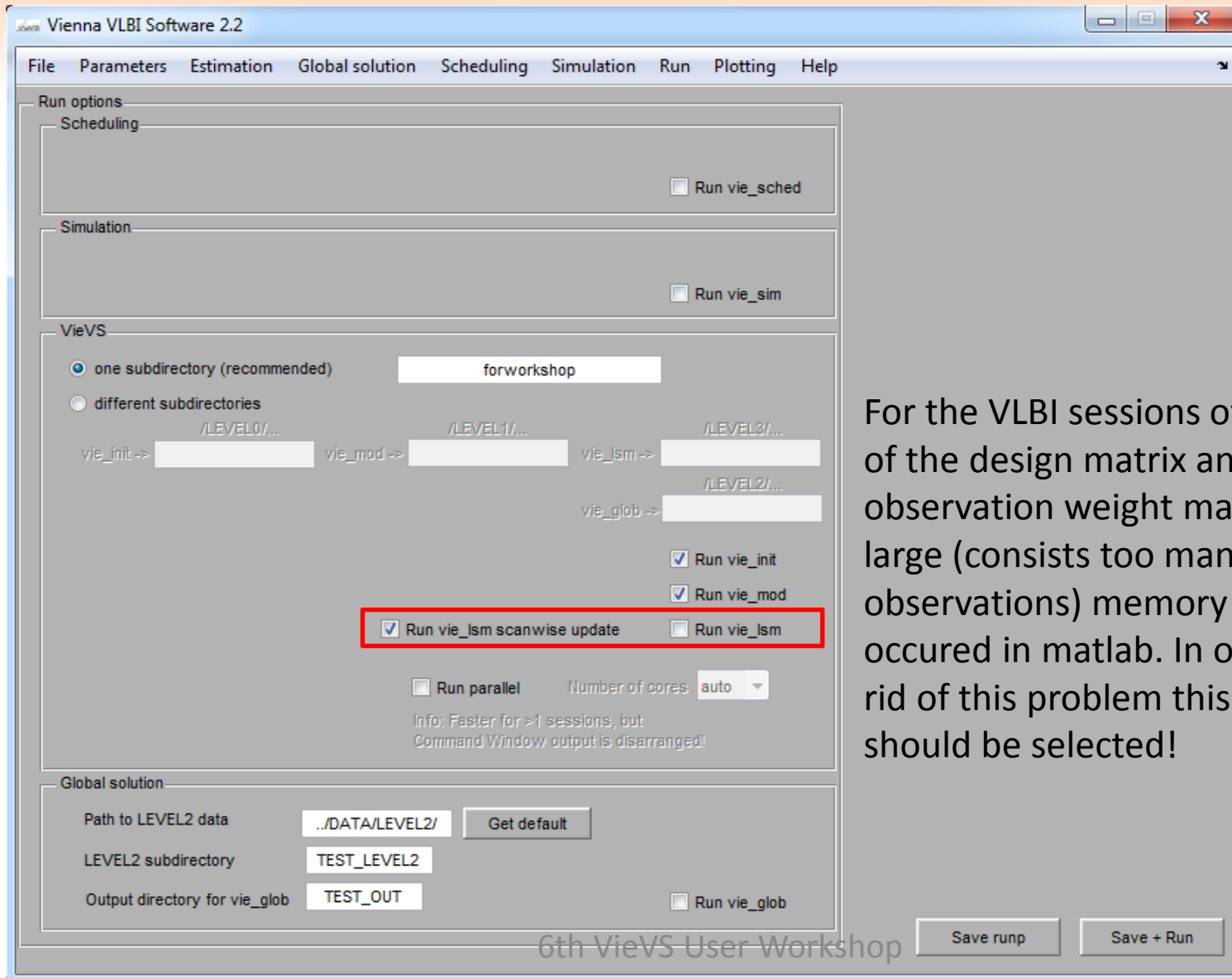
At the bottom of the dialog, there are two buttons: 'Save runp' and 'Save + Run'.

- NNT and NNR conditions are imposed to provide the estimated TRF would neither translate nor rotate w.r.t. the a priori TRF. Thus, 3 translations and 3 rotations between the estimated and a priori TRF will be zero.
- Non-TRF stations will not be a part of the datum when NNT and NNR are introduced!
- Non-TRF station coordinates will be estimated even station coordinates are not estimated!
- The scale of the estimated TRF for each session will be defined free from the scale of the a priori TRF.

# Source CRF coordinates



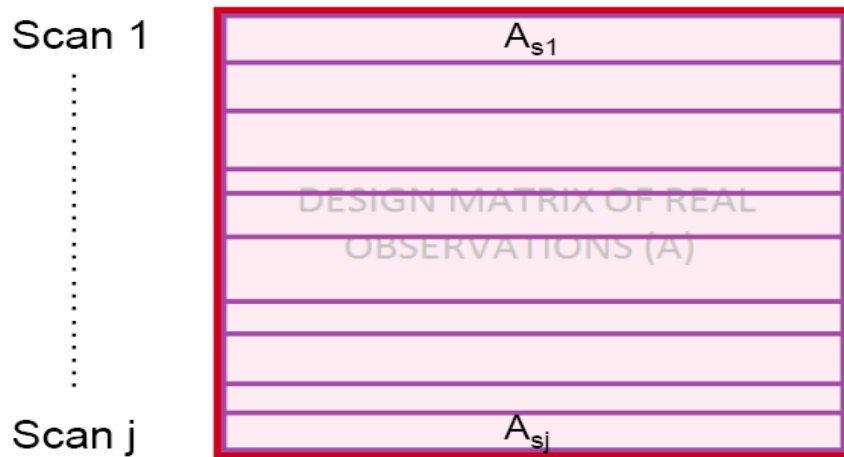
# vie\_lsm scan-wise update



For the VLBI sessions of which size of the design matrix and observation weight matrix is too large (consists too many observations) memory error occurred in matlab. In order to get rid of this problem this option should be selected!

# Scan-wise update of normal equation system

1 A-matrix per scan



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

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

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

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

j : number of scans in the session

# Conclusions

- vie\_lsm corrects clock breaks and detects outlier observations.
- vie\_lsm provides SINEX input and datum free normal equations for global solutions.
- PWLO 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.



# Vie\_LSM V2.2 (part 1: basics)

Thanks for your attention!