

# Piecewise linear offset functions for sub-daily VLBI parameter estimation



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What has already been done related to Vie\_lsm  
up to now?

## Vie\_lsm and ESTIMATES

- Piecewise linear (pwl) offset function is used for the estimation of most of the VLBI parameters in the module of VieVS, named as Vie\_lsm.
- Vie\_lsm module stands for estimating the VLBI parameters with Least Squares adjustment method.
- Most of the Vie\_lsm sub-routines has already been finished (up to now 30 separate subroutines).
- The estimates till now are:
  - Clocks (pwl offsets, rate and quadratic terms of clock function)
  - Zenith Wet Delays (pwl offsets)
  - Tropospheric gradients (pwl offsets)
  - Earth orientation parameters (pwl offsets)
  - Antenna coordinates (pwl offsets or one estimate)
  - Love and Shida number (one estimate)

# Design matrix

$$\begin{bmatrix} \frac{dL^1}{dx_{1,1}} & \frac{dL^1}{dx_{1,2}} & \frac{-dL^1}{dx_{2,1}} & \frac{-dL^1}{dx_{2,2}} & 0 & 0 \\ 0 & 0 & \frac{dL^2}{dx_{2,1}} & \frac{dL^2}{dx_{2,2}} & \frac{-dL^2}{dx_{3,1}} & \frac{-dL^2}{dx_{3,2}} \\ \frac{dL^3}{dx_{1,1}} & \frac{dL^3}{dx_{1,2}} & 0 & 0 & \frac{-dL^3}{dx_{3,1}} & \frac{-dL^3}{dx_{3,2}} \\ \dots \end{bmatrix}$$

$$A = \begin{bmatrix} A_1 & A_2 & \dots & A_{15} \end{bmatrix}$$

# Least Squares Adjustment

$$dx_{total} = N_{total}^{-1} b_{total}$$

$$N_{total}^{-1} = \begin{bmatrix} A^T P A + H^T P_c H & C^T \\ C & 0 \end{bmatrix}$$

$$dx_{total} = \begin{bmatrix} dx \\ x_c \end{bmatrix} b_{total} = \begin{bmatrix} A^T P l + H^T P_c h \\ b_c \end{bmatrix}$$

$$dof = n_{obs} + n_{constr} + n_{unk}$$

$$s0_c = (v^T P v + v_c^T P_c v_c) / dof \quad K_{xx} = s0_c N_{total}^{-1}$$

# What has already been done related to Vie\_lsm up to now?

## ESTIMATION INTERVALS; EXCHANGE FORMAT

- pwl offset estimation intervals can be selected according to the analysis requirements, ranges from 5 minutes to 2 days for a 24 hour session process.
- All the pwl offset estimates are at UTC integer hours, integer fractions or at integer multiples of integer hours.
- The partial derivatives of the respective models are the basic inputs of Vie\_lsm, provided from the outputs of Vie\_mod. The other main inputs are observations, weights of observations, apriori values of the estimates, etc.
- The basic exchange format inter modules is Matlab ,mat' files. The variables are stored in structure arrays.

What has already been done related to  $\text{vie\_lsm}$   
up to now?

## CONSTRAINTS; REASONS FOR USAGE

- Constraints on the estimates are applied.
- These constraints are introduced in design matrix as pseudo-observations for two reasons:
  - To avoid singularity (rank deficiency) caused by inadequate number of observations that might be the case for any or most of the estimation intervals.
  - To select the pwl offsets as tight, loose, or (quasi-tight) before processing stage according to the analysis requirements.

# CONSTRAINTS

$$x_{i+1} - x_i = 0 \pm m_{\Delta x}$$

$$H = \begin{bmatrix} H_1 & 0 & \dots & 0 \\ 0 & H_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & H_{15} \end{bmatrix}$$

$$H_i = \begin{bmatrix} 1 & -1 & 0 & \dots & 0 & 0 \\ 0 & 1 & -1 & \dots & 0 & 0 \\ 0 & 0 & 1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 & -1 \end{bmatrix}$$

What has already been done related to  $\text{vie\_lsm}$   
up to now?

CONDITION EQUATIONS; NNT & NNR

- Condition equations of No Net Translation (NNT), and No Net Rotation (NNR) are applied for antenna coordinate pwl offset estimates.
- Condition equations (NNT/NNR) are introduced to normal equation matrix.
- The datum definition of the VLBI network of the session can be provided as full-trace-minimum or partial-trace-minimum in other words condition equations can be introduced stationwise.



# CONDITION EQUATIONS

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ & \dots & \\ 0 & -z_i' & y_i' \\ z_i' & 0 & -x_i' \\ -y_i' & x_i' & 0 \\ & \dots & \\ x_i' & y_i' & z_i' \end{bmatrix}$$

What has already been done related to *vie\_lsm*  
up to now?

## ANALYSIS OPTIONS; CLOCK BREAKS

- All the estimation intervals, and constraints on the estimates can be arranged according to the analysis requirements as stationwise before processing.
- Stationwise and global estimates can be excluded or included stationwise or globally.
- Regardless from the number of clock breaks at any stations are treated properly by fitting clock functions to each partitions of which boundaries are defined by the MJD's of the breaks occurred.

What has already been done related to Vie\_lsm  
up to now?

## OUTPUTS

- Normal equation matrix without any reference clock or constraint, and respective right hand side vector is produced for global solutions with the auxiliary information that tells us which column of normal equation matrix or row of normal equation vector belongs to which estimate in the output of Vie\_lsm.
- The other outputs are estimates, standard deviations of the estimates, and estimate epoch of the estimates in MJD's (at integer hours, at integer fractions of integer hours or at integer multiples of integer hours).
- The all outputs are stored in structure arrays and saved as Matlab ,mat' files.

*What will be done in the future?*

FLEXIBILITY; OUTLIER DETECTION; TREATMENT

- Flexibility has utmost importance for every condition that might be encountered in future. For that reason much more tests should be performed on the estimation options and results by means of comparing with the OCCAM results.
- A proper outlier detection test for observations will be applied.
- Inaccurate observations will be treated properly by means of down weighting or excluding from the observation data set.

# What will be done in the future?

## NNT FOR CLOCKS; REDUCING INPUTS

- NNT conditions will be introduced which will satisfy the conditions of full-trace-minimum or partial-trace-minimum. The results will be analysed by means of accuracy improvements on the estimates.
- For specific analyses, if it would be possible to exclude stations e.g. Wettzell from the session or baselines e.g. Wettzell-Westford from the session in parameter estimation stage this would be very nice for testing purposes. Since, this will provide us the flexibility of selecting particular stations or even baselines before processing. The applicability of this target has not been discussed deeply yet but mentioned roughly.

## What will be done in the future?

BASELINE WISE RESIDUALS; CUT OFF;  
WEIGHTS OF CONSTRAINTS; GUI

- The significant harmonic variations of the residuals of observations (baselines) in a session are worth to analyse by means of Matlab spectral analysing components.
- Cut off elevation angle option will be added.
- Besides pwl offset estimates, one offset estimate for EOP parameters will be added.
- More investigations on the coefficients of the weights of constraints should be carried out.
- A graphical user interface (GUI) for creating the parameter estimation options will be formed.

- Thank you so much.