12.540 Principles of the Global Positioning System
Lecture 22

Prof. Thomas Herring

Kinematic GPS

- The style of GPS data collection and processing suggests that one or more GPS stations is moving (e.g., car, aircraft)
- To obtain good results for positioning as a function of time requires that the ambiguities be fixed to integer values
- Track is the MIT implementation of this style of processing

Styles of kinematic GPS

- Kinematic GPS techniques go by a number of names with features that are often receiver specific.
  - Kinematic GPS: Early term which implies that there is no loss of lock while the receiver is moving. In survey mode, if loss of lock occurs the antenna must be returned to a point of known location.
  - Rapid Static GPS: Technique that uses range and phase to resolve ambiguities. No need to maintain lock while receiver moving. Surveying where position during static portion all that is needed.
  - RTK Real-time kinematic: Kinematic solution with real-time radio telemetry link. Analysis is done on-the-fly. Very popular now with surveyors because results know instantly.

General aspects

- The success of kinematic processing depends on separation of sites
- The MIT software allows multiple stations to be used in the positioning (may by kinematic or static)
- For separations < 10 km, usually easy (most RTK systems work at these distances).
- 10>100 km more difficult but often successful. Depends on quality of data and ionospheric activity.
- >100 km very mixed results

Issues with length

- As site separation increases, the differential ionospheric delays increases, atmospheric delay differences also increase making modeling of phase data more difficult
- For short baselines (<10 km), ionospheric delay can be treated as ~zero and L1 and L2 resolved separately
- For longer baselines this is no longer true and ambiguities must be resolved with LC (and often the MW WL L1-L2 number of cycles)

Track features

- Track uses the Melbourne-Webena Wide Lane to resolve L1-L2 and then a combination of techniques to determine L1 and L2 cycles separately.
- For short baselines uses a search technique and floating point estimation with L1 and L2 separately
- For long baselines uses floating point estimate with LC and ionospheric delay constraint

Ambiguity resolution

- Basic problem is determine the integer number of cycles in the carrier phase double differences.
- Two generic classes of approach:
  - Searching methods: Two basic types
    - Search over integer ambiguities checking RMS fit of phase residuals
    - Search over position, minimizing a fit function that does not depend on integer part of ambiguity (e.g.. Cosine of phase residuals)
  - Estimation and then resolution using statistical testing.

Statistical Resolution

- The most common method now is estimation with statistical assessment of fitting to integer.
- Generic classes of cases:
  - NNNNN.01±0.01 Pretty clearly can be resolved
  - NNNNN.35±0.40 Highest probability answer is NNNNN but NNNNN+1 also has >10% of being correct. Since 10-100 ambiguities need to be resolved 1-10 of them would be incorrect in the above case.
  - NNNNN.01±0.55 clearly close to an integer but +1 value also very likely
  - NNNNN.35±0.01 should be resolvable to integer but value is far from integer,

Statistical resolution

- Uncertainties of ambiguities are always uncertain. Formal estimates come for inversion but these depend on data noise characteristics (most importantly correlations in data).
- Many kinematic surveys done with high sampling rates (0.1-1Hz) so white noise assumptions generate very small error estimates.
- Most testing methods use a “contrast” or “ratio” style test (ie., ratio of χ^2 with best and next best choice of ambiguities and an impact on χ^2 of setting the value to an integer. Covers last case shown--no integer seems correct implying modeling errors.)

LAMBDA Method

- In addition to individual values: Each ambiguity that is resolved, effects other estimates and thus there is a cascading effect.
- The LAMBDA Method tries to account for these correlations by projecting the ambiguities into an orthogonal space. (Use of eigenvectors and eigenvalues discussed in earlier classes).
- Method is from a linear operator that preserves integer values and transforms ambiguities so that estimates are nearly un-correlated. (Eigenvectors would make estimates uncorrelated, by integers would not be preserved).

Magnitudes of effects of ambiguities

- Basic changes in phase with ambiguities

$$\Delta LC = \frac{1}{1-(f_2/f_1)^2}N_1 - \frac{f_2/f_1}{1-(f_2/f_1)^2}N_2 = 2.54N_1 - 1.98N_2$$

$$\Delta LG = -(f_2/f_1)N_1 + N_2 = -0.78N_1 + N_2$$

- Notice that N1=N2=1 (not detectable in the MW Widelane) cause a change of 0.56 cycles in LC and only 0.22 cycles in LG (variations in LG can be several cycles)
- Combinations such as N1=3, N2=4 and N1=4 and N2=5 can cause small effects in LC (ie., geodetic fit looks good but ionospheric delay in error: if small can be detected but when large can be difficult).

Cycle slip detection in kinematic processing

- Detecting cycles slips can be difficult in kinematic processing because of vehicle movement. Normally in static GPS, coordinates are well enough known that changes on phase (LC combination) between epochs of data can be used. If a change is larger an a tolerance level (usually 0.2 to 0.5 cycles) then a cycle slip is detected.
- Cycle slips are resolved to integers to fitting with simply polynomials across the epoch with the jump.
- In kinematic processing this is much more difficult because the position of the moving receiver is not known.

Cycle slips

- Large jumps can be detected by using the pseudorange position estimate. In some cases,Doppler shift is also available and can be used.
- Small slips (just a cycle or so can be difficult). More common than expected because the receivers try to fix cycle slips and they often get it wrong be a small amount (slips based in SNR).
- MW WL and ionospheric delay jumps are common methods but can still leave slips un-detected.

Basics of MIT track program

- 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 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

Basic track use

- Recommended to start with above commands and see how the solution looks
- Usage: track -f track.cmd >&! track.out
- Basic quality checks:
- grep RMS of output file
  - Kinematic site rovr appears dynamic Coordinate RMS XYZ 283.44 662.53 859.17 m.
  - For 2067 Double differences: Average RMS 17.85 mm

Basic track use and evaluation

- Check on number of ambiguities fixed
  - grep FINAL output file
  - A 3 in column Fixd means fixed, 1 means still floating
- If still non-fixed biases or atmospheric delays are estimated then smoothing solution should be made (back_type smooth)
- output in NEU and/or geodetic coordinates

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)

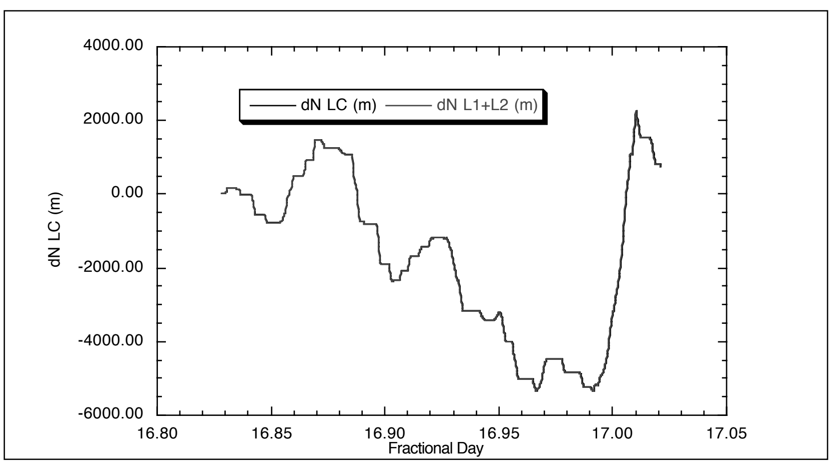
Advanced features

- 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
- Ion delay and MW WL used for editing.
- Explicit edit_svs command allows removal of problematic data

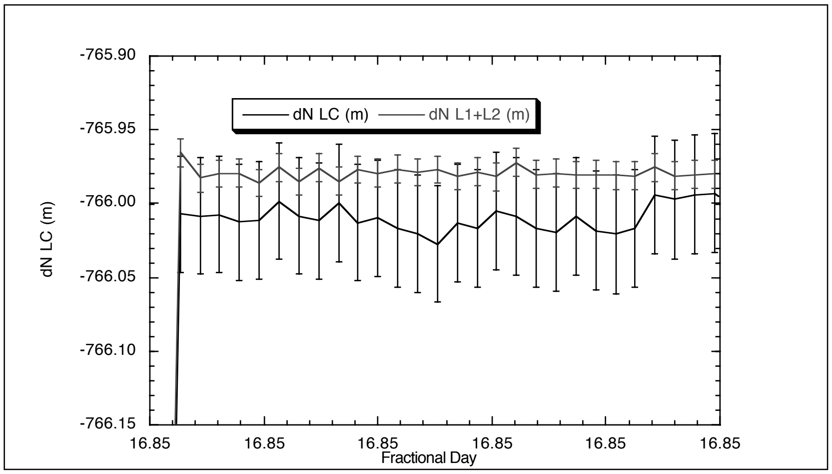
Some results

- Examine results from phase processing of homework #3.
- Solutions with LC and with L1+L2 (less noise but larger ionospheric delay.
- Output of processing in track.016f.out
- Solutions in North, East Up differential position from etab: d016f.NEU.rovr.LC and d016f.NEU.rovr.L1+L2

North Evolution



Zoom of features



Summary

- Track is still developmental and performance depends on quality of GPS data
- For short baselines it usually works well, for longer baselines it can be difficult
- see $HELP_DIR/track.hlp for more details.
- There are frequent updates to the program