

Introduction to and basics of processing with `track`

T. A. Herring M. A. Floyd

Massachusetts Institute of Technology, Cambridge, MA, USA

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

Virtual (online only) hosted by EarthScope

22–26 July 2024

http://geoweb.mit.edu/gg/courses/202407_EarthScope/

Material from R. W. King, T. A. Herring, M. A. Floyd (MIT) and S. C. McClusky (now at ANU)

Kinematic GNSS

- The style of GNSS data collection and processing suggests that one or more GNSS stations are moving (e.g., car, aircraft)
- To obtain good results for positioning as a function of time it helps if the ambiguities can be fixed to integer values. However, with the “back smooth” option in `track` this is not so critical.
- Program `track` is the MIT implementation of this style of processing.
- Unlike many programs of this type, `track` pre-reads all data before processing. (This approach has its pros and cons)

General aspects

- The success of kinematic processing depends on the separation of sites
- If there are one or more static base stations and the moving receivers are positioned relative to these.
- For separations < 10 km, usually easy
- 10–100 km more difficult but often successful
- >100 km very mixed results depending on the quality of data collected.

Slow moving sites

- For slow -moving sites (glaciers, early landslides), GAMIT solutions can be more easily automated than track solutions and can generate high-quality results, especially if motion is nearly linear (with high rates 100 m/yr, for example).
- With GAMIT solutions:
 - Put best estimate of velocity in the a priori coordinate file used in GAMIT (position estimate will be the mean offset from this linear model).
 - Use `sh_gamit` with “-sessinfo” option to have multiple solutions be day (set start time and duration of each session e.g., 8 3-hr sessions per day; 360 30-sec epochs per session). Use “-netext” option to put each session in different directory (“-noftp” after first session also speeds up run if sites missing).
 - Some tuning of “minxf” in `process.defaults` and reduce values in “trim_oneway_tol” in `autcln.cmd` so that small data sets are not removed.
- `track` can also be used for these types of analyses

Issues with length

- As site separation increases, the differential ionospheric delays increase, atmospheric delay differences also increase
- For short baselines ($< 2\text{--}3$ km), ionospheric delay can be treated as approximately zero, and L1 and L2 ambiguities can be resolved separately. Positioning can use L1 and L2 separately (less random noise).
- For longer baselines this is no longer true and `track` uses the MW-WL to resolve (L1 – L2) cycles
- IONEX files can now be included to help with the ionospheric delay on long baselines.

track features

- `track` uses the Melbourne-Wubbena Wide Lane (MW-WL) to resolve (L1 – L2) and then a combination of techniques to determine L1 and L2 cycles separately.
- “Bias flags” are added at times of cycle slips and the ambiguity resolution tries to resolve these to integer values.
- `track` uses floating point estimate with LC, MW-WL and ionospheric delay constraints to determine the integer biases and the reliability with which they are determined.
- Kalman filter smoothing can be used. (Non-resolved ambiguity parameters are constant, and atmospheric delays are consistent with process noise). When atmospheric delays are estimated, the smoothing option should always be used.

Ambiguity resolution

- Algorithm is “relative-rank” approach. Chi-squared increment of making L1 and L2 ambiguities integer values for the best choice and next best are compared. If best has much smaller chi-squared impact, then ambiguity is fixed to integer values.
- Test is on inverse-ratio of chi-squared increments (i.e., large relative rank (RR) is good).
- Chi-squared computed from:
 - Match of LC combination to estimated value (LC)
 - Match to MW-WL average value (WL)
 - Closeness of ionospheric delay to zero (less weight on longer baselines) (LG)
- Relative weights of LC, WL and LG can be set.
- Estimates are iterated until no more ambiguities can be resolved.

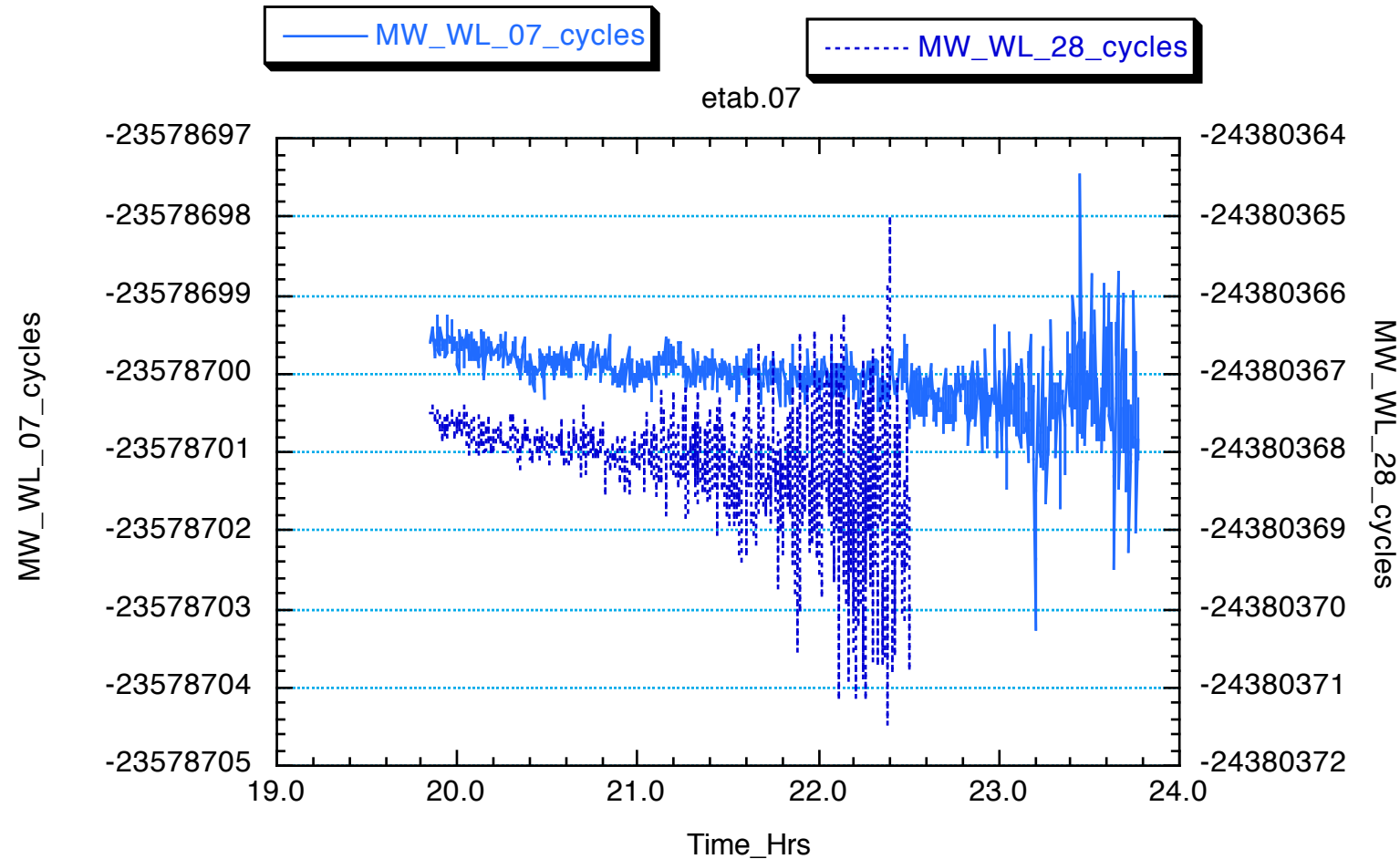
L1-L2 and Melbourne-Wubbena wide-lane

- The difference between L1 and L2 phase with the L2 phase scaled to the L1 wavelength is often called simply the wide-lane and used to detect cycle slips. However, it is affected by fluctuations in the ionospheric delay, which is inversely proportional to frequency squared.
- The lower frequency L2 has a larger contribution than the higher frequency L1
- The MW-WL removes both the effects on the ionospheric delay and changes in range by using the range measurements to estimate the difference in phase between L1 and L2

MW-WL characteristics

- In one-way form, as shown in next slide, the MW-WL does not need to be an integer or constant
- Slope in one-way is common, but notice that both satellites show the same slope.
- If same satellite-pair difference from another station (especially when same brand receiver and antenna) are subtracted from these results then would be an integer (even at this one station, difference is close to integer)
- The MW-WL tells you the difference between the L1 and L2 cycles. To get the individual cycles at L1 and L2 we need another technique.
- There is a formula that gives $(L1+L2)$ cycles but it has 10 times the noise of the range data and generally is not used.

Example MW-WL (PRN 07 and PRN 28)



Melbourne-Wubbena wide-lane (MW-WL)

$$mw - wl = \phi_1 - \phi_2 - \frac{(f_1 - f_2)}{(f_1 + f_2)} \left[R_1 f_1 / c + R_2 f_2 / c \right]$$

- Equation for the MW-WL. The term Rf/c are the range in cycles (notice the sum due to change of sign ionospheric delay)
- The $\Delta f / \Sigma f$ term for GPS is ~ 0.124 (for L1/L2) which means range noise is reduced by a about a factor of ten. (0.145 for L1/L5; Galileo)
- The MW-WL should be integer (within noise) when data from different sites and satellites (double differences) are used.
- However, receiver/satellite dependent biases need to be accounted for (and kept up to date) [tables/dcb.dat].

EX-WL extra-wide-lane

- The other measure of the difference in cycles between L1 and L2 used by track is the EX-WL (extra-wide-lane).

$$EX - WL = \phi_1 - \phi_2 \frac{\lambda_2}{\lambda_1} \quad ; \quad \frac{\lambda_2}{\lambda_1} = 1.28$$

- This measure is independent of geometry but is affected by the ionospheric delays. On short separations this measure is often more robust than the MW-WL.
- When we look at `track` bias fixing note that a 1 L1 and L2 slip (1/1 slip) changes the EX-WL by only 0.28 cycles (53 mm). (This is just 82 mm of L1 ionospheric delay, 0.5 TECU)

Basic inputs for `track`

- `track` runs using a command file
- The base inputs needed are:
 - “`obs_file`” specifies names of RINEX data files. Sites can be K kinematic or F fixed
 - “`nav_file`” specifies orbit file, either broadcast ephemeris file or SP3 file
 - “`mode air/short/long`” – “`mode`” command is not strictly needed but it sets defaults for variety of situations
 - Normally “`back_type smooth`” would also be specified.
- Normally start with just these commands and see how the run looks and based on this output start tuning `track`.

Basic use

- Recommended to start with above commands and see how the solution looks
- Usage: `track -f track.cmd >& track.out`

- **Basic quality checks:**

```
grep -E '^PRMS|TYPE' on summary file or track out (RMS by PRN in mm)
```

TYPE	Site	DT	ALL	02	05	08	10	15	21	26	29
PRMS	usn3	LC	7.0	9.4	3.6	10.5	7.9	7.5	7.2	3.9	3.5
TYPE	Site	DT	ALL	02	05	08	15	21	26	29	
PRMS	mitb	LC	7.2	8.3	3.7	11.0	6.5	8.4	3.6	4.5	
TYPE	Site	DT	ALL	02	05	08	15	21	26	29	
PRMS	rovr	LC	7.4	7.8	4.3	12.5	6.8	8.5	4.4	4.5	

```
grep 'Kinematic' track.out | head -n <number of sites>
```

```
TRACK Version 1.27 GPS Kinematic trajectory program
```

```
Kinematic site usn3 appears static Coordinate RMS XYZ 1.84 2.81 2.23
```

```
m, Apriori coordinates good: Diff XYZ -0.25 0.74 -0.17 m
```

```
Kinematic site mitb appears static Coordinate RMS XYZ 0.95 1.46 1.11
```

```
m, Apriori coordinates good: Diff XYZ 0.93 -1.77 1.70 m
```

```
Kinematic site rovr appears dynamic Coordinate RMS XYZ 17.84
```

```
18.26 17.40 m.
```

- The message is repeated during the run (thus the head above) but the RMS position drops to 0.00 for non-kinematic sites. This is a pseudorange solution so RMS will be high. Make sure sites behave the way you think they should.
- Check track.sum file for ambiguity status and RMS scatter of residuals.

track command line

```
% track -f <command file> -a <ambiguity file> -d <day> -w <week> -s  
<S01> <S02> .. <S10>
```

where <command file> is a required file containing a list of commands to control the program (see below)

<ambiguity file> is an optional file containing a modified set of integer bias parameters and settings (see full description below).

<day> the string in this argument replaces <day> in the command file lines (e.g., bas1<day>0.03o will become bas12220.03o if the -d 222 option is given.

<week> the string here will replace any <week> strings in the command file (useful for the nav_file name which could be a week of concatenated sp3 files.

<S01>, <S02> .. <S10> are up to 10 strings that can be replaced in the command file i.e. the string <S01> in the command file will be replaced by the first string, <S02> by the second and so on. If one of the strings is called space (all lower case), the corresponding <SXX> entry will be replaced by a blank character (This provides a means to un-comment lines)

Basic use: Things to check

- Check on number of ambiguities (biases) fixed
`grep 'FINAL' <summary file>`
- A 3 in column “Fixd” means fixed, 1 means still floating point estimate
- If still non-fixed biases or atmospheric delays are estimated then smoothing solution should be made (“back_type smooth”)
- Output in NEU, geodetic, DHU, XYZ coordinates. NEU are simple north and east distances and height differences from fixed site. (Convenient for plotting and small position changes). DHU is similar, but differences are from the a priori coordinates of the site.

More advanced features

- `track` has a large help file which explains strategies for using the program, commands available and an explanation of the output and how to interpret it.
- It is possible to read a set of ambiguities in.
 - Works by running `track` and extracting “FINAL” lines into an ambiguity file. Setting 7 for the `Fixd` column will force fix the ambiguity. Ambiguity file is then read into `track` (`-a` option or `ambin_file`)

Advanced features

- Commands allow control of how the biases are fixed and editing criteria for data
- Editing is tricky because on moving platform, jumps in phase could simply be movement
- Ionospheric delay and MW-WL used for editing.
- Explicit “edit_svs” command
- Explicit add and remove bias flags

Main tunable commands

- BF_SET <Max gap> <Min good>
 - Sets sizes of gaps in data that will automatically add bias flag for possible cycle slip. Default is 1, but high rate data often misses measurements.
- ION_STATS <Jump>
 - Size of jump in ionospheric delay that will be flagged as cycle slip. Can be increased for noisy data
- FLOAT_TYPE <Start> <Decimation> <Type> <Float sigma Limits(2)> <WL_Fact> <Ion_fact> <MAX_Fit> <RR>
 - Main control on resolving ambiguities. Float sigma limits (for LC and WL) often need resetting based on data quality.
 - <WL_Fact> <Ion_fact> control relative weights of WL and LG chi-squared contributions.
 - RR is relative rank tolerance
- Fcode in output is diagnostic of why biases are not resolved.

Other common commands

- `USR_ADDBF <site> <prn #> <time (ymdhms)>`
 - Allows user to add a bias file at site <site> for PRN <prn #> at time <time>. First valid measurement at or after time will be flags.
- `USR_DELBF <site> <prn #> <time (ymdhms)>`
 - Allows user to delete a bias file at site <site> for PRN <prn #> at time <time>. The time must match within 50% of sampling interval.

track output files

- `track` outputs progress directly to the screen and this output can be re-directed with `>` to a file. (Generally `track_xxx.out`)
- Summary file (`track.sum` by default)
- Position files (`NEU,GEOD,DHU,XYZ`)
- Phase residual files (optional)
- Wide-lane value files: (optional, sometime useful if cycle slip missed)
- Meaning of output entries discussed in help file.

Summary file

- This file is a short summary of the run. It lists
 - Files and parameters that were used for the run
 - Process noise values
 - Any editing specified by the user
 - FINAL bias flag report. The Fixd column indicates if the bias was fixed (denoted by value 3).
 - Summary of residual scatter as function of site and satellite and versus elevation angle (These are RMS differences from fixed station)
 - Generally residual RMS should be less than 10 mm although values up to 20 mm can be OK.

Output file from `track`

- `track` outputs extensive information during its run.
 - The initial output is status during reading of the RINEX files. Errors in the files are reported here and a summary of satellites seen.
 - Most common problem here is no sampling rate given in RINEX file. Command `INTERVAL` needs to be used.
 - An initial pseudorange solution establishes the trajectory of the kinematic sites and statistics on differences from apriori coordinates and RMS scatter of trajectory are given.
 - Bias flags being added due to jumps in wide-lanes are reported.
 - Bad apriori coordinates can lead to “BAD PREFIT” data (see “`site_pos`”)

Output continued

- Summary of bias flags needed with estimates of numbers of cycles. These are reported by site, satellite and epoch range. Initial set are labeled INITIAL.
- Estimates of mean MW-WL and mean ionospheric delay (EX-WL) along with sigma estimates are given. (A correlation time is assumed in the sigma calculation).
- Dependences of biases are given with the “DD bias refs” entries. Although listed as one ways, values are double differences.

Output continued

- Iteratively, `track` tries to resolve the ambiguities to integer values.
 - Floating point estimates of the biases as they are estimated.
 - RMS fit of the double difference residuals
 - Any bad double differences are reported and removed (repeating values can be indication of missed cycle slip).
 - Bias flag fixing report: Fix column (T or F) indicates if bias was successfully fixed. The Fcode column indicates why it was not fixed.
- This sequence is repeated until an iteration when no new biases are fixed.
- The final position estimates are then computed and output in the requested formats.

Fcode Interpretation

- For float_type LC the Fcode is
- S -- Floating point estimate sigma too large (Sig Limit)
- W -- MW WL sigma too large
- R -- Relative rank not large enough
- C -- Chi**2 increment too large for the best choice of ambiguities
- O -- One other bias in the double differences not fixed yet.

* BF	S	PRN	Epoch	Range	F	Estimate	dLC	Sig	Limit	Relative	Rank	Fix	Fcode	Change	L1	L2	Residual	L1
L2	Fits	Best	LC	WL	LG													
175	5	PRN 15	1	43	1	1.86 +-	0.24	SL	0.25	RR	2.36	F F	--R--	dL1,2	3	3	dL12	0.31
-0.08	Fits	11.7	0.8	0.3	105.7													
48	2	PRN 07	1	429	1	-0.16 +-	0.74	SL	0.25	RR	9660.51	F F	S---O	dL1,2	0	0	dL12	-0.28
-0.02	Fits	0.4	0.1	0.1	2.1													

Improving ambiguity resolution

- The Fcodes can indicate how to fix ambiguities that `track` by default is not able to fix.
- Common fixes:
 - S and W indicate that the estimated sigmas on the float estimates and/or MW-WL are too large. If the relative ranks are large, the the sigma tolerances can be increased with the “float_type” command,
 - If ambiguities seem to have the same value then “usr_delbf” can be used to remove an extra one but care should be taken because some receivers can have 1/1 L1 L2 cycle slips.
 - Chi-squared increments may be too large (especially LG (ionosphere) and sometimes WL so, by down-weighting in the “float_type” command, relative rank can be improved.

Input ionospheric delay model

- Version 1.26 and greater of `track` have the ability to read a gridded ionospheric delay model. The format of this model is expected to match the current IGS global ionospheric models available from <https://cddis.nasa.gov> (requires authentication) in the `archive/gnss/products/ionex/<yyyy>/<ddd>` directory.
- `IONEX_FILE <file name>`
invokes the features. The EX-WL estimates are affected by this model and its inclusion should help ambiguity resolution on long baselines (> 100 km).

Use of input ambiguity file

- For certain analyses, it can be useful to manually supply ambiguity file to track using either the `-a` option or the “amb_file” command.
- The ambiguity file can be generated by `grep`'ing “FINAL” in the track summary or output file and re-directing into a file

Recently added commands (1.40+)

- Version 1.40 (10.71 release) has new commands:
- USE_BLQ Turns on ocean tide model and requires <site>.BLQ files be available (These files are same format as site dependent tide model files in GAMIT. There are options to turned Solid Earth tide on and off as well.
- ATM_MODLEC (replaces use_gptgmf command) allows different atmospheric delay models to be used including VMF1 grid models.
- RINEX 3 data file support with the option to explicitly name primary and secondary phase and range observables (3-char codes).

Other tunable parameters

- Process noise to be used if the atmospheric delay is variable
 - If noise is too large, then height estimates and atmospheric delay estimates are highly correlated
 - If noise is too small, then atmospheric delay variations map into height variations
 - For aircraft, `track` now has process noise that depends on the rate of change of altitude.
 - Units of process noise are random-walk change in meters per unit time (standard deviation grows as square of number of epochs), where the default unit time is the sampling interval, but the unit can be set with the “`time_unit`” command

track commands: “Rules”

- `track` command files share the properties as GLOBK command files:
 - All command lines must start with a less one blank space; arguments are separated by spaces
 - Order of commands is generally not important except that later versions of a command replace the previously assigned arguments
 - Site dependent commands in `track` issue the command name first and then lines that contain station names and arguments (all is a valid name).

Plotting `track` results

- `sh_plot_track` is a script (using GMT) that can plot `track` results. Features are still being added to this script.
- For quick plots we use the GAMIT/GLOBK X-windows program `cplotx`.
- We also use Matlab and GMT
- Output files are ASCII with a variety of time tags (YY MM DD HR MIN SEC, Fractional Day and Epoch number)

Final comments

- The most common parameters that need to be changed in `track` are:
 - The data gap that will automatically be treated as a cycle slip (default is 1) but most high rate data (≥ 1 Hz) has gaps due to recording problems.
 - The sigma limits for the LC estimate and MW-WL estimates often need to be increased. `track` has a correlation time in sigma calculation that for the default setting can make the sigmas too large.
 - Make sure antenna and receiver information (if mixed) are correct.
 - Treatment of the atmospheric delay. There is a high correlation between the atmospheric delay and height when both are stochastic (“RhoUA” column in output time series).
 - Weight for the EX-WL (effected by the ionosphere) on long baselines and when the ionosphere is active. “`ionex_file`” command may help.