

GLOBK: Combination methods

Lecture 02

Thomas Herring
tah@mit.edu

GLOBK Overview

- Advanced topics in the use of GLOBK
- Topics:
 - Reference frame realization; center of mass versus center of figure
 - Use of the MIT binary H-files for global frames
 - Analysis of earthquakes; detection and post-seismic modeling
 - Analysis of large data sets
 - Use of SINEX files GLOBK
 - Noise processes and how to treat.
- As needed we will discuss these topics at different levels of detail.

GLOBK Purpose

- GLOBK is a suite of programs designed to combine geodetic results together. GPS 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 GPS sites).

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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
 - 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

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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 apriori 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 chi**2 increments from run
 - CMDS -- Echos globk command file into output file

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Reference frames in Geodetic Analyses

- Output from GAMIT
 - Loosely constrained solutions
 - Relative position well determined, “Absolute position” weakly defined
 - Need a procedure to expressed coordinates in a well defined reference frame
- Two aspects
 - Theoretical (e.g., rigid block, mantle-fixed, no-net-rotation of plates)
 - Realization through a set of coordinates and velocities
 - “finite constraints” : a priori sigmas on site coordinates
 - “generalized constraints” : minimize coordinate residuals while adjusting translation, rotation, and scale parameters
- Three considerations in data processing and analysis
 - Consistent with GPS orbits and EOP (NNR)
 - not an issue if network small or if orbits and EOP estimated
 - Physically meaningful frame in which to visualize site motions
 - Robust realization for velocities and/or time series

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Basics of reference frame realization

- Reference frame realization is the method used to align your solutions to a system which makes sense for the problem you are studying.
 - For global tectonic problems: Align to ITRF2008 (IGS08 version) using the IGS reference sites (~100 globally)
 - For regional problems, use a plate fixed frame or even zero for local sites.
- The alignment consists of rotation, translations and possibly scale (must be estimated in globk; apr_scale command) to best fit the positions/velocities of the reference frame sites.
- GLOGR module does this in globk. tscon can do this for time series files.
- System must be free to rotate and translate for glorg algorithm to operate correctly (discuss translation later since this is subtle).
- Two issues: What to align to and which stations to use.

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GLOBK frame realization methods

- In GLOBK analyses, normally all stations and orbit initial conditions are loosely constrained, the reference frame is defined in a module called glorg (global origin). The methods used are similar to other programs but there are some subtle differences. Specifically, the frame transformation is implemented with a Kalman filter constraint equation, not by direct application of the rotations, translations and scale.
- Details are discussed in Dong, Herring and King, J. Geodesy, 1998.

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Specific implementation

- Glog computes a set of condition equations using weighted least squares. The weights are settable to be dependent on site uncertainty (iteratively) and with weight between horizontal and vertical site positions and rates.
- The condition equations are then applied through a Kalman filter formulation to the loose solution covariance matrix and solution vector. The KF formulation allows zero variance for the condition (LSQ approach would need a small but finite variance). The condition can also be given finite variance (avoids zero eigenvalues).
- If the original loose solution is free to translate, rotate and scale, the application of the condition solution generate the same answer explicit application of transformation (SDET option).
 - For VLBI, translation is rank deficient and rotation is explicitly estimated (scale needs to be explicitly estimated if included in the constraints)
 - For GPS, translation is not rank deficient and so condition modifies solution if translation not explicitly estimated. It is not clear whether translation should be estimated explicitly.

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Formulation

- Condition application, T are estimates of transformation parameters, W is weight matrix, and superscript – and + denote values before and after the conditions are applied. R is the variance of the condition and can be set to zero. (MIT weekly IGS sinex submission, sets 1 m² on translation so not forced to zero)

$$\bar{T} = (A^T W A)^{-1} A^T W \Delta X_s \equiv H \Delta X_s$$

$$\Delta X^+ = P^- H^T [H P^- H^T + R]^{-1} (\Delta X^- - A \bar{T}) \equiv K \delta X^-$$

$$P^+ = [I - KH] P^-$$

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Coordinate Weight effect

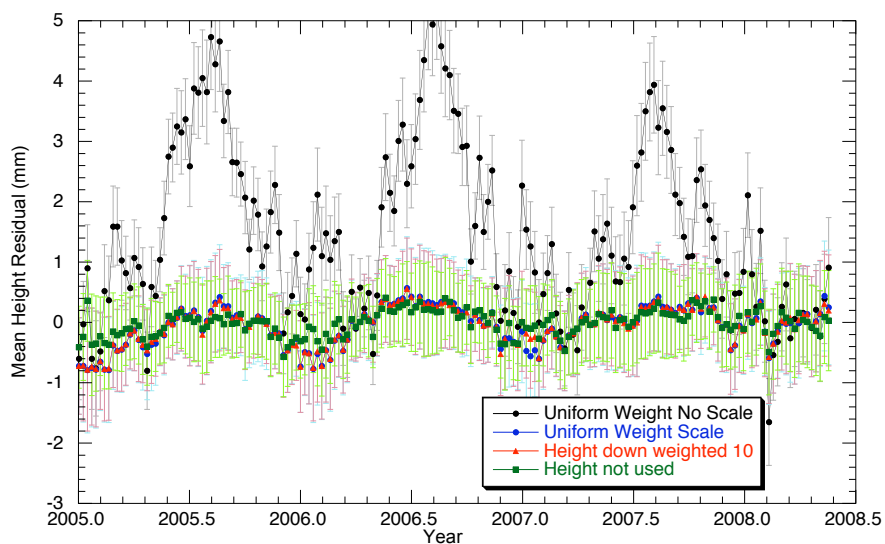
- Next set of slides show the effects of height weight on the means of site position residuals after transformation:
 - when uniform weight (i.e., height is weighted same as horizontal) is used with no scale estimated (mean height residual is scale)
 - when scale estimated with
 - Uniform height weight
 - Heights down weighted by 10 (consistent with sigmas, default)
 - Height so down weighted so much that effectively not used.

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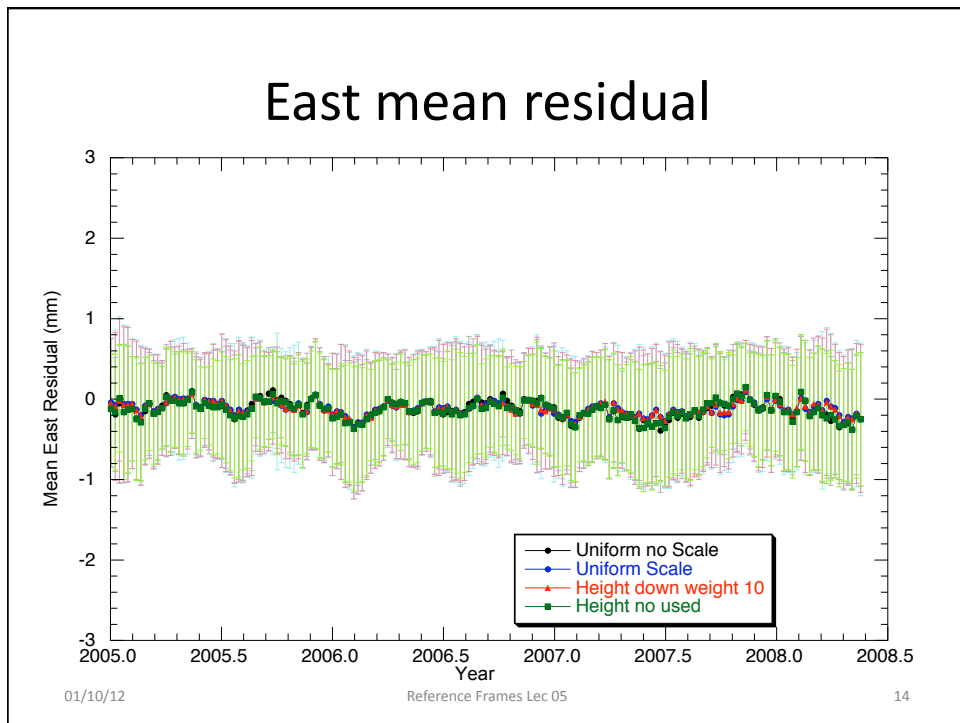
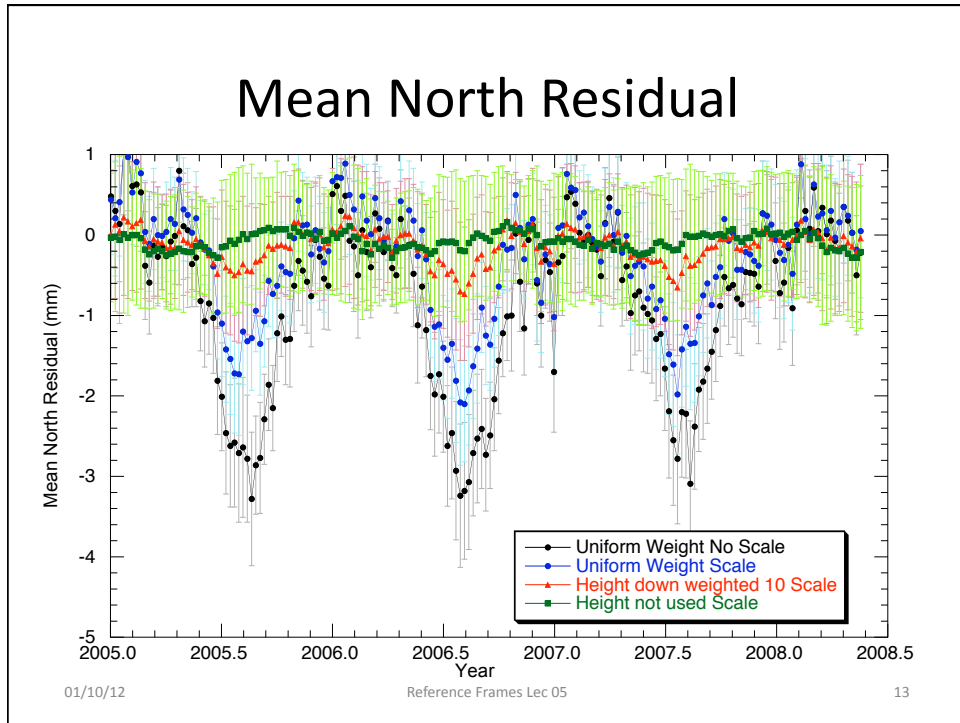
Mean Heights



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Local Frame Realization

- When dealing with a local region (100-3000 km in size), there are a number of choices of approach:
 - Sometime motion relative to a stable plate (e.g., Eurasia) is needed
 - Often since local strains are important, a local reference frame provides a more useful way of viewing results.
 - In the GLORG, translation/rotation method only the rotational part of the strain tensor is effected by how the reference frame is realized. (This is not the case when tight constraints are applied).

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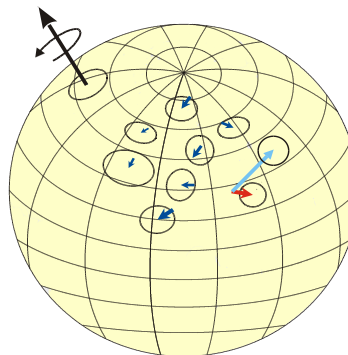
Referencing to a horizontal block ('plate')

Applied in glorg: first stabilize in the usual way with respect to a reference set of coordinates and velocities (e.g. ITRF-NNR), then define one or more 'rigid' blocks

```
apr_file IGS08.apr
pos_org xtran ytran ztran xrot yrot zrot
stab_site algo pie1 nlib drao gold sni1 mkea chat
cnd_hgtv 10 10 0.8 3.
plate noam algo pie1 nlib
assign_p noam drao fair
plate pcfc sni1 mkea chat
noplateran
```

After stabilization, glorg will estimate a rotation vector ('Euler pole') for each plate with respect to the frame of the full stabilization set and print the relative poles between each set of plates. Normally noplateran option used unless truly global.

Use sh_org2vel to extract the velocities of all sites with respect to each plate



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Handling Steps due to Earthquakes

- **Level 1 (always necessary)**

Rename the site, either automatically (e.g. Tohoku-Oki, 2011 event)

```
<Code> <Lat> <Long> <Radius> <Depth> <epoch>
```

```
* EQ_DEF M 9.0 Mw=9.0 Tohoku, Japan Earthquake
```

```
eq_def TO 38.290 142.400 4890.8 8 2011 3 11 5 46 318.135
```

```
eq_rename TO
```

```
eq_coseis TO 0.001 0.001 0.001 318.135 318.135 318.135
```

The eq_coseis is constant sigmas (m) and distance dependent values (depth/dist)² multiplier. (e.g. 1000 km from event, 20 mm coseismic sigma)

- Effect is to make the site's coordinates and velocities independent in the solution.
- CAUTION: Offsets estimated from apriori coordinates and so make sure coordinates are consistent in apriori files when sites renamed.
- The script `sh_makeeqdef` can be used to generate an eq definition file bases on the NEIDC seismic catalog and program `stinf_to_rename` can used to generate renames due to antenna changes.

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Handling Steps due to Earthquakes

- **Level 2 (almost always desirable)**

- In glorg equate the velocities, either explicitly

```
equate iisc_gps ndot iisc_1ps ndot
```

```
equate iisc_gps edot iisc_1ps edot
```

```
equate iisc_gps udot iisc_1ps udot
```

- or automatically

```
eq_dist 1000 ndot
```

```
eq_dist 1000 edot
```

```
eq_dist 1000 udot
```

```
unequate chdu_gps ndot chdu_gwc ndot
```

```
unequate chdu_gps edot chdu_gwc edot
```

```
unequate chdu_gps udot chdu_gwc udot
```

- Effect is to (re)link the adjustment (should be used with the FIXA option)
- Can create a soft link with "constrain" command (so that values are not forced to be exactly the same).
- Equates are applied to adjustments to apriori coordinates, so in general these should be the same (FIXA option will often do this automatically; `unify_apr` is another method).

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Handling Steps due to Earthquakes

- **Level 3 (often useful to improve far-field velocities)**
- Equate the positions when a site within the EQ radius has a small displacement
 - equate xian_gps npos xian_gwc npos
 - equate xian_gps epos xian_gwc epos
 - equate xian_gps upos xian_gwc upos
- The steps above can also be applied for equipment renames (due to antenna changes)

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Post-seismic modeling

- There are two approaches possible
- In GLOBK estimation:
 - use eq_log option in eq definition file. Sigmas of the log coefficients set the same way as the co-seismic sigmas
 - Eq_post allows random walk process after earthquake. Most flexible but needs back solution to extract time series (best generated with finite constraints).
- tsfit estimation of log and/or exponential decay terms from time series and these applied in GLOBK run with EXTENDED apriori coordinates entries. (Approach also allows periodic signals). Apriori files generated by tsfit contain the necessary entries. We use latter approach for large data set analysis.

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sh_makeeqdef example

- EQ-entries generated by sh_makeeqdef. Comments gives distance from hypocenter and coseismic sigma (CoS) expected. Eq_log is given but commented out. 2-character code needs to be set by user (sequential number given).

```
SEQ Earthquake # 15
* EQ 88 BING_GPS      120.24      120.50 CoS      44.0 mm
* EQ 88 BAYB_GPS      78.45      120.50 CoS      103.3 mm
* EQ 88 TUNC_GPS      66.95      120.50 CoS      141.8 mm
* EQ 88 TNCE_GPS      66.95      120.50 CoS      141.8 mm
* EQ 88 GUMU_GPS      81.24      120.50 CoS      96.3 mm
* EQ 88 ERZI_GPS      8.99      120.50 CoS      7865.8 mm
* EQ 88 ELZT_GPS      119.04     120.50 CoS      44.9 mm
* EQ 88 RHIY_GPS      74.17      120.50 CoS      115.6 mm
* EQ_DEF M 6.7
eq_def AO 39.710 39.600 120.5 27.0 1992 3 13 17 18 0.8721
eq_rename AO
eq_coseis AO 0.001 0.001 0.001 0.872 0.872 0.872
#eq_log AO 10.0 0.001 0.001 0.001 0.872 0.872 0.872
```

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Earthquake evaluation

- Once an eq-file has been generated, it can be tested in tsview (matlab/UNIX executable) or run through tsfit.
- The sh_makeeqdef script uses a list of site positions but does not know if data exists at the time of the earthquake and so often reports earthquakes that do not affect stations.

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Large Data-set Analysis

- Very large data sets (e.g. 1000-sites for a decade; PBO class analysis) can take a long time for the forward GLOBK run.
- Approaches:
 - Weekly-to-monthly combinations. Positions only estimated (not velocities, use MIDP option)
 - Care with earthquakes and offsets; log estimates are a problem far from the earthquake. Free_log command with negative sigma turns off log estimate
 - Process noise not that critical in combination but needed when monthlies are combined.
 - Decimation: Works very well and with process noise is almost the same solution as the full combination
 - Initial limited station selection (e.g., 100 best stations); combine to generate reference solution; use this solution for time series analyses and then test and evaluate with tsfit/tsview. When solution looks good in time series; run the full globk solution.

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Large Data sets

- Cautions:
 - Log estimated can be unstable when monthly/weekly solution constructed; applying apriori is often better.
 - Numerical stability: Better to combine weekly/monthly first and then combine these (accumulation of error is better).
 - Keep apriori sigmas on positions and velocities modest (Herring et al., 1990: Effect of apriori constraint is $\sim(\sigma_{\text{aposteri}}/\sigma_{\text{apriori}})^2$ so 100:1 ratio reduces effect of error in apriori by 10-thousand fold. (You can test this yourself).

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SINEX files

- SINEX files (Solution Independent Exchange format) can be read and written by GLOBK.
- The reading of the files is directly detected by htoglb and often, depending on how the SINEX was generated, the files need to be "loosened" for use in GLOBK. This is done with the -d=TR (translation/rotation) option.
- The -s option can also be useful in converting globk style names to IGS Occ and Pt codes.
- SINEX files are created in GLOBK through the combined GLOBK binary h-files. The out_glb command will output a loose h-file. When the out_sol (output solution) command is used in GLORG, GLOBK will create a h-file with .CON appended (frame constrained). This h-file converted to SINEX will generate one the same as the .org solution (i.e., no loose). The -d option can be used to re-instate the rotation/translation uncertainty.
- Advanced feature: The cond_sig command in glorg will control how tightly the origin will be forced to zero in the SINEX file (see discussion in help files).
- head.snx file in local directory or ~/gg/help contains the long names of sites (replaces the one that have been propagated through from the GAMIT hfiles or SINEX files).

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Process noise models

- GPS results all exhibit temporally correlated noise which needs to be accounted for or else sigmas on derived quantities will be very optimistic.
- Tests you can do:
 - Use the decimation feature in sestbl. and compare 30-sec with 2-minute solution (only difference sigmas factor of 2 smaller).
 - Compare daily GLOBK combination of continuous data with weekly decimated solution (again difference will be in sigmas if not process noise; with realistic process noise solutions will be almost exactly the same).
 - Comparisons here are in sense of differences compared to sigmas (i.e., differences < 0.1 sigma normally seen).

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Process noise models

- `sh_gen_stats` is the script used on time series to create Markov process noise models for the sites and to “recommend” reference frame sites based on those sites that have the lowest levels of process noise.
- The process noise models use the “realistic sigma” option in `tsfit` and `ensum` (also used in `tsview` where the correlation functions can be plotted).
- Concept of algorithm is use the characteristics of the RMS scatter of position time series residuals averaged over increasingly longer times to predict the likely uncertainty of velocity estimates.
- The files generated by `sh_gen_stats` are “sourced” in the `globk` and `glorg` command files (see `source` command).

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Network Selection

- Two classes of program/scripts are available for network selection
 - `global_sel` and `sh_network_sel` make N networks each of a user specified size that try to distribute stations globally. The list of sites to be chosen from is based on ftp directories of various archives
 - `netset` works the other way round: Given a set of `rinex` files already available; it makes a variable number of networks of upto a user specified size that use all data. One network is created that links all other networks together.
- Both approaches try to minimize multiple use of data from sites.
- Implementations create `sites.defaults.<yyyy>.<ddd>` files to be used in processing.

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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 `apr_neu` and `mar_neu` commands are changed?
- Some of these concepts and how earthquakes are treated are shown in the tutorial session this afternoon.