

Overview of post-processing with GLOBK

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GNSS Data Processing and Analysis with GAMIT/GLOBK and `track`

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GLOBK overview

- Here we review the main features of `globk` and `glred`
 - Program flow
 - Kalman filtering
 - GLOBK files and estimation rules
 - `glorg` program/function: Define origin plus other things
 - Output options
 - Flow of programs
- Always keep in mind that there are often multiple ways to do effectively the same thing. A good self-test is to see if you can think of some of these.
- All GLOBK programs have extensive help which is printed if no arguments are given (`~/gg/help/` typically contains the help files).

GLOBK purpose

- GLOBK is a suite of programs designed to combine geodetic results together. GNSS phase processing can take a considerable time and GLOBK provides a fast method for make large network solutions, combining many days to years of data together and studying alternative parameterization and reference frames for the velocities of sites.
- GLOBK uses as data input, quasi-observation files called binary h-files which contain geodetic solutions with loosely constrained full covariance information. These files can generated from GAMIT solutions or SINEX files.
- GLOBK is a smoothing Kalman filter and can incorporate random walk process noise in its estimation (method for accounting for temporally correlated noise in time series).
- Its two main uses are to generate velocity field estimates and time series in a well-defined and often different reference frames. (It can also be used to merge large networks of GNSS sites or different GNSS processing).

Common applications of GLOBK

- Repeatability analysis (`glred`)
 - individual sessions
 - combine regional and global files for orbit control and reference frame (orbit control is not so important anymore; IGS orbits are very good apriori)
- Combine sessions to get average position over survey or to combine GNSS solutions.
 - connects stations observed separately
 - reduces number of h-files to be used for velocities
- Combine averaged positions to estimate velocities
 - and/or earthquake offsets and post-seismic motion
- When `globk` is run in parallel in the same directory, care should be used in scratch file names (discussed later)

Processing stages

- `htoglb` generates input binary h-files (use `-A` option if baseline mode and subnetworks processed in GAMIT)
- GLOBK has distinct modules that are used:
 - Initialization: Header information from the binary h-files are read to determine the nature of the solutions i.e., parameters in the state vector, all site names accounting for offsets and earthquakes etc.
 - Forward Kalman filter: Binary h-files are combined to generate solution. Normally most parameters are loosely constrained.
 - Possible backwards smoothing filter (not that common)
 - Simple output of the solution (program `glout`: generates `.prt` file)
 - Reference frame realized solution and post-solution constraints. Generates `.org` file. Program `glorg` can be used separately for multiple realizations and constraints.
 - Saving binary version of solution for additional processing ("`out_glb`" option in command file and `glsave` program).
- Modules in GLOBK can be called within GLOBK as subroutines or run externally as stand-alone programs (program names are lower case)

Using non-GAMIT files in `htoglb`

- `htoglb` can convert other types of solution/covariance matrix files into GLOBK binary h-files (e.g., SINEX).
- There are caveats when this is done because these other file formats don't contain the same meta data as the GAMIT h-files.
- For GAGE/PBO Frame resolved SINEX files:
 - Use the `-d=R` option to apply rotation loosening (`-d=RT` also loosens translation).
 - `-m=512` (allocate 512 Mb memory) is needed from more recent files
 - There are "loose" SINEX files for which `-d=TR` is not needed except for CWU files which are not loose (these are the submitted AC files)
- IGS SINEX files
 - Use `-s` option for name translation with point codes. `-d=R` should also be used also.
 - Variance-covariance matrix will need scaling depending on AC (scaling value supplied in `.gdl` file). COD solution is most different from unity ($\sim 10^{-4}$)

GLOBK function and file flow

htoglb: Translate GAMIT h-files to (e.g., hameda.10256) to GLOBK
h-files (e.g. h1009131200_emed.glx)

[h-file list].gdl →
globk_comb.cmd
igb14_comb.apr
igb14_comb.eq

G
L
O
B
K

→ globk_comb.prt
globk_comb.log
[h-file list].com (binary solution file
that can be used in glorg)

comb.com →
glorg_comb.cmd
igb14_comb.apr
stab_site [list]

G
L
O
R
G

→ globk_comb.org

Names of files here can be chosen arbitrarily and use of “wild cards” in command file is possible

GLOBK command files

- GLOBK is controlled by a command file that “instructs” the program what to do.
- The command file contain the following classes of commands:
 - Estimation command: Tells globk what to estimate and constraints on a priori values and temporal behavior of the parameters. “apr_XXX” and “mar_XXX” commands.
 - a priori information commands: Coordinates, discontinuity times, selection of sites
 - Output (types and files), and control commands (e.g., to run `glorg`)
- GLORG (post-processing program/module) also has its own command file.
- The simplest globk command can have one line:

```
apr_neu all 10 10 10 0 0 0
```

but in general have several other commons commands (see examples in `~/gg/tables/globk.cmd` and `~/gg/tables/glorg.cmd`)

GLOBK file name conventions

- GLOBK uses arbitrary file names but there are some conventions used:
 - Binary h-files from `htoglb`: `.glx` is bias fixed, `.glr` is bias free (normally not used), `.gls` for SINEX derived files.
 - List of binary h-files to process: `.gdl` extent
 - GLOBK and GLORG command files: `globk_<type>.cmd` and `glorg_<type>.cmd`
 - Output files: print file (no `glorg` reference frame) `.prt` (often not output); `glorg` output `.org`; log file `.log`
 - a priori coordinate files: `.apr`
 - Earthquake and rename file: `.eq`
 - Lists of stabilization sites (used with source command): `.stab`

Kalman filtering

- Equivalent to sequential least-squares estimation but allowing for stochastic processes, usually a first-order Gauss-Markov process
- GLOBK allows a random walk for coordinates, EOP, network translation and scale, and satellite parameters; variance grows linearly with time
- Because a Kalman filter works with covariance matrices (rather than normal matrices), all parameters must have a priori constraints (usually loose)
- See Herring et al. (1990) and Dong et al. (1998) for a more thorough description as applied to geodetic analysis

GLOBK structural confusions

- `globk` and `glred` are the same program with (slightly) different ways of treating the h-file (.gdl) list:
 - `globk`: all h-files in combined in a single solution
 - `glred`: each h-file generates a separate solution (unless followed by a “+” in .gdl-file). `glred` is a small program that generates sub-set .gdl-files and runs `globk`
- Two types of solution files:
 - h-files for saving and external exchange (backward compatible)
 - com/sol file is internal, format changes with versions
- `glorg` called by `globk/glred` or run separately to apply generalized constraints to solution and estimate plate rotations. “com_file” command must be used in `globk` command file for `glorg` to run by itself.

GLOBK files

- User supplied
 - command files (may include “source” files)
 - .gdl list of h-files
 - binary h-files (created from SINEX or GAMIT h-files)
 - .apr-file(s) (optional but recommended)
 - EOP (in_pmu file, optional but recommended)
 - eq_file (optional, but must appear at top)
- Generated by globk
 - .srt, .com, .sol , .svs (all except .sol must be named and commands need to be at the top of GLOBK command file)
- Output files
 - screen, log, prt, org and output h-file

GLOBK file handling

- log-, prt-, org-files are concatenated, so should be removed or renamed unless you want them together (e.g. `glred`). The “eras” option can be used in the “prt_opt” and “org_opt” command in the GLOBK command file to erase these files (should not be used with `glred`).
- com-, srt-, sol-files are overwritten; com/sol should not be renamed since the original sol-file name is imbedded in the com-file.
- Automatic naming using wild-cards is available for com, srt, sol, org, and output h-files (i.e., name used depends on name of gdl-file or date/time designations; needed for parallel processing.)

Estimation commands rules

- For a parameter to be estimated in GLOBK, `apr_xxx` command must be used where `xxx` is a parameter type (e.g., `neu`, `svs`, `wob`, `ut1`, `atm`)
- If a parameter is not mentioned, it does not appear in the solution, but if it appears in the h-file (i.e, estimated in GAMIT), its uncertainty is implicit in the GLOBK solution; e.g., if orbits are estimated in GAMIT and you want them constrained in GLOBK, use `apr_svs`. If `apr_svs` is not used, orbits are left unconstrained.
- If zero given as a priori sigma, then parameter is not estimated (effectively left unconstrained)
- To force a parameter to its a priori value, use “F” as the a priori sigma
- Parameters estimated in `glorg` must be kept “loose” in `globk`; if rotation or scale is not estimated in `glorg`, it must be tightly constrained in `globk`. In GAMIT baseline processing, rotations are fixed and translation constrained by orbit. Default is to automatically deconstrain rotation and translation in `htoglb`; `-A` option undoes this default).
- “Loose” constraints mean the apriori sigmas are large compared to how well the parameter can be estimated without constraints.

Earth orientation parameters (EOPs)

- Normally used in two forms:

- Global network of stations (allows rotation in `glorg`): Units are mill-arc-seconds and mas/day. 1 mas = 30 mm on the surface of the Earth (6371 km).

```
apr_wob 10 10 1 1
apr_ut1 10 1
```

- Regional network (constrained). When constrained this way system is not free to rotate so `xrot`, `yrot`, `zrot` should **not** be used in “`pos_org`” command (see “`pos_org`” in `glorg`)

```
apr_wob .25 .25 .1 .1
apr_ut1 .25 .2
```

- In many analyses, the global form is used even for regional networks in order to allow rotation estimation in `glorg`

- Care is needed if network is not surrounded by stations with well defined motions

“Data” editing (coordinate data)

- To account for temporal correlations in time series we typically use random-walk (RW) process noise with the “mar_neu” command (units m^2/yr)
- Typical values are $2.5 \times 10^{-8} \text{ m}^2/\text{yr}$ (0.5 mm in 1 yr) to $4 \times 10^{-6} \text{ m}^2/\text{yr}$ (2 mm in 1 yr)

```
mar_neu all 2.5e-8 2.5e-8 2.5e-8 0 0 0
mar_neu chdu 4e-6 4e-6 4e-6 0 0 0
```
- `sh_gen_stats` can be used to generate process noise estimates provided sufficiently time series have large number of position estimates. (glred and tssum/tsfit)
- To down-weight noisy segments or equalize continuous and survey-mode data in a combined h-file, can add random noise (units are m)

```
sig_neu all .001 .001 .003
sig_neu ankr .005 .005 .020 2002 10 01 00 00 2002 11 30 24 00
sig_neu all EMED0504 .010 .010 .1 ! EMED0504 string is in h-file name
```
- To remove an outlier, can down-weight severely or rename (in `eq_file`)

```
sig_neu ankr .1 .1 .1 2002 10 01 00 00 2002 10 01 24 00
rename ankr_gps ankr_xcl 2002 10 01 00 00 2002 10 01 24 00
```

glog

- Invoked by `globk` to apply generalized constraints after h-files are stacked and loose solution performed
 - Can be run as a separate program using the `com/sol` files from `globk`
- Also allows linking of parameters and estimation of Euler poles
- Parameters estimated in `glog` must be kept loose in `globk`
 - Site coordinates
 - EOPs (for estimation of rotation)
 - Scale
- `glog` is used to define and refine the reference frame for `globk` solutions. No strain is introduced into networks when this approach is used provided original h-files are loosely constrained.

Invoking `glogrg` from `globk` command file

- The `globk` command file contains commands that cause `glogrg` to run when `globk` completes the solution combination:

`org_cmd` <`glogrg` command file name> (invokes `glogrg`)

`org_opt` <options for output>

`org_out` <output file name>

- `org_out` Normally not used because name will be generated from `prt` file name in the `globk` runstring
- If “`org_out`” is not given then the extent on the print file name is replaced with “.org”

g_l_o_r_g commands

- `apr_file` – Need not be the same as for `g_l_o_b_k`; needs to contain values only for sites used for stabilization and sites for which coordinates or velocities are equated
- `pos_org`, `rate_org` – Control what parameters are estimated in stabilization
 - `xtran ytran ztran` – allows translation (`apr_tran` in `g_l_o_b_k` if GAMIT “BASELINE” choice of experiment)
 - `xrot yrot zrot` – allows rotation
 - `scale` – allows rescaling of system (if used, estimate scale in `globk`; `apr_scale` and possibly `mar_scale`)
- `cnd_hgtv` – Control relative weights of heights (variances, nominally 10 but increasing value will reduce heights effecting horizontal position estimates; 1000 is good for this)
- `stab_ite` – # of iterations and sigma-cutoff to remove a site
- `stab_site` – List of sites to use in stabilization

Controlling print output

- `crt_opt`, `prt_opt`, `org_opt` specify output options for screen, print and org files
- `globk/glog` help gives all options, main ones are:
 - ERAS -- erase file before writing (normally files appended)
 - NOPR -- Do not write output (e.g. for `globk` when invoking `glog`)
 - BLEN -- Baseline lengths
 - BRAT -- baseline rates when velocities estimated
 - RNRP -- generates reports on differences in parameter estimates after renames.
 - FIXA -- makes a priori coordinates and velocities consistent when equates are used in `glog` (can sometimes fail in complicated rename scenarios--best if `apr_file` is provided with consistent values)
 - VSUM -- lat/long summary of velocity (needed to plot velocities)
 - PSUM -- lat/long position summary
 - GDLF --Include list of hfiles and χ^2 increments from run
 - CMDS -- echos `globk` command file into output file

Program flow

- Read all the h-file headers to determine their contents (sites, other parameters, epoch range)
- Apply renames as requested in the eq_file
- Sort the h-file list forward or backward in time (srt_dir)
- Initialize the Kalman filter with the a priori constraints (apr_xxx)
- Read in the h-files, one at a time, a run sequential Kalman Filter. Compute the χ^2 increment, coordinate adjustment, and rotation implied by the new data; if within tolerance (max_chii), update the solution and write the χ^2 increment to the log file.
- (optional: Back filter run; recent versions of GLOBK allow reference frame realization and binary h-file output in back solution).
- Write the solution to the sol_file and prt file (and optionally to a new h-file)
- Optionally invoke `glog` to apply generalized constraints
 - Apply the constraints (iterative “stabilization”)
 - Apply linkage of parameters (equate, constrain, force), computing the χ^2 increment for each
 - Estimate plate rotations (“plate” command)
 - Write the solution to the org file (`glog prt` file)

Things GLOBK cannot do

- Repair mistakes in original analysis
 - Cycle slips
 - Wrong antenna phase center models
- Resolve ambiguities
 - Would make files too large
- Overcome non-linear effects
 - As in GAMIT, adjustments must be less than ~ 30 cm
- But GLOBK can delete stations
 - Can help avoid contaminating solution

.apr-files in GLOBK processing

- GAMIT
 - 10 m accuracy for all sites for cycle-slip repair
 - < 30 cm final adjustment for linearity (first solution guarantees)
 - ~5 cm accuracy in constrained site(s) for ambiguity resolution
- globk
 - If invoking `glorg` for reference frame, `apr_file` usually optional in `globk`
 - If not invoking `glorg`, need accurate `apr_file` entries for constrained sites
 - For complicated renames and equates, `apr_file` may be needed in `globk`
 - EXTENDED entries that allow periodic terms and post-seismic models (caution when renames are used, make sure EXTENDED entries are applied consistently)
- glorg
 - `apr_file` needs coordinates only for reference sites and equates

What can go wrong?

- `globk`
 - h-files not used: removed automatically for high χ^2 , coordinate adjustment, or rotation (`max_chii` command)
 - High χ^2 increment: inconsistent data. Can be an issue when estimating orbits (“RELAX” mode) if MIT GLX file use different modelling (e.g. albedo, gravity field)
 - Station “missing”: not present in h-file or renamed out (use `glist`)
- `glorg`
 - Stabilization fails: too few sites in stabilization: Use as many as possible for robustness.
 - Large uncertainties: poor stabilization or sub-networks not connected
 - Uncertainties too small for some stabilization sites: rotation parameters absorbing coordinate adjustment
 - High χ^2 in equate: inconsistent data
 - Wrong velocity for equated sites: unmatched a priori (see `FIXA` option in `GORG`).

Iteration of solutions

- A common approach is repeated runs of globk and glred.
 - (1) Run glred with igb14_comb.apr and igb14_hierarchy.stab_site (include igb14.eq in globk) to generate time series for all sites.
 - (2) Use tssum and tsfit and sh_gen_stats to get process noise models.
 - (3) Run globk to combine all data and use igb14_comb.apr and igb14_hierarchy.stab_site (include igb14.eq in globk) to get globally aligned coordinates and velocities.
 - (4) Extract positions and velocities (sh_exgk) to get coordinates and velocities of all sites in network and use these coordinates as apriori; add local sites with small correlated noise to stabilization list (additional file and use source command).
 - (5) Go back to step with refined local reference frame. Iterate to improve local coordinates and process noise models.

Associated programs

- `htoglb`: Translates various ASCII solution files (GAMIT h-files, SINEX) into GLOBK binary h-files
- `glbtosnx`: Generates SINEX files from binary h-files
- `glist`: Lists the contents of a series of h-files
- `hfupd`: Updates binary h-files for changes in station.info or SINEX header file (distributed by IGS). Only eccentricity can be fixed.
- `tssum`, `tsfit`, `tscon`: Time series analysis (batch)
- Matlab-derived programs (interactive):
 - `velview`: displays and analyzes velocity fields
 - `tsview`: displays and analyses time series

NOTES on switch to IGS20

- The ITRF2020/IGS20 uses different satellite antenna phase center calibrations (PCC) than Igb14 and there is a small differences between Igb14 and IGS20 ground station coordinates.
- Some ground antennas have updated PCC values in IGS20, and their positions will change with IGS20.
- Ground antenna azimuths were included in repro3/igs20 and some IGS sites centimeter level position changes results from this change (ULAB).
- Pole tide model is different from IGS20, and the change will cause a position discontinuity (Tides applied in sestbl.)
- REPRO3 used yet another satellite PCC model (based on Galileo ground calibrations). Minimal effect on satellite (CoM) orbits.
- When changing antenna ATX files, be aware of these possible changes.

Summary

- GLOBK has many features and due to its evolution, there are often multiple ways of doing the same or similar things
- There is extensive help in the `~/gg/help/` directory and discussion in the documentation
- GLOBK is where all the major analysis decisions are made and hence can be quite complex for large analyses
- Experimentation and testing your ideas of how different options effect the results is one the best ways to learn the software, e.g.
 - What happens to position/velocity estimates if the “`apr_tran`” command is added to the `globk` command file?
 - How do my estimates and uncertainties change if the values in the “`apr_neu`” and “`mar_neu`” commands are changed?
- Experimentation is the best way to learn.