# VLBI modeling and data analysis – Exercise

Thomas Artz et al.

Institut für Geodäsie und Geoinformation

Rheinische Friedrich-Wilhelms-Universität Bonn

2013/03/04

# Educational Objectives

## you should be able to

1. use interactive solve
2. perform initial VLBI solution
3. use SOLVE in batch mode
   - individual solution
   - global solution

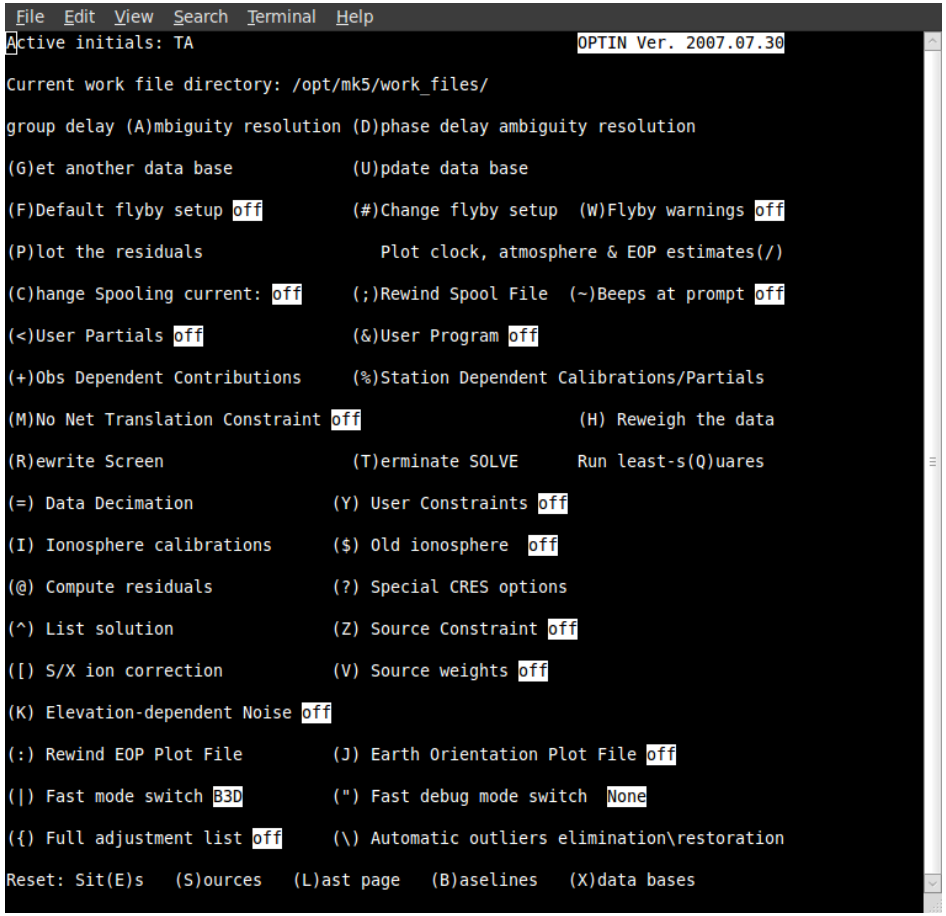
see also:

`http://lacerta.gsfc.nasa.gov/mk5/help/solve_guide_01.html`

# Table of contents

# Starting interactive SOLVE

1. open a terminal
2. start c-shell > `tcsh`
3. change to folder with SOLVE binaries > `cd /opt/mk5/bin`
4. start SOLVE > `./enter XX` where XX are your SOLVE initials (here, E0)

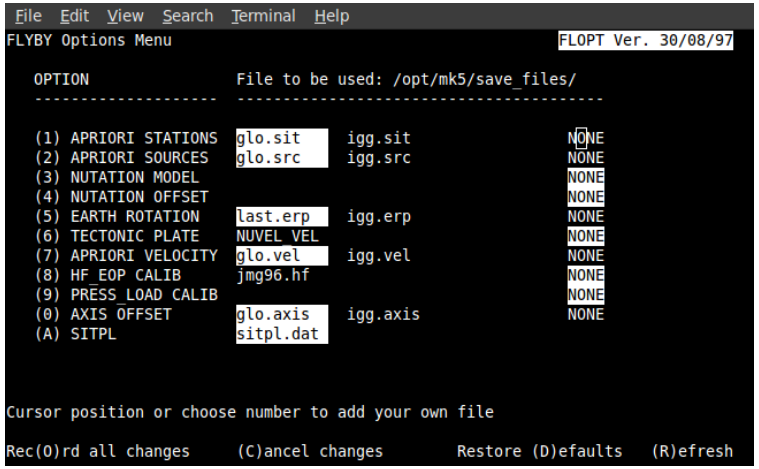


# load a database (DB)

1. `(G)et another data base`
2. `(K)eyboard`
3. Single (standard) database mode:
   ALL SOLVE scratch files are GOING to be RESET!
   Type R to confirm the reset and S to save current files
   $\Rightarrow$ type `R`
4. Database name and version $YYMMMDACC VV $\Rightarrow$ `$02OCT16SY`
5. read correlator report and comments and finally `(G)et data`
6. return to OPTIN page (`O`)

# initial settings

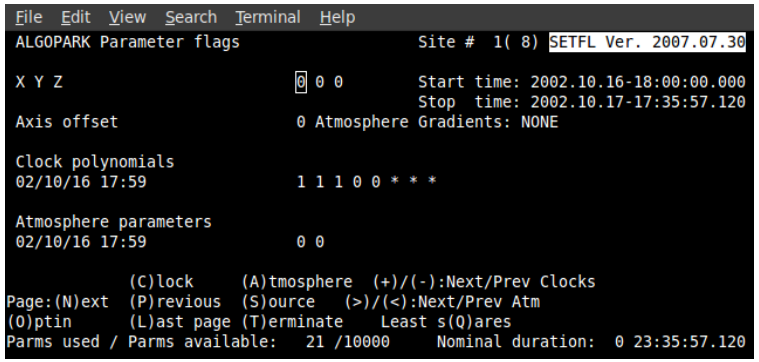
- set calibration status
  - `%` at OPTIN page
  - de-select cable cal for all stations
  - goto `(F)lyby` menu and apply NMFDRFLY for all stations
  - return to OPTIN page (`O`)
- check `(+)Obs Dependent Contributions`
  Pol Tide, WobXCont, WobYCont, EarthTid, Ocean, UT1Ortho, XpYpOrth should be applied
- check flyby set-up (`(#)Change flyby setup`)



# initial parameterization

in a first solution only 3 clock parameters should be estimated

1. go to `Sit(E)s` page
2. de-select gradients: `G, 0`
3. navigate through menu and select/de-select parameters




4. go to next site (`n`)
5. keep in mind a that one reference clock has to be fixed, e.g., don't estimate clock params of WETTZELL
6. go to `(L)ast page` and de-select UT1 rate (`~`)
7. altogether $3 \cdot (n - 1)$ params should be estimated ($n$ = number of sites)

# first parameter estimation

## ambiguity resolution

First, the ambiguities have to be resolved. Thus, delays and delay rates are used as observations, however, the delays are down weighted. By this approach we get delay residual by only/mainly using delay rates in the estimation

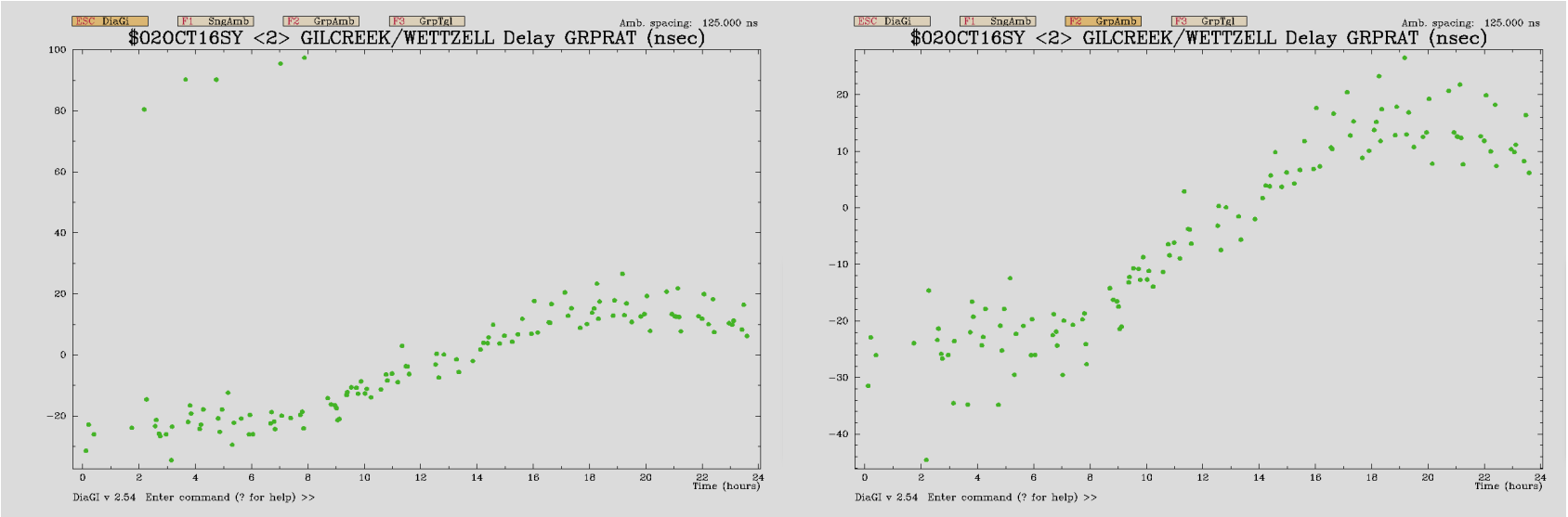
$$\mathbf{y} = \begin{pmatrix} \boldsymbol{\tau} \\ \dot{\boldsymbol{\tau}} \end{pmatrix}, \qquad \boldsymbol{\Sigma}_{yy} = \begin{pmatrix} 10^{-9}\boldsymbol{\Sigma}_{\tau\tau} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Sigma}_{\dot{\tau}\dot{\tau}} \end{pmatrix}$$

$$\mathbf{r} = \begin{pmatrix} \mathbf{r}_{\tau} \\ \mathbf{r}_{\dot{\tau}} \end{pmatrix} = \mathbf{y} - \mathbf{A} \cdot \mathbf{x}$$

- hit `W` at last page
- got to OPTIN page and press `B` to enter the baseline menu
- de-select all baseline (`Z`) and use only independent baselines from one station (e.g., WETTZELL)
- estimate parameters (`(Q)Least squares`)

# remove ambiguities 1

- plot delay residuals by hitting `P`
- if ambiguities are present, one or more jumps of $n$ times the ambiguity spacing (e.g., typically 50 ns in X-band) can be seen
- click with the left mouse button one baselines sub-figure
- press `F2` and click with your mid mouse button in the majority of points




- press `ESC` and then right mouse button to get to the main plot window
- when all ambiguities are removed press `X`

# remove ambiguities 2

- go to last page and use normally weighted delays (W), perform a LSQ adjustment (Q), plot (P) and validate that all residuals are around zero
- go to baseline menu (O, B) and select all baselines (W)
- go to OPTIN page and plot (O, P); **dont't estimate params**
- remove all ambiguities and take care to shift the residuals to zero

- update S-band (in OPTIN page press: U, N, #, 3, 6, 7, N) enter vi and type some comments, leave vi and update DB

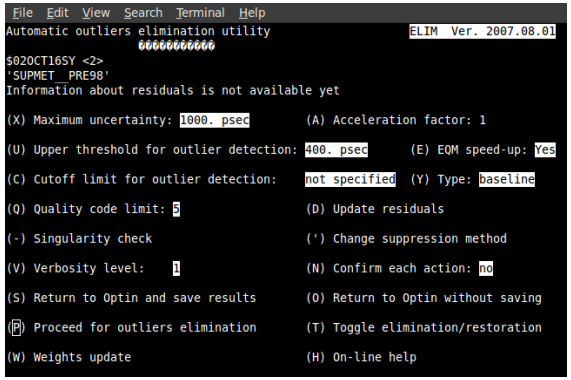
- proceed in the same way with the X-band but don't update DB

# calculate ionosphere correction

- when all ambiguities are resolved load S-band data again. Take that scratch files will not be reset (from OPTIN page press: `G, *, K`)
- perform a solution and have a look at WRMS residual delay
- on OPTIN page press `([) S/X ion correction` to calculate ionosphere correction
- perform a LSQ adjustment and check if WRMS residual delay has been improved
- inspect residuals

# refinement of parameters, first outlier elimination

- estimate clocks and ZWDs with CPWLF of 300 min temporal resolution
  - go to site menu, press `*` until the clock/atmosphere line reads
    `(*)Automatic:(C)lock (A)tmosphere (+)/(-):Next/Prev Clocks`
  - press `C`, insert `300, 2, B` and select the station with the reference clock
  - press `C` and insert `300`
  - solve the LSQ-adjustment
  - inspect residuals
- set initial correction to weights: go to the OPTIN menu and then hit (`H`). in the REWAY menu, hit (C) (Good choice: 10 psec variance will be added quadratically to the formal uncertainty of each observation)
- go to last page and press `;` for not using delay rates
- enter ELIM menu (\ on OPTIN page) and change it and hit `P`




- apply cable cal and compare solutions by means of WRMS residual delay

# check solution

solution is considered

- good if the WRMS residual delay is in the range [15, 100] psec and more than 80% recoverable observations are in the solution
- poor if the WRMS residual delay is in the range [100, 250] psec or the number of observations used in solution is in the range [50%, 80%]
- unsatisfactory if WRMS residual delay is more than 250 psec and/or the number of recoverable observations used in the solution is less than 50%

# further refinement of parameters, outlier elimination

- estimate clocks and ZWDs with CPWLF of 60 min temporal resolution
- estimate 24 h CPWLF gradients
- estimate UT1 rate (`~` on LAST page)
- estimate nutation (`.` on LAST page)
- station positions (`!` on LAST page)
- perform a solution

- check whether `Baseline-(C)lock offsets` (`C` on LAST page) are significant

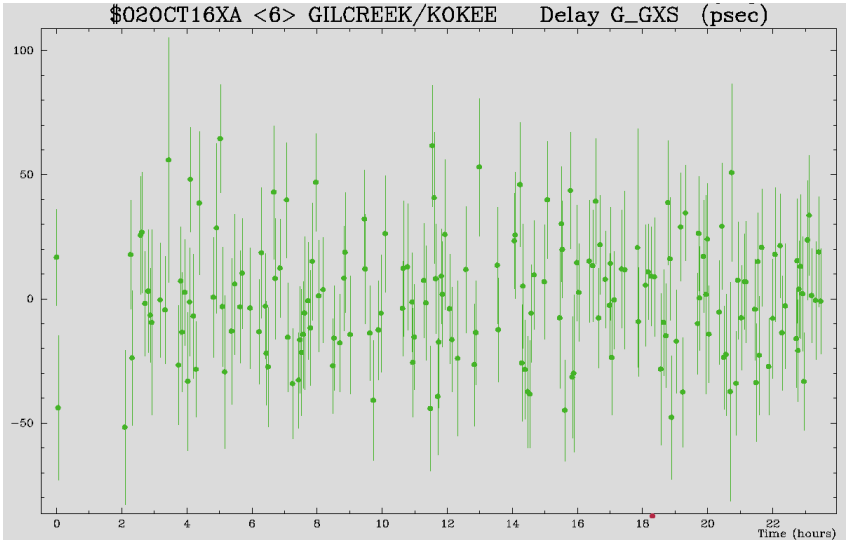
- go to ELIM menu
  - set `maximal uncertainty 1000 psec, upper threshold for outlier detection not specified` and `cutoff limit for outlier detection: 3.0 sigma`
  - update weights (`W`)
    - set `floor to 10.0 psec` by hitting `L`
    - hit `I` to update weights
    - go back ELIM menu by hitting (`O`)
  - press `P` to eliminate outliers
  - save status and perform an adjustment (`S`)

# outlier elimination and restoration

- go to ELIM menu and set `cutoff limit for outlier detection:  4.0 sigma`
- update weights
- press `T` to change from elimination to restoration
- press `P` to restore observations
- update weights
- again set `cutoff limit for outlier detection:  3.0 sigma` , and press `T` to eliminate outliers and press `P`
- save status and perform an adjustment (`S`)

# DB update

- check WRMS residual delay, should be around 20-40 ps
- look at residuals, they should provide no systematics




- perform further refinements (see, e.g., `http://lacerta.gsfc.nasa.gov/mk5/help/solve_guide_01.html`
- update DB

# run a batch solution

- all settings of the interactive mode can be inserted in a control file to be applied to several sessions
  `> /opt/mk5/bin/enter E0 /opt/mk5/control/solve/cont02_indep.cnt`
- results can be found in /opt/mk5/spool_files/SPLFE0

- before a batch solution can be performed, so-called super-files have to be created, e.g.:
  `> /opt/mk5/bin/liptn E0 1 1 02OCT16XA 0`

- the final IVS databases are (DBC: XA) already imported to the catalog and control files for a independent and global solution can be found in /opt/mk5/control/. Perform both solutions and compare the EOPs. How can the differences be explained? Try to improve the agreement by modifying the independent solution.

for detailed information see
`http://lacerta.gsfc.nasa.gov/mk5/help/solve_guide_03.html`