Static and Kinematic Precise Point Positioning with gd2p.pl (GNSS Data 2 Position)

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Introduction to gd2p.pl

- gd2p - GNSS data 2 Position
- High Level Gipsy interface for processing data from a single GPS receiver (or GLONASS).
  - gd2p.pl is the preferred black box for single receiver data
  - Easy to make changes to existing run, (e.g. run_again)
  - Better error detection
    - Small output to STDERR with early detection of errors.
  - Static Point Positioning
  - Kinematic Point Positioning
    - Use care in initialization

Examples of gd2p Applications

- Precise point positioning: static and kinematic
  - Single receiver ambiguity resolution (gd2p.pl with wlpb files.)
    - Resolves integer biases in phase measurements to improve accuracy.
  - Network solutions using smapper and resolvemerged.
    - Described in Release Notes for version 6.1.2.
- Troposphere estimation.
- Automatic Precise Point Positioning Service (APPS).
  - http://apps.gdgps.net
- Precise orbit determination.
  - Low Earth Orbiters
    - Used operationally for Jason-1, GRACE, CHAMP, SACC, COSMIC, Jason-2.
- Past applications also include:
  - Shuttle Radar Topography Mission.
  - Antarctic Ice Flow Studies

Help for gd2p Flags

- gd2p.pl –h | more
  - Gives the entire help/man; written in POD (Plain Old Documentation)
- gd2p.pl –h_sub
  - Gives a listing of subtopics.

  -h_global – Help on flags that apply to multiple steps

  -h_edit – Help on editing data

  -h_model – Help on qregres/measurement model

  -h_wash – Help on filter/smoother

  -h_orbit – Help on orbiter solution options

  -h_examples – Example runs

  -h_files – Input/output file information

  -h_env – Help on environment variables
- **Beginners should start with –h_examples.**

Point Positioning Examples from gd2p.pl –h_examples

- gd2p.pl –h_examples | more
  - Yields many examples

- 5-minute data, static position, nominal position from the station database ($GOA_VAR/sta_info), troposphere, clock, and position adjusted.
  - **Same example from GIPSY Overview package.**

  (gd2p.pl -i $GOA/class_gd2p/gol20100.10o -n GOL2 -r 300 -type s –d 2010-01-10 > gd2p.log) > & gd2p.err &

  - Simple command to automatically invoke the necessary GIPSY modules and to generate the required input namelist files.
  - Motivating reasons for gd2p.
    - Point positioning should be simple.
    - Input RINEX and output precise point position solution.

gd2p flag Details

- Details on flags are easy to find in the help.
  - **gd2p.pl –h | more**
  - Search for "-*flag*" where *flag* is the appropriate string.

  - For example, if you look for –tides:

-tides [WahrK1 PolTid FreqDepLove OctTid]

Adds solid tide models to the station qregres namelist.

Default tide model includes WahrK1 and PolTid. WahrK1 is a subset of FreqDepLove. Any input will override the default values with the input list. To turn off all the solid tides just use the option with an empty list (e.g., -tides).

gd2p Files (-h_files)

- gd2p produces many files.

  gd2p.pl –h_files | more
- **Also refer to GIPSY Overview package for description of many of these files.**

Defining a Base Working Directory for Examples

- In this package, examples assume a working directory defined by the user with **absolute** path name: ***WORKDIR***.
- Examples will be relative to this user-defined working directory.

mkdir *WORKDIR*

cd *WORKDIR*

Fetch JPL Orbit/Clock Products for Examples

- gd2p.pl by default will fetch orbit/clock products from JPL's host server.
  - See –orb_clk flag.
- To avoid ftp fetch for same products, download files needed for examples one time only.

mkdir jplorbclk

cd jplorbclk

goa_prod_ftp.pl -d 2010-01-10 -s flinnR –hr

– Or copy output from example from $GOA:
cp $GOA/class_gd2p/orbits_forclass/* .

ls

2010-01-10.ant.gz 2010-01-10.frame.gz 2010-01-10.pos.gz 2010-01-10.tdp.gz
2010-01-10.eo.gz 2010-01-10_hr.tdp.gz 2010-01-10.shad.gz 2010-01-10.wlpb.gz

Example 1: Receiver Position and Clock Only

- Basic example, adjusting position and clock only.
  - **WARNING: NOT advisable to ignore troposphere.**
    - **This example is just a starting point for other examples.**

cd ..

mkdir spp1

cd spp1

(gd2p.pl –i $GOA/class_gd2p/gol20100.10o -n GOL2 -d 2010-01-10 -r 300 -type s -w_elmin 15 -e "-a 20 -PC –LC -F” -pb_min_slip 1.0e-3 -pb_min_elev 30 -amb_res 2 -dwght 1.0e-5 1.0e-3 -post_wind 5.0e-3 5.0e-5 -trop_z_rw -1.0 –tides –orb_clk “flinnR *WORKDIR*/jplorbclk” > gd2p.log) >& gd2p.err

  - Could also use defaults for many of these options.
    - Defaults intentionally not used to highlight options.

Example 1: Summary of options used.

Option	Description (Required options in bold, others have defaults)
-i	**Input RINEX file**
-n	**Name of Receiver**
-d	**Day to process. Used to define daily orbit/clock product to use.**
-r	Measurement data rate to output from data editor for the filter.
-type	Type of positioning (s for static, k for kinematic)
-w_elmin	Minimum elevation angle cutoff. (usually 7 or 15 degrees)
-e	Quoted string of flags to pass to data editor. This example says used minimum arc length of 20 minutes, LC and PC data
-dwght	**Phase and range** data weights in km. Usually LC=1 cm and PC=1 meter.
-post_wind	Final postfit **range and phase** window in km for edit point cycle. (5-sigma)
-pb_min_slip	Minimum slip for inserting phase break in postbreak (km)
-pb_min_elev	Minimum elevation angle at which postbreak criteria are applied.
-amb_res	Number of iterations for ambiguity resolution with wlpb file.
-trop_z_rw	Random walk parameter for zenith troposphere. Negative means not estimated.
-tides	Tide models to apply to station model. Empty list means no tides modeled.
-orb_clk	Defines type and location of orbit and clock products for transmitting satellites.

Be Careful of Reverse Order

Example 1: Which Orbit/Clock Products

- gd2p defaults to automatically downloading and using JPL's final (flinnR) orbit/clock products.
  - Equivalent to using –orb_clk flinnR option.
  - In this example, pointed to a local directory containing required "flinnR" orbit/clock products.
- Will automatically apply transmitter antenna calibrations identified in YYYY-MM-DD.ant.gz file in product package for that day.
- Other possibilities:
  - Use JPL's Rapid (qlR) or Ultra-Rapid products (ultra)
  - Explicitly point to a local archive of products with the same naming convention of the product type.
  - See –orb_clk option.

Example 1: Useful output from gd2p

- *gd2p.log* provides summary of GIPSY modules executed.
- gd2p.err provides summary of any error or warning messages.
- *logs* directory provides output logs from some of the executed GIPSY modules.
  - **Refer to GIPSY Overview for more details about executed modules.**
- *run_again* script created by gd2p.pl.
  - Can be used to duplicate this run exactly with all options used, e.g.,

    cat run_again
  - Could either edit this file or make a copy, modify options, and re-run.
    - Will do this in following gd2p examples.

Example 1: First look at run

- First sign of trouble is existence of file "EDIT_POINT_FAILURE"
  - The edit point "wash" cycle failed to converge.
  - See also gd2p.err

  cat gd2p.err

    - Indicates edit point failed to converge.

- Potential sign of trouble is large phase (LC) post-fit residuals and large number of phase (LC) outliers.
  - Typical LC RMS of residuals is < 1 cm.
  - Typical PC RMS of residuals is 20-80 cm.

  cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	1.5847E-05	1938	230
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.8335E-04	2168	0

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Example 1: Check postfit residuals

- Generate tables of LC and PC postfit residuals.

  residuals.pl

  cat residuals.txt | awk '{if ($4 == 120) print $0}' | cl h1 5 > spp1_lc_res.txt

  cat residuals.txt | awk '{if ($4 == 110) print $0}' | cl h1 5 > spp1_pc_res.txt

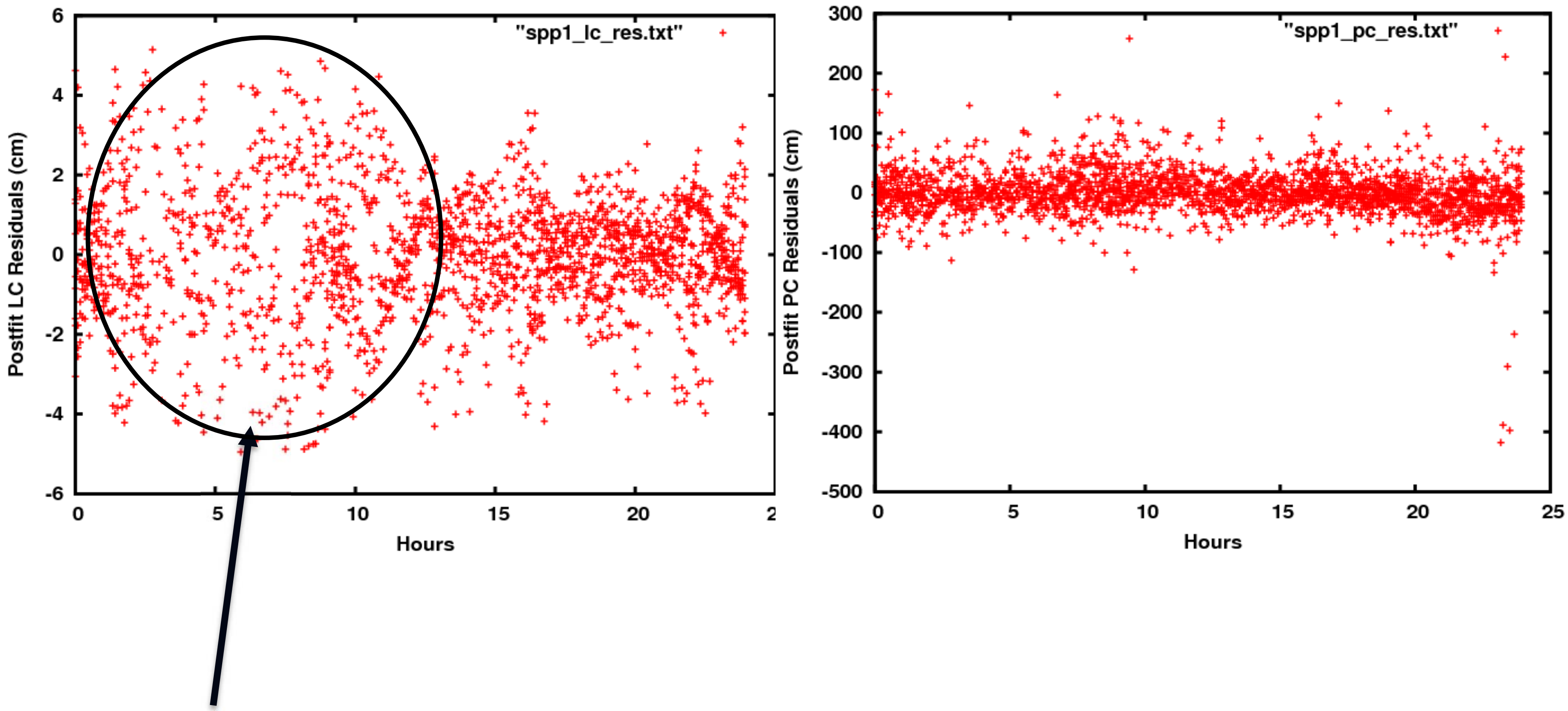
  - Same approach used to generate sppN_XX_res.txt files for future examples.
  - NOTE: **cl h1 5** equivalent to **cl '(c1-f1)/3600' 5**
    - hN means use column N to determine time in hours with respect to time on first line.

- Generate plots of LC and PC postfit residuals.

  gnup –p spp1_lc_res.txt –xl 'Hours' –yl 'Postfit LC Residuals (cm)'

  gnup –p spp1_pc_res.txt –xl 'Hours' –yl 'Postfit PC Residuals (cm)'

Example 1: Plots of postfit residuals



- Higher residuals in first half of the day are suspicious.
- cm-level LC residuals is higher than expected.

Example 1: Where is the solution

- Note: Two solutions actually generated by gd2p because non-zero –amb_res option used.
  - 1: Pre-ambiguity resolution solution.
    - Post-fit RMS of residuals in Postfit.sum, and solution in tdp_final_pre_amb
  - 2: Post-ambiguity resolution solution.
    - Post-fit RMS of residuals in Postfit_amb.sum, and solution in tdp_final
- TDP files (tdp_final, tdp_final_pre_amb) provide all parameters that were adjusted (estimated) from the provided nominals.
  - Nominal (provided first guess) in column 2.
  - Solution (sum total of nominal and estimated adjustment) in column 3.

Example 1: Content of TDP file

- TDP files indicate which parameters were estimated.
  - Minimum set of parameters in static PPP gd2p run:
    - Receiver clock defined by **STA BIAS (km)**
    - Phase biases defined by **PB GPSXX (km)**
    - Station position in **STA X, STA Y, STA Z (km)**
  - Anything else?

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]"
  - Only dummy parameter left, "DUM", used by filter.

Example 2: Add zenith troposphere estimation

- Add estimation of zenith troposphere.

  cd ..

  mkdir spp2

  cd spp2

  cp ../spp1/run_again r2 # Copy run_again, and modify as needed.

  – Edit script r2, and change zenith troposphere line to:

  -trop_z_rw 5.0e-8 \

  – Experience has shown recommended random walk value of 5.0e-8 km/sqrt(sec) for static positioning.

  – Execute script

    ./r2

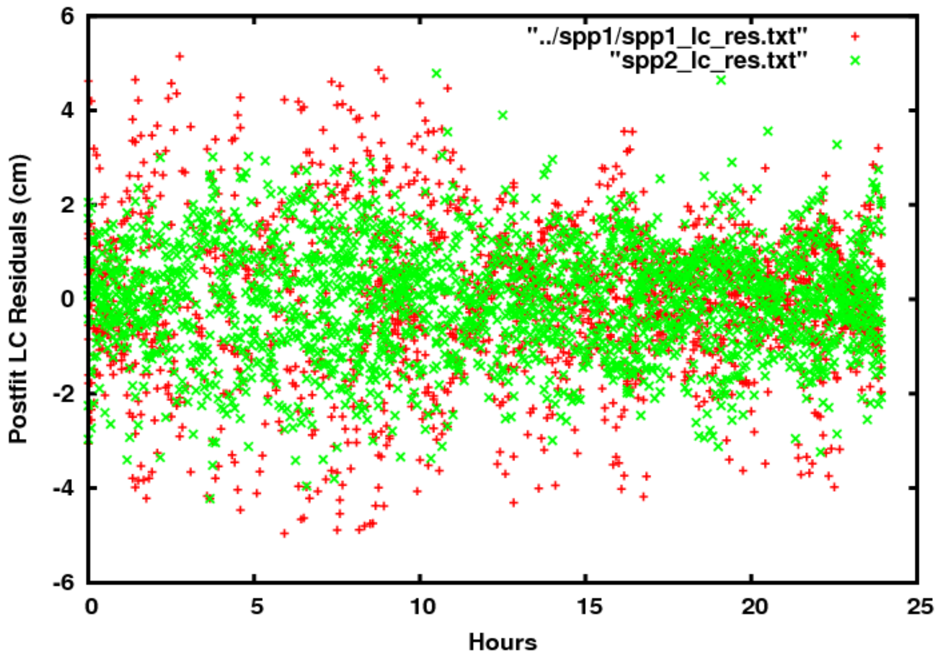
Example 2: First look at run

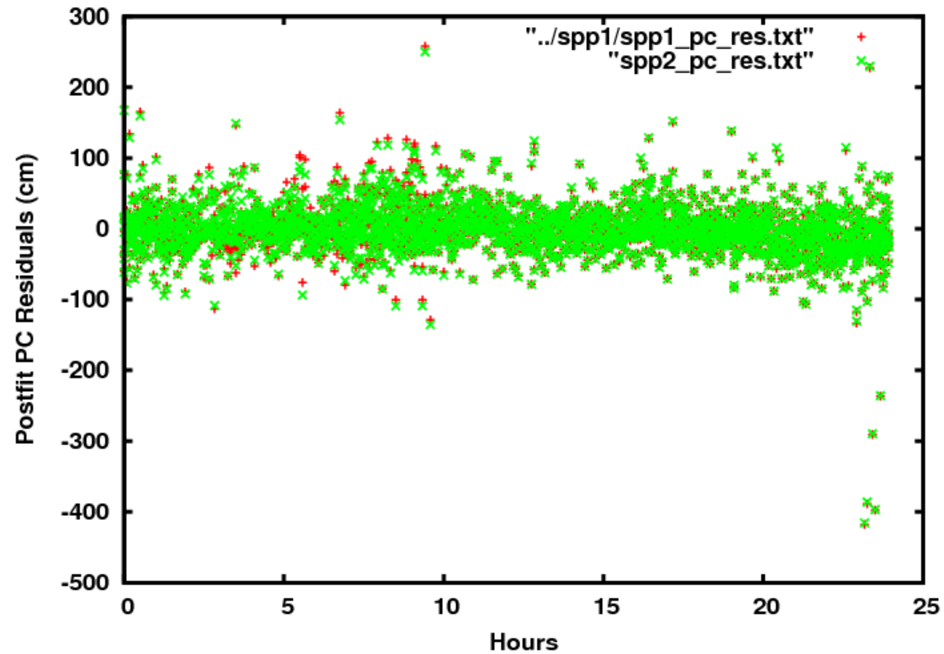
- Edit point cycle seems to have converged – Good news.
  - No "EDIT_POINT_FAILURE" file.
  - No errors in gd2p.err file.
    - Just some warnings that the regres file (rgfile) was modified from its original qregres output.
      - Expected with outlier editing and ambiguity resolution.
- Postfit phase (LC) residuals are significantly smaller AND many fewer outliers.
  - Estimating more parameters (troposphere) might explain smaller residuals, but still good news.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	1.1738E-05	2157	11
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7924E-04	2168	0

Example 2: Plots of postfit residuals





gnup -p ../spp1/spp1_lc_res.txt spp2_lc_res.txt -xl 'Hours' -yl 'Postfit LC Residuals (cm)’

gnup -p ../spp1/spp1_pc_res.txt spp2_pc_res.txt -xl 'Hours' -yl 'Postfit PC Residuals (cm)'

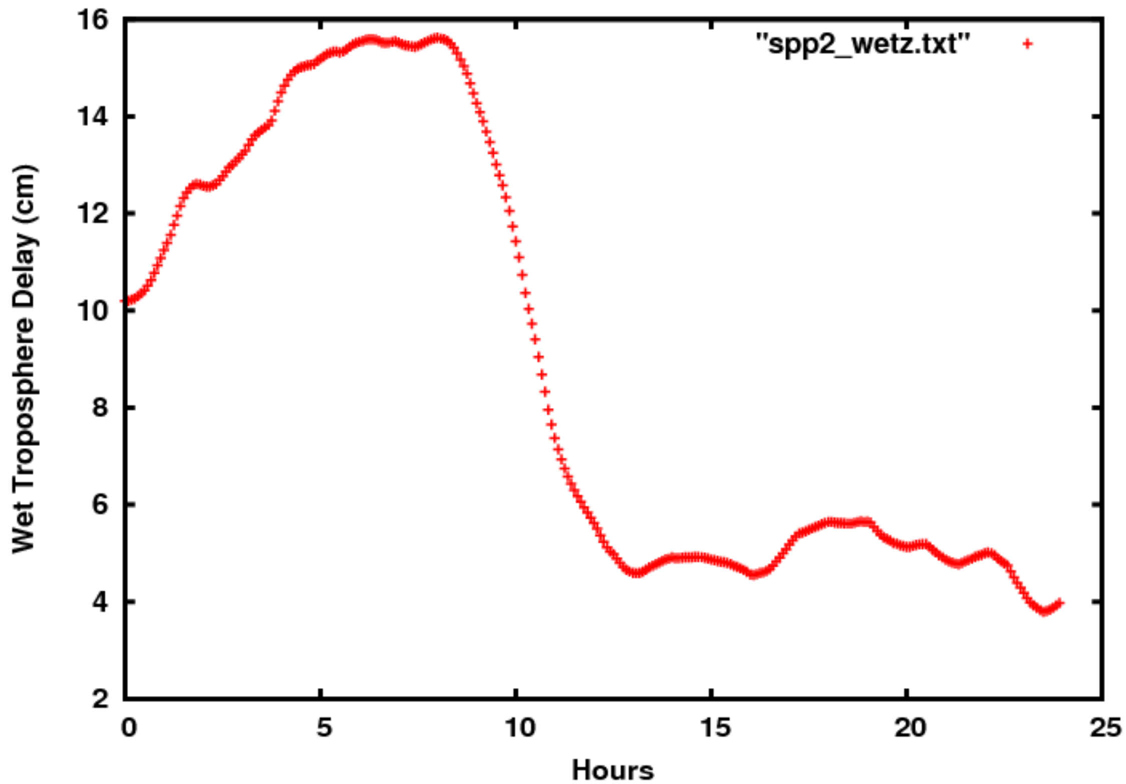
- Scatter of residuals improved in first half of day.
  - Probably have wet troposphere conditions.

Example 2: Plot Troposphere Solution

Units of troposphere parameters in tdp file is m. All other parameters use km.

grep WETZ tdp_final | cl h1 '1.0e2*c3' > spp2_wetz.txt

gnup -p spp2_wetz.txt -xl 'Hours' -yl 'Wet Troposphere Delay (cm)'



Example 2: What changed?

- Compare qregres namelists from Examples 1 and 2.

  diff qregres.nml ../spp1/qregres.nml

  – No changes, except generation time.

  – Means that none of the models changed.

- Compare wash namelists from Examples 1 and 2.

  diff wash.nml ../spp1/wash.nml

```
<      WETZTROP  = .TRUE.
<      TROPDRIFT = 5.0e-8
---
>      WETZTROP  = .FALSE.
>      TROPDRIFT = -1.0
```

  – Zenith troposphere estimation turned on in example 2.

Example 2: First look at solution

- What were the additional parameters estimated?

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]"

  – Zenith troposphere estimates, **WETZTROP**, now in TDP file.

  – WETZTROP has units of meters.

  – **NOTE: This parameter includes zenith wet troposphere and any error in the nominal value of the dry troposphere.**

  – Nominal value of dry troposphere for this run is 2.0507 meters.

    - More on this later.

  grep DRY qregres.nml

  NMLTROP_DRY(1) =   2.0507

  – NOTE: Default NIELL troposphere mapping function used in run.

    - Maps line-of-sight to zenith.

  grep NMLTropMap qregres.nml

  NMLTropMap(1) = 'NIELL'

Example 3: Use Tide Models

- Add solid Earth tide models for station position.

  cd ..

  mkdir spp3

  cd spp3

  cp ../spp2/run_again r3 # Copy run_again, and modify as needed.

  – Edit script r3, and change tide models line.

  -tides WahrK1 FreqDepLove OctTid PolTid \

  – WahrK1, FreqDepLove, and OctTid invoke complete solid Earth tide models from IERS standards.

    - Note: WahrK1 is just a subset of FreqDepLove

  – PolTide invokes solid Earth pole tide from IERS standards.

  – Execute script

    ./r3

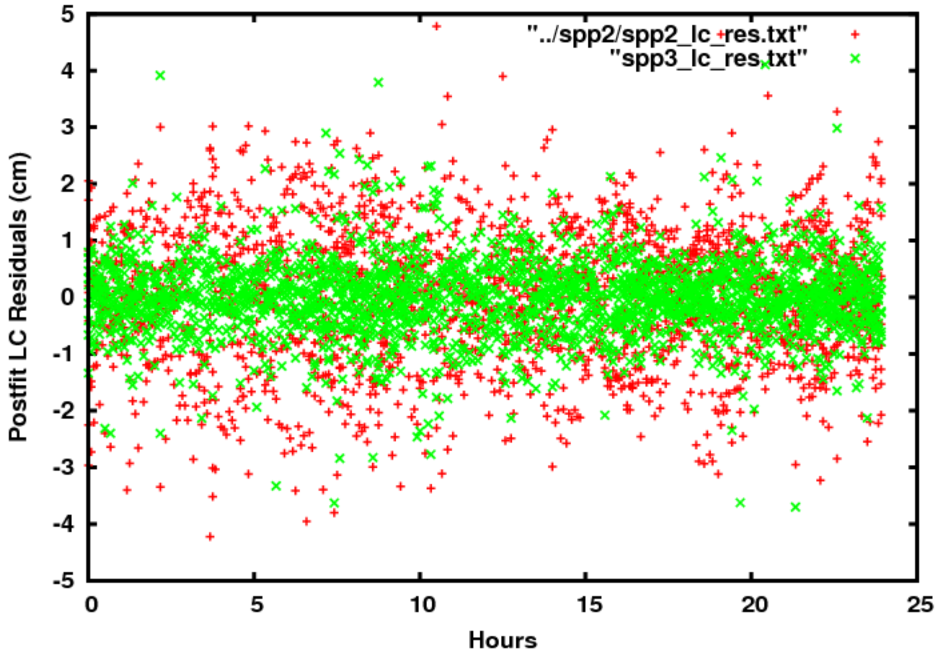
Example 3: Looking at run

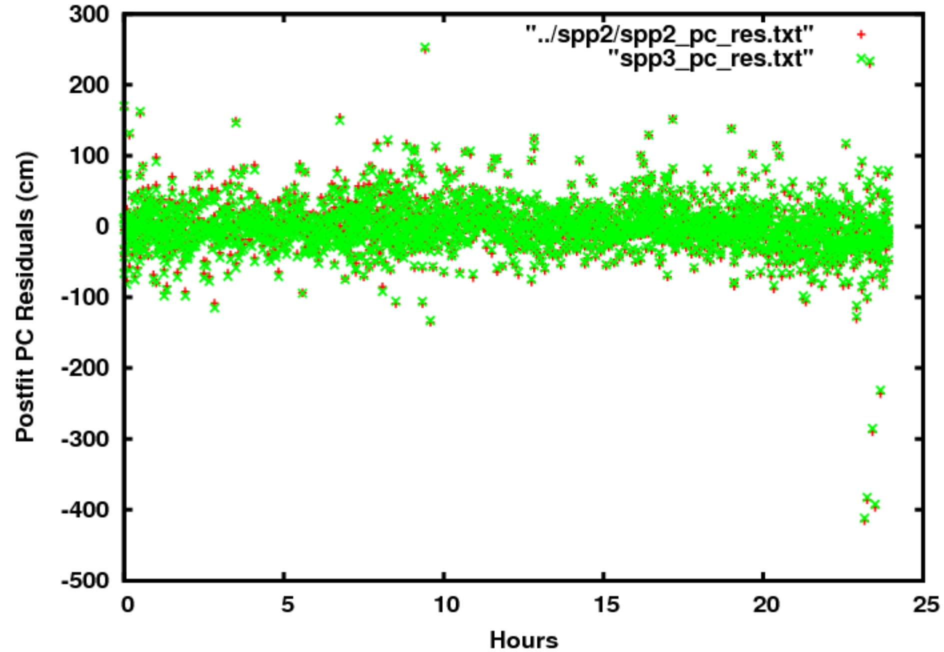
- Edit point cycle converged – Good news.
  - No “EDIT_POINT_FAILURE” file.
  - No errors in gd2p.err.
- Postfit phase (LC) residuals are significantly smaller AND fewer outliers.
  - No additional parameters estimated, so smaller residuals and fewer outliers indicates tide models are helping.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.8493E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7494E-04	2168	0

Example 3: Plots of postfit residuals





gnup -p ../spp2/spp2_lc_res.txt spp3_lc_res.txt -xl 'Hours' -yl 'Postfit LC Residuals (cm)'

gnup -p ../spp2/spp2_pc_res.txt spp3_pc_res.txt -xl 'Hours' -yl 'Postfit PC Residuals (cm)'

- Reduced (improved) scatter of LC residuals.

Example 3: What changed?

- Compare qregres namelists from Examples 2 and 3.

  diff qregres.nml ../spp2/qregres.nml

  ```
  <  NMLFreqDepLove = .TRUE.
  <  NMLOctTid = .TRUE.
  <  NMLPolTid = .TRUE.
  ---
  >  NMLSolidTideOn( 1 ) = .FALSE.
  ```

  – Solid earth tide models turned on in example 3.
    - WahrK1 not explicitly found because it is a subset of FreqDepLove.

- Compare wash namelists from Examples 2 and 3.

  diff wash.nml ../spp2/wash.nml

  – No differences.
    - No change to estimation strategy.

Example 3: First look at solution.

- Verify no additional parameters estimated:

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]” | grep –v “WETZ”

  – Only dummy parameter left, “DUM”, used by filter.

Example 4: Add ocean load tide model

- Add ocean load tide model for station position.

cd ..

mkdir spp4

cd spp4

cp ../spp3/run_again r4 # Copy run_again, and modify as needed.

– Edit script r4, and add two lines.

-add_ocnld \

-OcnldCpn \

– Execute script

./r4

Example 4: Ocean load tide flags

- -addocnld adds ocean load tide coefficients to qregres.nml.
  - 11 tidal frequencies, M2, S2, K2, N2, K1, O1, P1, Q1, Mf, Mm, Ssa.
  - NOTE: Default uses ocean load tide coefficients from:
    - $GOA_VAR/sta_info/ocnld_coeff_cm_got48ac_wtpxo8ofunc
  - Could point to your own database by using the following option:
    - **-add_ocnld "-c your_own_ocean_loading_coefficient_file"**
    - **E.g. use http://holt.oso.chalmers.se/loading/**
  - NOTE: When using JPL's orbit and clock products be sure to use load tide coefficients with respect to center of mass of solid Earth + oceans.
    - JPL's orbit/clock products are delivered with respect to center of mass of total Earth system.
- -OcnldCpn uses 11 tidal frequencies to infer other frequencies (hardisp.f from IERS standards)

Example 4: First look at run.

- No errors in gd2p.err.
- Additional reduction in RMS of postfit phase (LC) residuals, without estimating any new parameters.
  - Load tide model seems to add value.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.6587E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7503E-04	2168	0

Example 4: What changed?

- Compare qregres namelists from Examples 3 and 4.

  diff qregres.nml ../spp3/qregres.nml

  – -add_ocnld adds the amplitude and phase of ocean load tides at 11 frequencies:

  NMLOceanLoad(1) = .true.

  NMLOcnLoad_Amp(1, *, 1)

  NMLOcnLoad_Phs(1, *, 1)

  – -OcnldCpn adds the following:

  NMLOcnldCpn = .TRUE.

  – Presently invoking IERS hardisp subroutine.

- Compare wash namelists from Examples 3 and 4.

  diff wash.nml ../spp3/wash.nml

  – No differences.

    - No change to estimation strategy.

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Example 4: First look at solution

- Verify no additional parameters estimated:

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]" | grep –v "WETZ"

  – Only dummy parameter left, "DUM", used by filter.

Example 5: Add ocean load pole tide model

- Add ocean load pole tide model for station position.
  - Displacement of crust due to load of the pole tide in the oceans.
    - Primarily has 12 and 14 month periods.

cd ..

mkdir spp5

cd spp5

cp ../spp4/run_again r5 # Copy run_again, and modify as needed.

- Edit script r5, and add two lines.

-add_ocnldpoltid \

- Execute script

./r5

Example 5: First look at run.

- No errors in gd2p.err.
- Very small increase in post-fit LC residuals at level of 1e-4 mm.
  - May not be statistically significant.
  - Expected because ocean load pole tide effect is < 1 mm and has periods of 12 and 14 months.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.6588E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7503E-04	2168	0

Example 5: What changed?

- Compare qregres namelists from Examples 4 and 5.

  diff qregres.nml ../spp4/qregres.nml

  – -add_ocnldpoltid turns on the model, and adds a path to a file containing a map of the coefficients for the model.

  – See $GOA/file_formats/ocnld_pole_tide_map for description of ocean load pole tide coefficient file.

  NMLOcnldPolTid = .TRUE.

  NMLOcnldPolTidMap = '/GIPSY_source/goa-var/sta_info/oceanpoletide_load_0.5deg.txt'

- Compare wash namelists from Examples 4 and 5.

  diff wash.nml ../spp4/wash.nml

  – No differences.

  - No change to estimation strategy.

Example 5: First look at solution

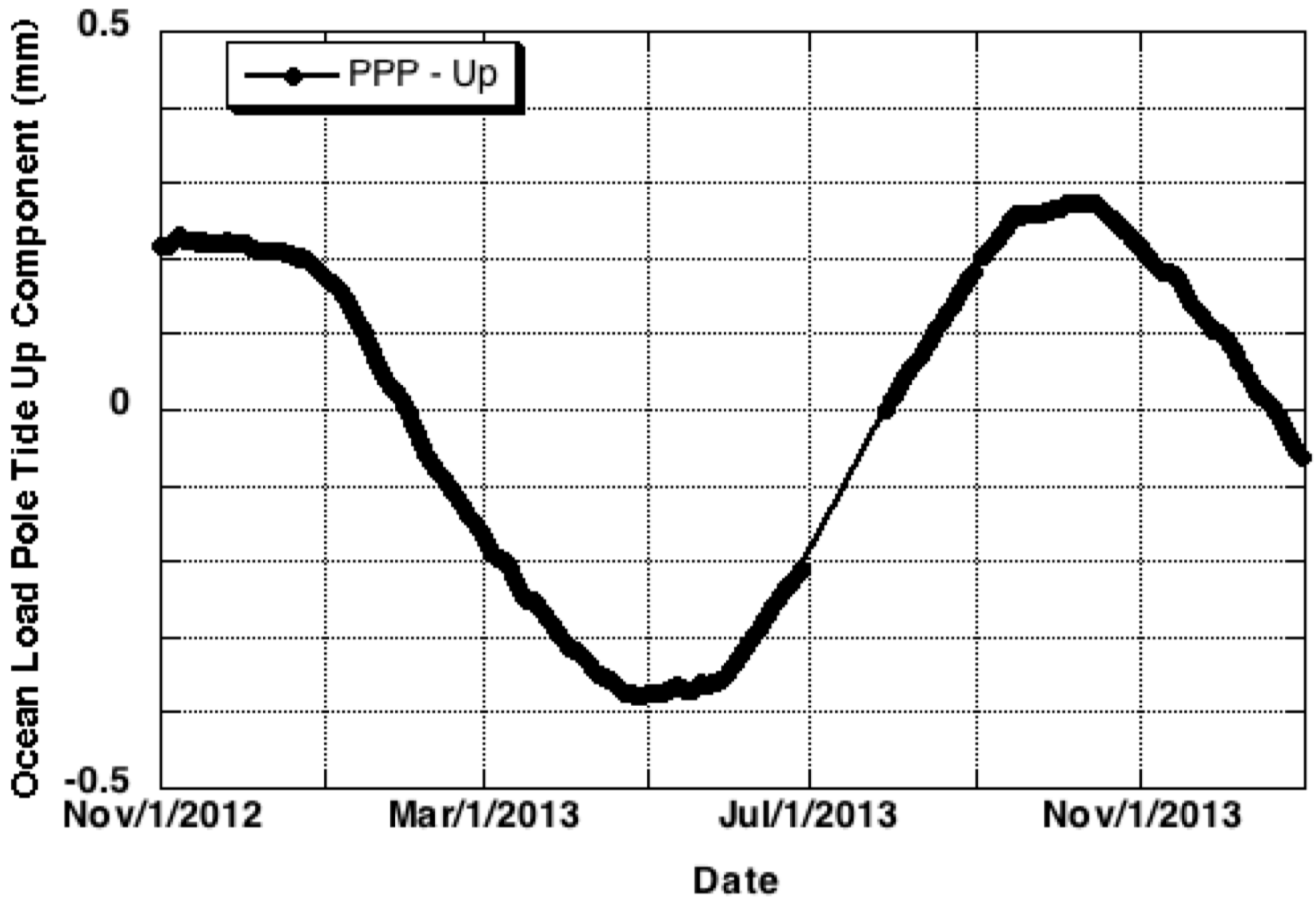
- Verify no additional parameters estimated:

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]" | grep –v "WETZ"

  – Only dummy parameter left, "DUM", used by filter.

Example 5: Effect of ocean load pole tide

- Effect is typically at the sub-mm level, primarily with periods of 12 and 14 months, e.g., Easter Island (ISPA).



Example 6: Add troposphere gradients

- Add estimation of troposphere gradients.

  cd ..

  mkdir spp6

  cd spp6

  cp ../spp5/run_again r6   # Copy run_again, and modify as needed.

  – Edit script r6, and add one line.

  -wetzgrad 5.0e-9 \

  – Experience has shown recommended random walk value of 5.0e-9 km/sqrt(sec) for static positioning.

  – Execute script

    ./r6

Example 6: First look at run

- No errors in gd2p.err.
- Additional improvement to postfit phase (LC) residuals.
  - Expected when estimating additional parameters.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.1667E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7481E-04	2168	0

Example 6: What changed?

- Compare qregres namelists from Examples 5 and 6.

  diff qregres.nml ../spp5/qregres.nml

  – No changes to any models.

- Compare wash namelists from Examples 5 and 6.

  diff wash.nml ../spp5/wash.nml

```
<   WETZGRAD  = .TRUE
---
>   WETZGRAD  = .FALSE.
```

  – Estimation of troposphere gradients turned on in example 6.

Example 6: First look at solution

- Check for additional parameters estimated:

  grep -v "STA BIAS" tdp_final | grep -v "PB GPS" | grep -v "STA [XYZ]” | grep –v “WETZ”

  – Troposphere gradient parameters are in TRPAZSIN and TRPAZCOS.

    - Some consider these to be parameters that absorb other error sources, others consider them to have scientific value.

      – Depends on application, processing approach, and station.

Example 7: Change troposphere mapping function

- Change troposphere mapping function.

  cd ..

  mkdir spp7

  cd spp7

  cp ../spp6/run_again r7   # Copy run_again, and modify as needed.

  – Edit script r7, and add one line.

  -trop_map GPT2\

  – GPT2 = Global Pressure and Temperature Mapping Function.
    - Shown to be better than NIELL.
    - Predecessor is GMF (Global Mapping Function), part of GPT (Version 1).
    - A better option is VMF1GRID (Vienna Mapping Function) or VM1SITE (site-specific Vienna Mapping Function).
      – Requires local database of VMF grid or site files, maintained by user.
      – Path to database specified by **–vmf1dir** option.

  – Execute script

  ./r7

Example 7: First look at run

- No errors in gd2p.err.
- Small reduction in postfit residuals for this station/day of 4e-4 mm.
  - May not be statistically significant.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.1663E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7481E-04	2168	0

Example 7: What changed?

- Compare qregres namelists from Examples 6 and 7.

  diff qregres.nml ../spp6/qregres.nml

  < NMLTropMap(1) = ’GPT2'

  > NMLTropMap(1) = 'NIELL'

  – Just the mapping function model changed.
- Compare wash namelists from Examples 6 and 7.

  diff wash.nml ../spp6/wash.nml

  – No differences.
    - No change to estimation strategy.
- Save zenith troposphere solution for comparison to next example.

  grep WETZ tdp_final | cl h1 '1.0e2*c3' > spp7_wetz.txt

Nominal Values of Zenith Troposphere

- Default troposphere nominals in qregres are:
  - Zenith dry troposphere (NMLTROP_DRY) = 2.0 m
  - Zenith wet troposphere (NMLTROP_WET) = 0.1 m
- If NMLStochMonment is .TRUE.:
  - Zenith dry troposphere: 1.013*2.27*exp(-0.116e-03*ht) meters.
  - Nominal station position height used to compute dry.
- If a TDP file with station position(s) is provided (STA [XYZ]):
  - Zenith dry troposphere: 1.013*2.27*exp(-0.116e-03*ht) meters.
  - Zenith wet troposphere: 0.1*exp(-ht/2000e0) meters.
- Nominal model can be improved and provided to gd2p with an input TDP file.
  - See: **tropnominal**

tropnominal – Models of nominal troposphere delay

- **tropnominal** generates times series of zenith dry and/or wet troposphere models:
  - STATIC: Dry based on exponential function
    - 1.013 * 2.27 * exp(-.116e-3 * h) meters
    - No wet.
  - GPT: Dry based on Global Pressure and Temperature climatological model (mean, annual, and 20-degree horizontal resolution)
    - http://ggosatm.hg.tuwien.ac.at/delay.html
    - No wet.
  - GPT2: Dry and wet using the GPT2 climatological model.
    - Mean, annual, semiannual, and 5-degree horizontal resolution.
  - VMF1GRID: Wet and dry based on Vienna mapping function:
    - http://ggosatm.hg.tuwien.ac.at/delay.html
    - Based on ECMWF meteorological data (post-processed)
    - User needs to maintain own database.
- **tropnominal** can accept time series of station positions.

tropnominal – Example of getting required inputs

- Determine appropriate inputs to cover observation window.
  - UTC start and stop times required.

cd ..

mkdir tropnominal

cd tropnominal

grep WETZ ../spp7/tdp_final | head -1 | cl 1 | gps2utc –

316353585.00000000

grep WETZ ../spp7/tdp_final | tail -1 | cl 1 | gps2utc –

316439685.00000000

  - Station lat, lon, and height required.
    - Grab from qreges namelist, for example from ../spp7/qregres.nml

```
!    lat           long          elev (m)
!    35.4251561   -116.8892511   987.0973
```

tropnominal - Example

- Execute tropnominal:

  tropnominal -n GOL2 -m GPT2 -latdeg 35.4251561 -londeg -116.8892511 -h_m 987.0973 -stsec 316353585.0 -endsec 316439685.0 -samp 300

  - By default the output files are defined according to the station name (-n option).
  - In this case, output files are GOL2.TDPdry and GOL2.TDPwet

- Make a combined file, and rename output files.

  cat GOL2.TDPdry GOL2.TDPwet > GOL2_GPT2.TDPdryandwet

  mv GOL2.TDPdry GOL2_GPT2.TDPdry
  mv GOL2.TDPwet GOL2_GPT2.TDPwet

- Execute tropnominal using the default static model applied in GIPSY, and rename output file.

  tropnominal -n GOL2 –m STATIC -latdeg 35.4251561 -londeg -116.8892511 -h_m 987.0973 -stsec 316353585.0 -endsec 316439685.0 -samp 300

  mv GOL2.TDPdry GOL2_STATIC.TDPdry

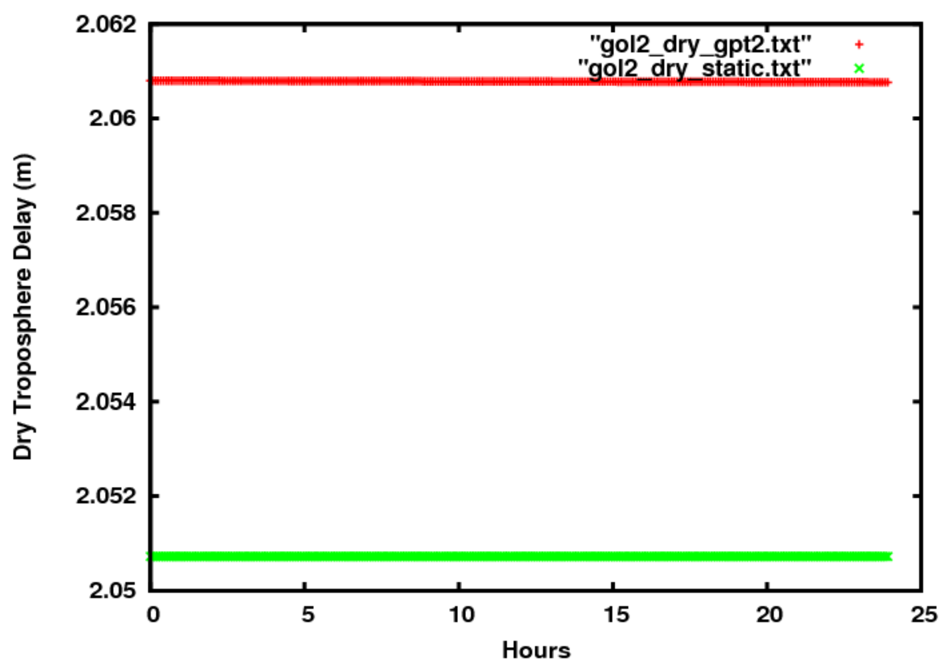
Comparison of tropnominal models

cat GOL2_GPT2.TDPdry | cl h1 3 > gol2_dry_gpt2.txt

cat GOL2_STATIC.TDPdry | cl h1 3 > gol2_dry_static.txt

gnup -p gol2_dry_gpt2.txt gol2_dry_static.txt -xl 'Hours' -yl 'Dry Troposphere Delay (m)'

- GPT2 model is ~ 1.0cm higher than GIPSY's default.
  - GPT2 is time-varying (although not obvious on this scale, and for this particular station-day)



Example 8: Provide apriori dry troposphere model (GPT2)

- Use GPT2 model for nominal dry troposphere delay.

  cd ..

  mkdir spp8

  cd spp8

  cp ../spp7/run_again r8 # Copy run_again, and modify as needed.

  – Edit script r8, and add one line.

  -tdp_in ../tropnominal/GOL2_GPT2.TDPdry \

  – Input TDP file provides nominal time series of dry troposphere delay.

  – Execute script

    ./r8

Example 8: First look at run

- No errors in gd2p.err.
- Small reduction to postfit residuals.
  - GPT2 has positive impact, since no change to estimation strategy

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.1648E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7481E-04	2168	0

Example 8: What changed?

- Compare qregres namelists from Examples 7 and 8.

  diff qregres.nml ../spp7/qregres.nml

  – No change to internal models.

  – **However, qregres command now ingests information from tdp file.**

- Compare wash namelists from Examples 7 and 8.

  diff wash.nml ../spp7/wash.nml

  – No differences.

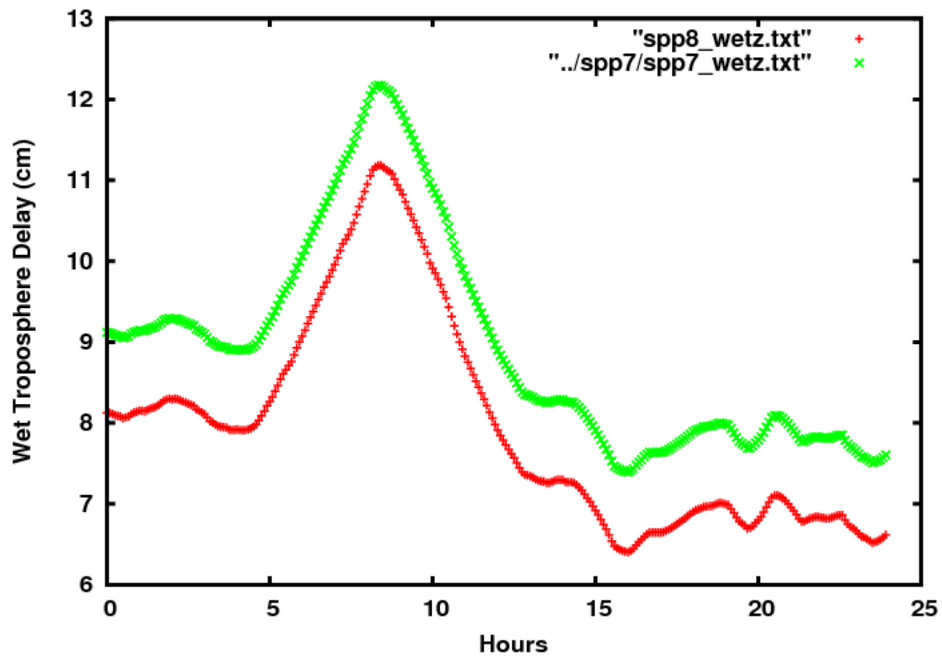
    - No change to estimation strategy.

Example 8: Plot of Zenith Wet Troposphere Solution

grep WETZ tdp_final | cl h1 '1.0e2*c3' > spp8_wetz.txt

gnup -p spp8_wetz.txt ../spp7/spp7_wetz.txt -xl 'Hours' -yl 'Wet Troposphere Delay (cm)'

- Total troposphere delay remains about the same.
  - Input nominal dry increased by 1 cm, so estimated "wet" decreased by 1 cm.
  - But, improved residuals suggests we have a better nominal dry.



Example 9: Provide apriori wet troposphere model (GPT2)

- Use GPT2 model for nominal wet and dry troposphere delay.

  cd ..

  mkdir spp9

  cd spp9

  cp ../spp8/run_again r9 # Copy run_again, and modify as needed.

  – Edit script r9, and change one line.

  -tdp_in ../tropnominal/GOL2_GPT2.TDPdryandwet \

  – Input TDP file provides nominal time series of dry and wet troposphere delay.

  – Execute script

    ./r9

Example 9: First look at run

- No errors in gd2p.err.
- No change to postfit residuals.
  - Providing nominal wet troposphere, but also estimating wet troposphere.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.1648E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7481E-04	2168	0

Example 9: What changed?

- Compare qregres namelists from Examples 8 and 9.

  diff qregres.nml ../spp8/qregres.nml

  - No change to internal models.
  - **However, qregres is ingesting information from tdp file.**

- Compare wash namelists from Examples 8 and 9.

  diff wash.nml ../spp8/wash.nml

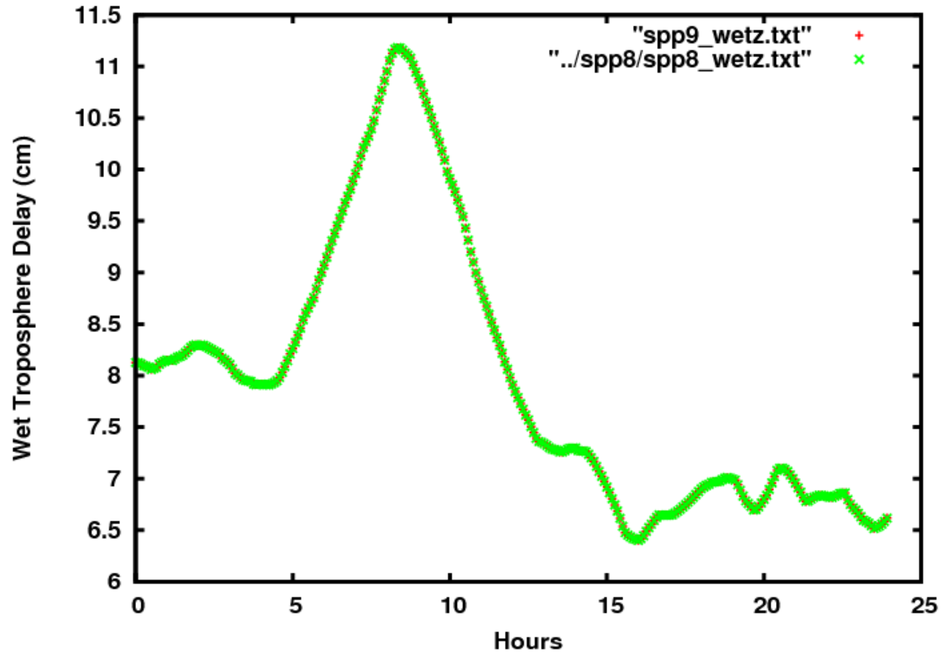
  - No differences.
    - No change to estimation strategy.

Example 9: Plot of Zenith Wet Troposphere Solution

grep WETZ tdp_final | cl h1 '1.0e2*c3' > spp9_wetz.txt

gnup -p spp9_wetz.txt ../spp8/spp8_wetz.txt -xl 'Hours' -yl 'Wet Troposphere Delay (cm)'

- Estimated wet troposphere delay remains about the same.
  - Usually not necessary to provide wet troposphere nominal when estimating wet troposphere.



Example 9: Station position estimate

- However, providing a nominal wet delay even when estimating wet delay can influence the estimated station position.
  - Some prefer to provide a nominal wet delay.

paste tdp_final ../spp8/tdp_final | grep "STA [XYZ]" | cl '1e6*(c3-c10)'

0.000350155460182577

-0.000470208760816604

-0.000240106601268053

- Depends on application, but typically no need to use nominal wet delays when estimating wet delay. Providing nominal dry delay is useful.

Example 10: Use Second Order Ionosphere Correction

- Use IRI2012 model of total electron content to derive second order ionosphere correction to data.

  cd ..

  mkdir spp10

  cd spp10

  cp ../spp9/run_again r10 # Copy run_again, and modify as needed.

  – Edit script r10, and add following lines.

  -ion_2nd \

  -shell_height 600 \

  -tec_mdl iri \

  – See –iri_dir option for path to IRI2012 coefficient files.
    - Default is $GOA_VAR/etc/iri

  – Execute script

    ./r10

Example 10: First look at run

- No errors in gd2p.err.
- Small reduction to postfit residuals.
  - Second order ionosphere correction has positive impact, since no change to estimation strategy

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.1619E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7467E-04	2168	0

Example 10: What changed?

- Compare qregres namelists from Examples 9 and 10.

  diff qregres.nml ../spp9/qregres.nml

```
< $ionosphere_mdl
<     Ion_2nd = .true.
<     mag_mdl = 'IGRF'
<     tec_mdl ='IRI'
<     Ion_2nd_shell_hgt = 600
< $end
```

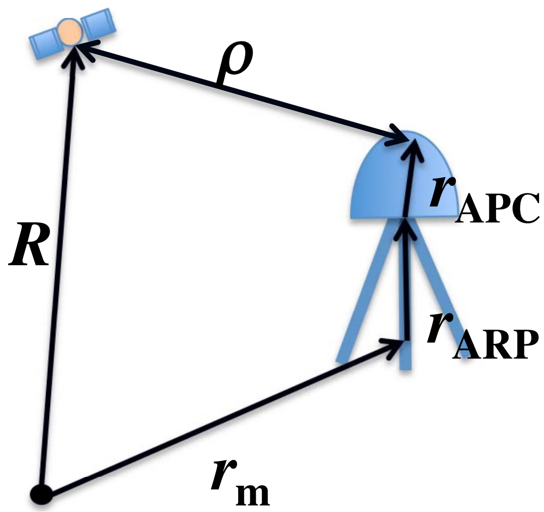
  – Ionosphere models are now defined.

- Compare wash namelists from Examples 9 and 10.

  diff wash.nml ../spp9/wash.nml

  – No differences.
    - No change to estimation strategy.

Monument, ARP, and APC



- **M = Monument**
- **ARP = Antenna Reference Point**
- **APC = Antenna Phase Center**

- Phase and range measurements, ρ, are between transmitter and receiver APCs.
  - Orbit products are associated with a model of transmitter APC.
    - e.g., specified in YYYY-MM-DD.ant file

$\mathbf{r}_{APC}$	$\mathbf{r}_{ARP}$	**What position is being determined?**
Not Modeled	Not Modeled	APC
Modeled	Not Modeled	ARP = APC - $\mathbf{r}_{APC}$
Not Modeled	Modeled	APC-$\mathbf{r}_{ARP}$
Modeled	**Modeled**	**Monument = APC – $\mathbf{r}_{APC}$ - $\mathbf{r}_{ARP}$**

Where does GIPSY/gd2p Define and Get ARP and APC Information?

- Monument, ARP, and APC information defined in qregres namelist.
- gd2p defaults to using s2nml which uses the station database:
  - $GOA_VAR/sta_info (See $GOA/file_formats/sta_info)
- NMLMonument in qregres namelist defines point being positioned (usually the monument):
  - s2nml uses site position/velocity from sta_pos
    - Station dependent
- NMLSite in qregres namelist defines sum total of $\mathbf{r}_{ARP}$ and $\mathbf{r}_{APC}$.
  - s2nml defines $\mathbf{r}_{ARP}$ from sta_svec
    - Station dependent
  - s2nml defines $\mathbf{r}_{APC}$ from pcenter.
    - Antenna model dependent.

Example 11: Use –arp option

- Change reference for estimation to Antenna Reference Point.

  cd ..

  mkdir spp11

  cd spp11

  cp ../spp10/run_again r11 # Copy run_again, and modify as needed.

  – Edit script r11, and add one line.

  – Add one line:

  -arp

    - Effectively sets $\mathbf{r}_{\mathbf{APC}}$ to zero (i.e. ignores information in pcenter file).
    - Recommended when using antenna calibration file (next example).

  – Execute script

    ./r11

Example 11: Effect of -arp

- **In general, would expect a different result if pcenter file had $\mathbf{r}_{APC} \neq 0$.**
- For this particular example there was no impact from using the –arp option.

  diff tdp_final ../spp10/tdp_final

  – Explained by fact that GOL2's antenna type is AOAD/M_T, which has $\mathbf{r}_{APC}$**=0** in the pcenter file.

  grep "AOAD/M_T" $GOA_VAR/sta_info/pcenter
- All examples so far have effectively been positioning the point represented by APC-$\mathbf{r}_{ARP}$ since ARP-APC vector was unrealistically set to zero.
  – We need to define a realistic model for the station's APC relative to the ARP in order to better position the monument.

IGS Antenna Calibrations – ANTEX files

- IGS provides receiver calibrations in file called "ANTEX".
- JPL orbit/clock products identify the adopted transmitter and receiver calibrations.

zcat ../jplorbclk/2010-01-10.ant.gz

```
SAT igs08_1604.xyz    ftp://sideshow.jpl.nasa.gov/pub/gipsy_files/gipsy_params/antenna_cals_xmit/igs08_1604.xyz.gz
GRN igs08_1604.atx    ftp://sideshow.jpl.nasa.gov/pub/gipsy_files/gipsy_params/antenna_cals_xmit/igs08_1604.atx.gz
```

  - SAT line indicates transmitter calibration file (in GIPSY format) used to generate orbit/clock product, and location on JPL server.
    - **gd2p uses SAT line to add transmitter calibrations to qregres namelist.**
  - GRN line indicates receiver calibration file used to generate orbit/clock product, and location on JPL server.
  - In this example, an IGS antex file was used for the antenna calibrations of the ground station network used to generate the orbit/clock products.
- Best to use consistent set of calibrations.
  - Main consideration for consistency is reference frame identifier (e.g. igs08).

antex2xyz.py - Generating a receiver antenna calibration file

- GOL2 RINEX file identifies antenna type AOAD/M_T and radome type NONE.
  - All of the igs08 antex files have the same calibration for this antenna.
  - Calibration changes usually occur when reference frames change.
- Native GIPSY format for antenna calibrations is "xyz" format.
  - See $GOA/file_formats/antenna_cal
- Generate xyz file from ANTEX file:

cd ..

mkdir antcal

cd antcal

antex2xyz.py -antexfile $GOA_VAR/etc/antenna_cals_xmit/igs08_1604.atx -xyzfile GOL2_antex.xyz -anttype AOAD/M_T -recname GOL2 -radcode NONE -fel 0 –del 5 -daz 5 –extrap

  - NOTE: Effective phase center offset, $\mathbf{r}_{APC}$, in mm is (see GOL2_antex.xyz):
    - NORTH = 1.600180 : EAST = -0.029940 : UP = 47.796758

sta2antxyz.py – Generating a receiver antenna calibration file from sinex file

- If station is part of IGS network, could use IGS SINEX file to determine antenna and radome type.
  - Accounts for any recorded changes to antenna
- Generate antenna calibration from ANTEX and SINEX files.

  sta2antxyz.py -s GOL2 -sinex $GOA_VAR/sta_info/igs.snx -antex $GOA_VAR/etc/antenna_cals_xmit/igs08_1604.atx -o GOL2_antex_sinex.xyz -d 2010-01-10
- Two files are identical:

  diff GOL2_antex.xyz GOL2_antex_sinex.xyz
  - sta2antxyz.py and antex2xyz.py use same library.
  - antex2xyz.py is probably more flexible but means user must keep track of station equipment.

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Example 12: Add receiver antenna calibration

- Add receiver antenna calibration.

  cd ..

  mkdir spp12

  cd spp12

  cp ../spp11/run_again r12 # Copy run_again, and modify as needed.

  – Edit script r12, and add one line:

  -AntCal ../antcal/GOL2_antex.xyz \

  – Execute script

  ./r12

Example 12: First look at run

- No errors in gd2p.err.
- Reduction of postfit residuals.
  - Receiver antenna calibration has positive impact, since no change to estimation strategy

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	5.9454E-06	2167	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	3.7453E-04	2168	0

Example 12: What changed?

- Compare qregres namelists from Examples 11 and 12.

  diff qregres.nml ../spp11/qregres.nml

  – Additional namelist items for receiving antenna calibration.
    - NMLGCen, NMLG*

  – **NOTE: gd2p automatically adds transmitter antenna calibrations to qregres namelist based upon "SAT" information provided in orbit/clock products (.ant file).**
    - NMLOCen, NMLO*

- Compare wash namelists from Examples 11 and 12.

  diff wash.nml ../spp11/wash.nml

  – No changes to solution strategy.

Example 13: Lower Elevation Angle Cutoff

- Modify elevation angle cutoff.

  cd ..

  mkdir spp13

  cd spp13

  cp ../spp12/run_again r13 # Copy run_again, and modify as needed.

  – Edit script r13.

  – Change elevation angle cutoff to 7 degrees.

  -w_elmin 7 \

    - Recommended cutoff with troposphere gradients and antenna calibration.

  – Execute script

    ./r13

Example 13: First look at run

- No errors in gd2p.err.
- Increase in RMS of postfit residuals, but associated with increase in number of measurements.
  - More low elevation data used in solution.
  - Low elevation data usually have higher data noise.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	7.1846E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0513E-04	2429	0

Example 14: Elevation-Dependent Weighting

- De-weight low elevation data since it has higher data noise.

  cd ..

  mkdir spp14

  cd spp14

  cp ../spp13/run_again r14   # Copy run_again, and modify as needed.

  – Edit script r14.

  – Add one line:

  -eldepwght SQRTSIN \

    - Data weight = sqrt(sin(elevation))/sigma.
    - Depending on receiver and application, might also consider “SIN” weighting. (Data weight = sin(elevation)/sigma)
    - Without this option data weight is constant, 1/sigma.

  – Execute script

    ./r14

Example 14: First look at run

- No errors in gd2p.err.
- Increase in RMS of postfit residuals, because lower elevation (higher noise) data has lower impact on the solution.
  - More low elevation data used in solution.
  - Low elevation data usually have higher data noise.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	7.8489E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0521E-04	2429	0

Example 14: What changed?

- Compare qregres namelists from Examples 13 and 14.

  diff qregres.nml ../spp13/qregres.nml

  – No changes to model.

- Compare wash namelists from Examples 13 and 14.

  diff wash.nml ../spp13/wash.nml

  < SIGELV = .TRUE., .TRUE.

  < SQRELP1 = .FALSE.

  – Data weight options to filter are set.

Example 15: Not using station database

- For improved transparency, explicitly provide monument position, monument to ARP vector, and antenna calibrations.

  cd ..

  mkdir spp15

  cd spp15

  cp ../spp14/run_again r15 # Copy run_again, and modify as needed.

  – Edit script r15.

  – Add two lines:

  -p -2353.614421 -4641.385321 3676.976407 \

  -env_km 0.0 0.0 0.0000254 \

  - Chose position (-p) and site vector (-env_km) coordinates from prior qregres namelists only for consistency with previous examples.

  – Remove line with –arp (not needed when using –p option).

  – Execute script

    ./r15

Example 15: First look at run

- No errors in gd2p.err.
- No change to postfit residuals.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	7.8489E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0521E-04	2429	0

Example 15: What changed?

- Compare qregres namelists from Examples 14 and 15.

  diff qregres.nml ../spp14/qregres.nml

  – Some changes in order of parameters and format only.
- Compare wash namelists from Examples 14 and 15.

  diff wash.nml ../spp14/wash.nml

  – No changes to solution strategy.
- Using –p and –env_km options resulted with an identical run.
  - Might have round-off effects.
  - E.g., compare station position lines in TDP file.

  grep "STA [XYZ]" tdp_final

  grep "STA [XYZ] ../spp14/tdp_final

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Example 16: Generate stacov file

- Add option to generate stacov file.

  cd ..

  mkdir spp16

  cd spp16

  cp ../spp15/run_again r16 # Copy run_again, and modify as needed.

  – Edit script r16, and add one line.

  -stacov \

  – Option results with generation of a stacov file with the position solution and covariance matrix.
    - See $GOA/file_formats/stacov

  – Execute script

    ./r16

Example 16: What changed?

- Compare qregres namelists from Examples 15 and 16.

  diff qregres.nml ../spp15/qregres.nml
- Compare wash namelists from Examples 15 and 16.

  diff wash.nml ../spp15/wash.nml
  - No changes to solution strategy.
- Identical solution but additional output files:
  - stacov_final_pre_amb – Pre-ambiguity resolution solution.
  - stacov_final – Post-ambiguity resolution solution

Example 16: Pre- and Post-amb Residuals

- Ambiguity resolution results with larger post-fit residuals.
  - Expected because of constraints on phase biases.
  - Should be the case for all examples.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	7.8489E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0521E-04	2429	0

cat Postfit_amb.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	7.9731E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0541E-04	2429	0

Example 16: Compare Pre- and Post-Amb Position Solutions

```
grep "STA [XYZ]" tdp_final_pre_amb > pre_amb.pos
grep "STA [XYZ]" tdp_final > post_amb.pos
paste pre_amb.pos post_amb.pos | cl '1.0e6*(c3-c10)'
0.0456102497992106        (Z = 0.0 mm)
0.514080056746025         (Y = 0.5 mm)
-0.851220192998881        (X = -0.9 mm)
```

- Some other things to consider:
  - Pre- vs Post- amb clocks?
  - Pre- vs Post-amb wet?

Evaluating Effectiveness of Ambiguity Resolution

- Ambiguity resolution performance can be evaluated from percent of narrow lanes that are close to an integer.
  - Look at NLCUM statistics in logs/smap_ambigon.log
  - Reflects cumulative distribution of number and percent of narrow lanes that are close to an integer.

grep NLCUM logs/smap_ambigon.log

```
PNLCUM   0   3542  87.2843765402
PNLCUM   5    366   9.0192212913
PNLCUM  10     78   1.9221291276
...
```

  - Column 2 is centicycles from integer.
  - Column 3 is number of narrow lanes within bin.
  - Column 4 is percent of narrow lanes within bin.
    - E.g., 87.3 percent of narrow lanes < 5 centicycles of integer.
    - Larger numbers closer to integer implies better solution prior to ambiguity resolution. (likely means better ambiguity resolution).

Example 16: Station Position Estimate

- How much did the station move relative to the provided nominal value?

grep "STA [XYZ]" tdp_final | cl '1.0e6*(c3-c2)'

8.11517975307652	(Z = 8.1 mm)
32.6875997416209	(Y = 33.7 mm)
26.7990303655097	(X = 26.8 mm)

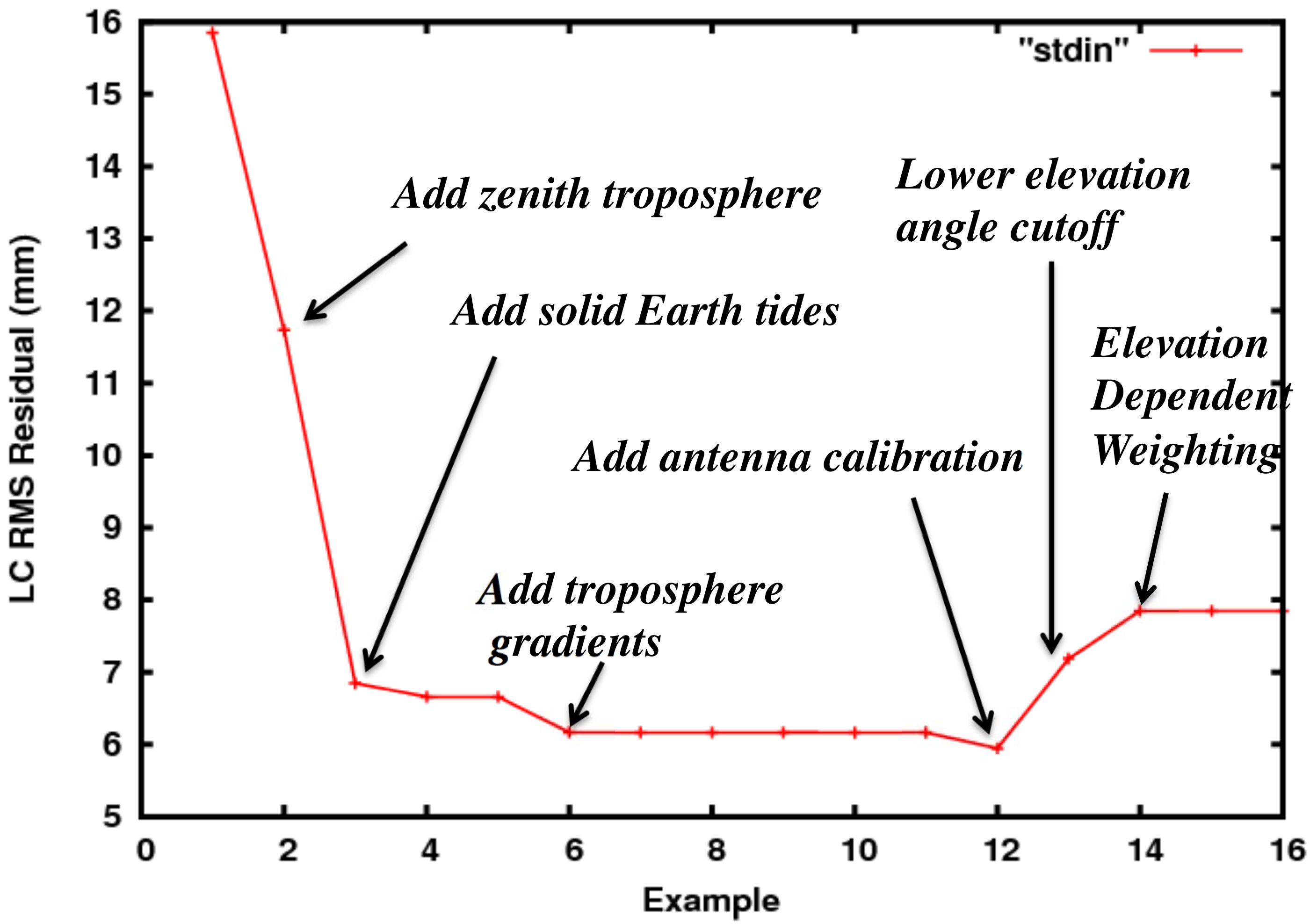
gd2p.pl settings from Example 16

```
( gd2p.pl \
    -i  $GOA/class_gd2p/gol20100.10o \
    -n GOL2 \
    -d 2010-01-10 \
    -r 300 \
    -type s \
    -w_elmin 7 \
   -eldepwght SQRTSIN \
    -e "-a 20 -PC -LC -F" \
    -pb_min_slip 1.0e-3 \
    -pb_min_elev 30 \
    -amb_res 2 \
    -dwght 1.0e-5 1.0e-3 \
    -post_wind 5.0e-3 5.0e-5 \
    -trop_z_rw 5.0e-8 \
    -wetzgrad 5.0e-9 \
    -trop_map GPT2 \
    -tdp_in ../tropnominal/GOL2_GPT.TDPwetanddry \
    -tides WahrK1 FreqDepLove OctTid PolTid \
    -add_ocnld \
    -OcnldCpn \
   -add_ocnldpoltid \
    -ion_2nd \
    -shell_height 600 \
    -tec_mdl iri \
    -orb_clk "flinnR WORKDIR/jplorbclk"
    -AntCal ../antcal/GOL2_antex.xyz \
    -p -2353.614421 -4641.385321 3676.976407 \
    -env_km 0.0 0.0 0.0000254 \
    -stacov \
 > gd2p.log ) |&  sed '/^Skipping namelist/d' > gd2p.err
```

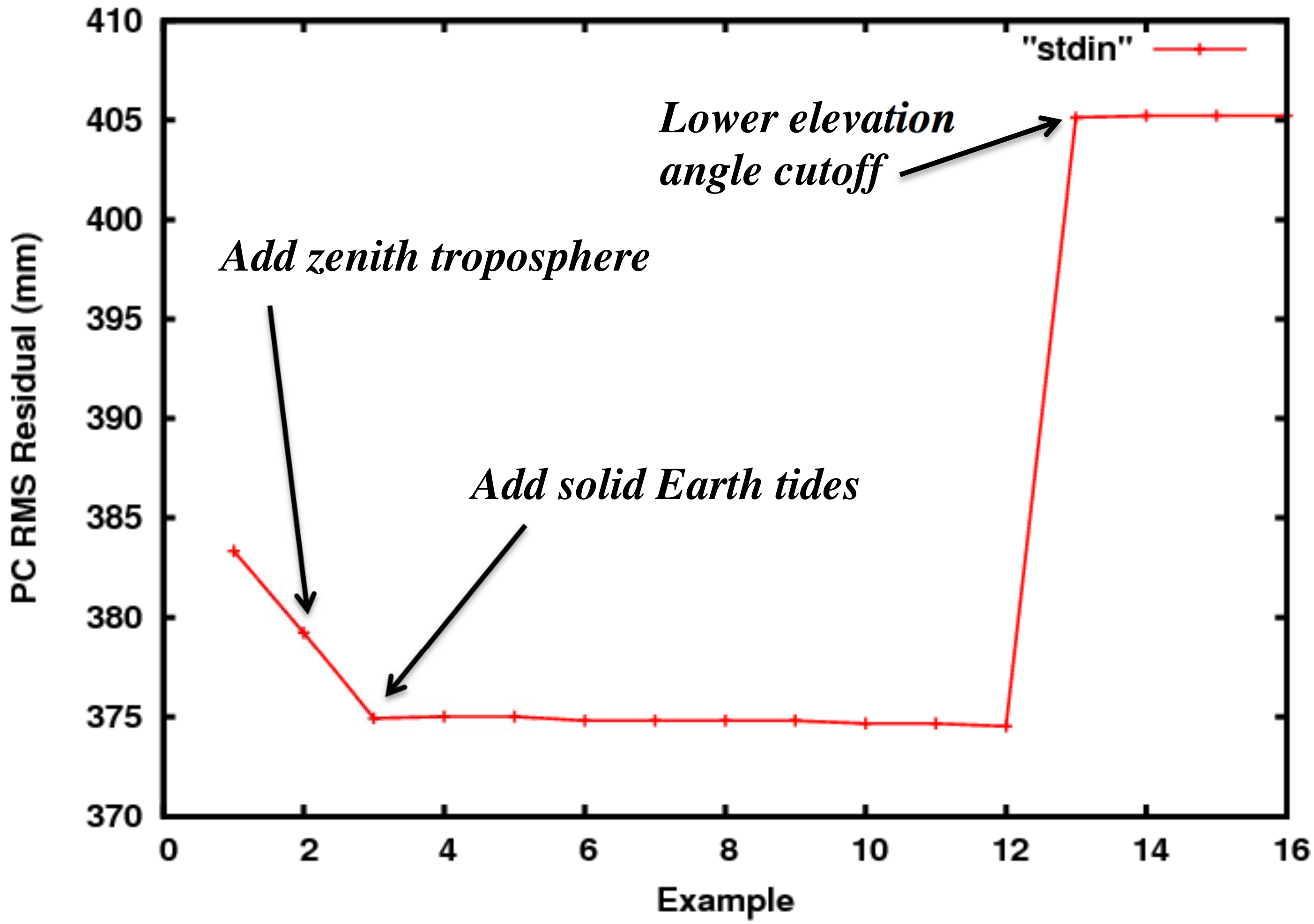
gd2p.pl for typical station

- run_again from Example 16 reflects the gd2p.pl settings for a typical IGS-quality GPS station.
  - Could be improved by:
    - Using VMF1GRID or VMF1SITE (via tropnominal) for input nominal wet and dry troposphere delay.
      - Nominal wet is less important when estimating wet.
    - Using VMF1GRID or VMF1SITE troposphere mapping function
    - Some prefer to set -pb_min_slip to large value so that postbreak is not exercised. Some prefer smaller value. User choice.
      - We have found 1 meter pb_min_slip and 30-degree elevation lower limit (-pb_min_elev) to search for breaks is reasonable for modern receivers.

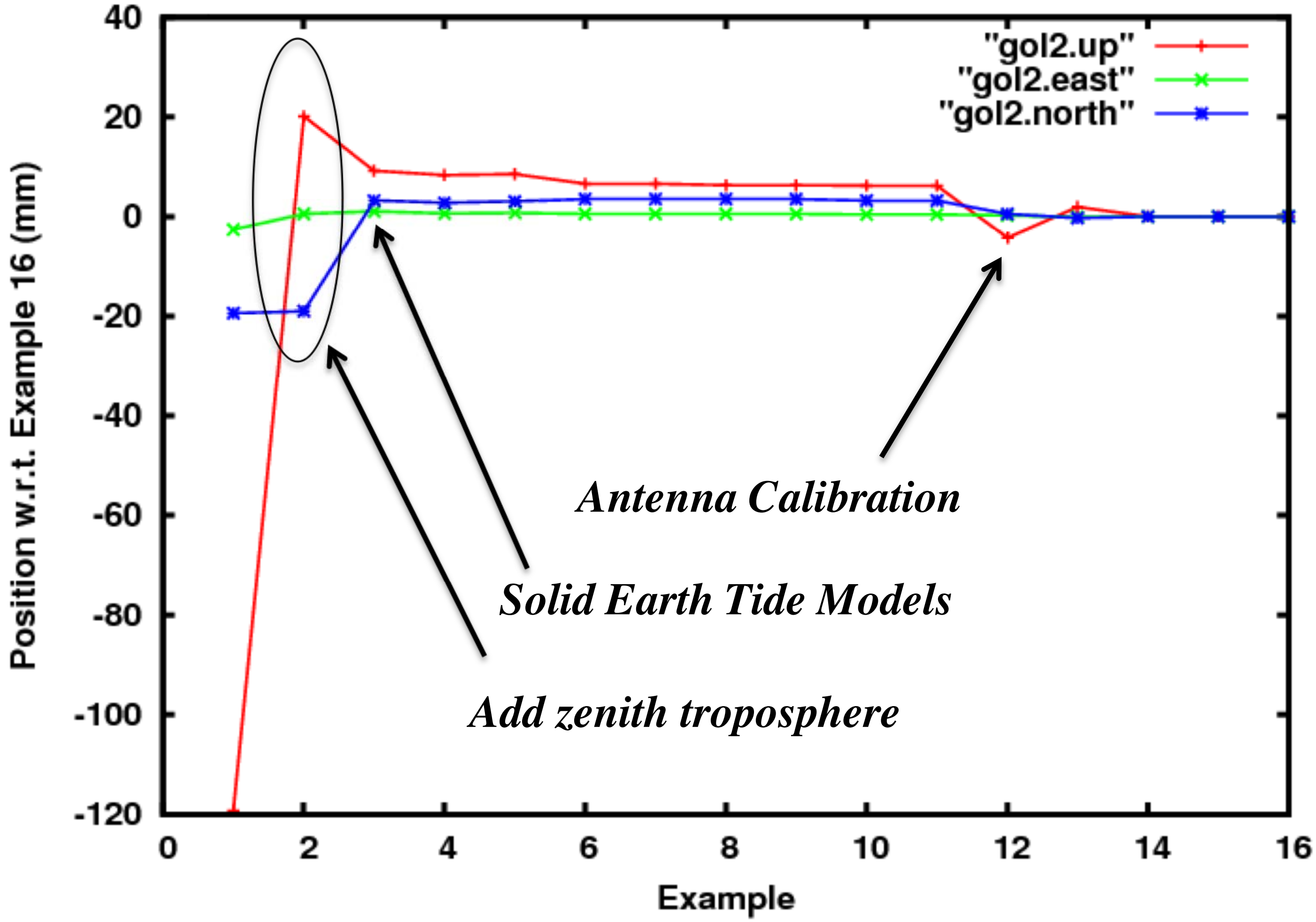
Effect of models/estimation approach on Postfit LC RMS Residual



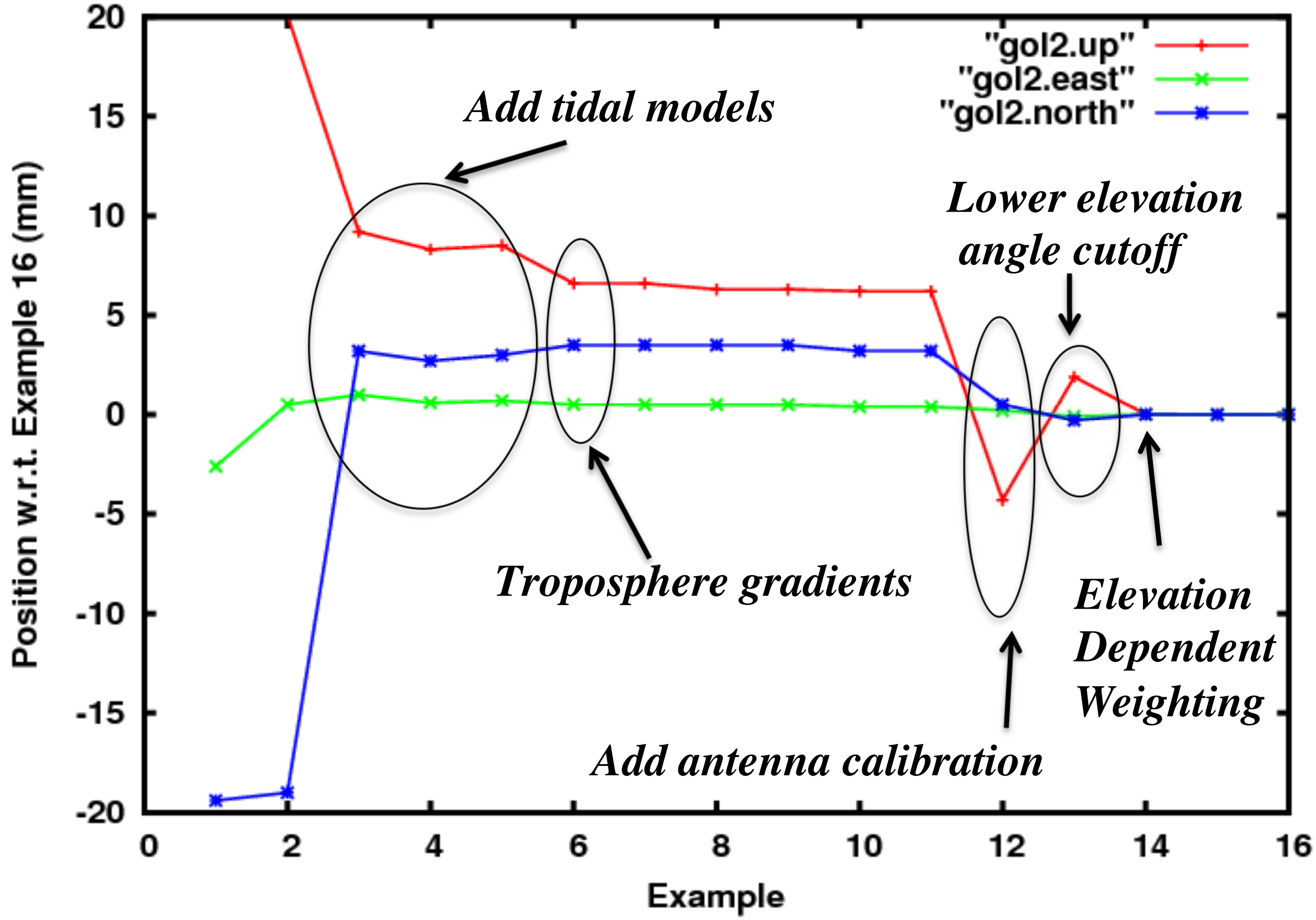
Effect of models/estimation approach on Postfit PC RMS Residual



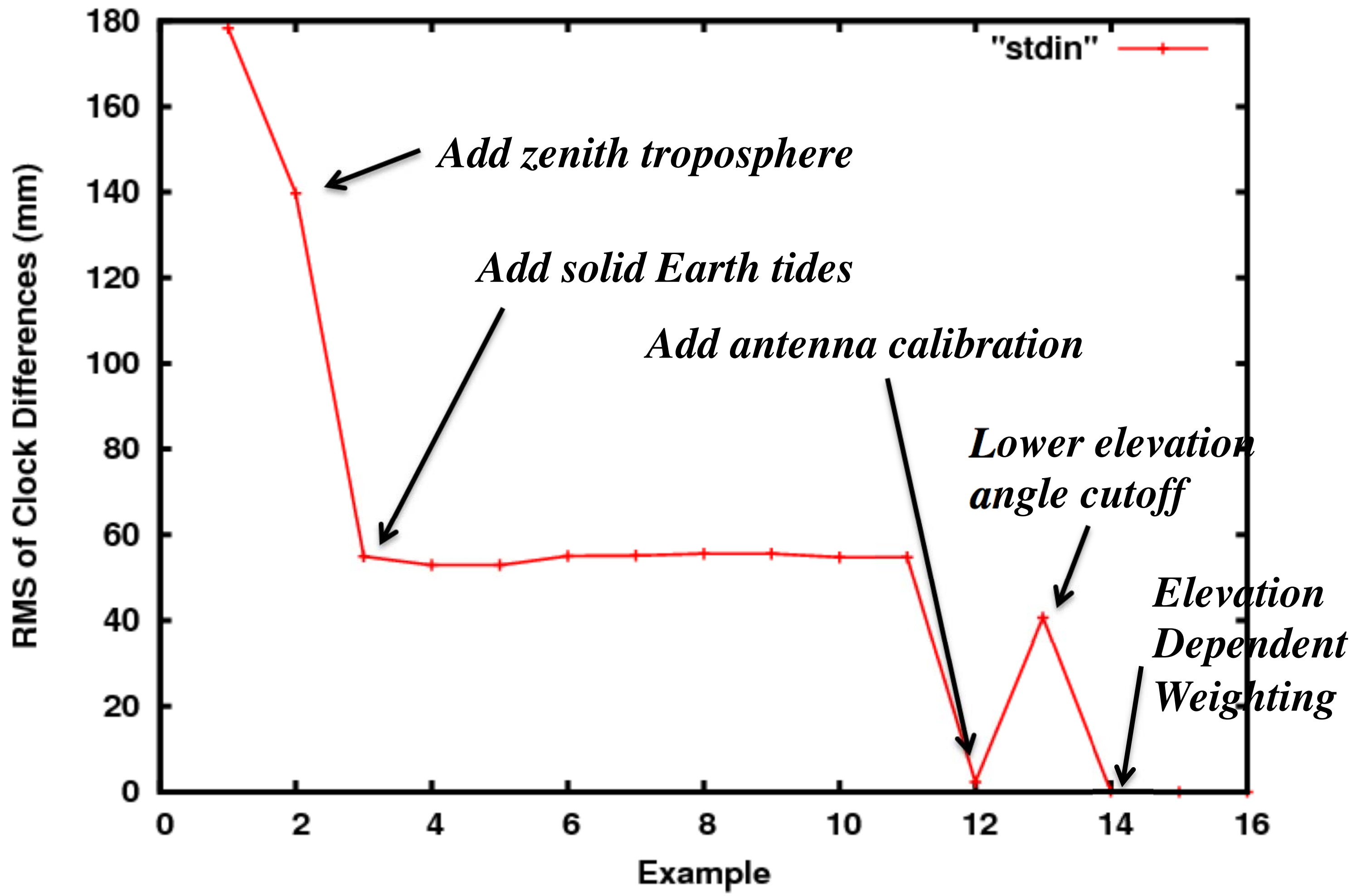
Effect of models/estimation approach on station position (Relative to Example 16)



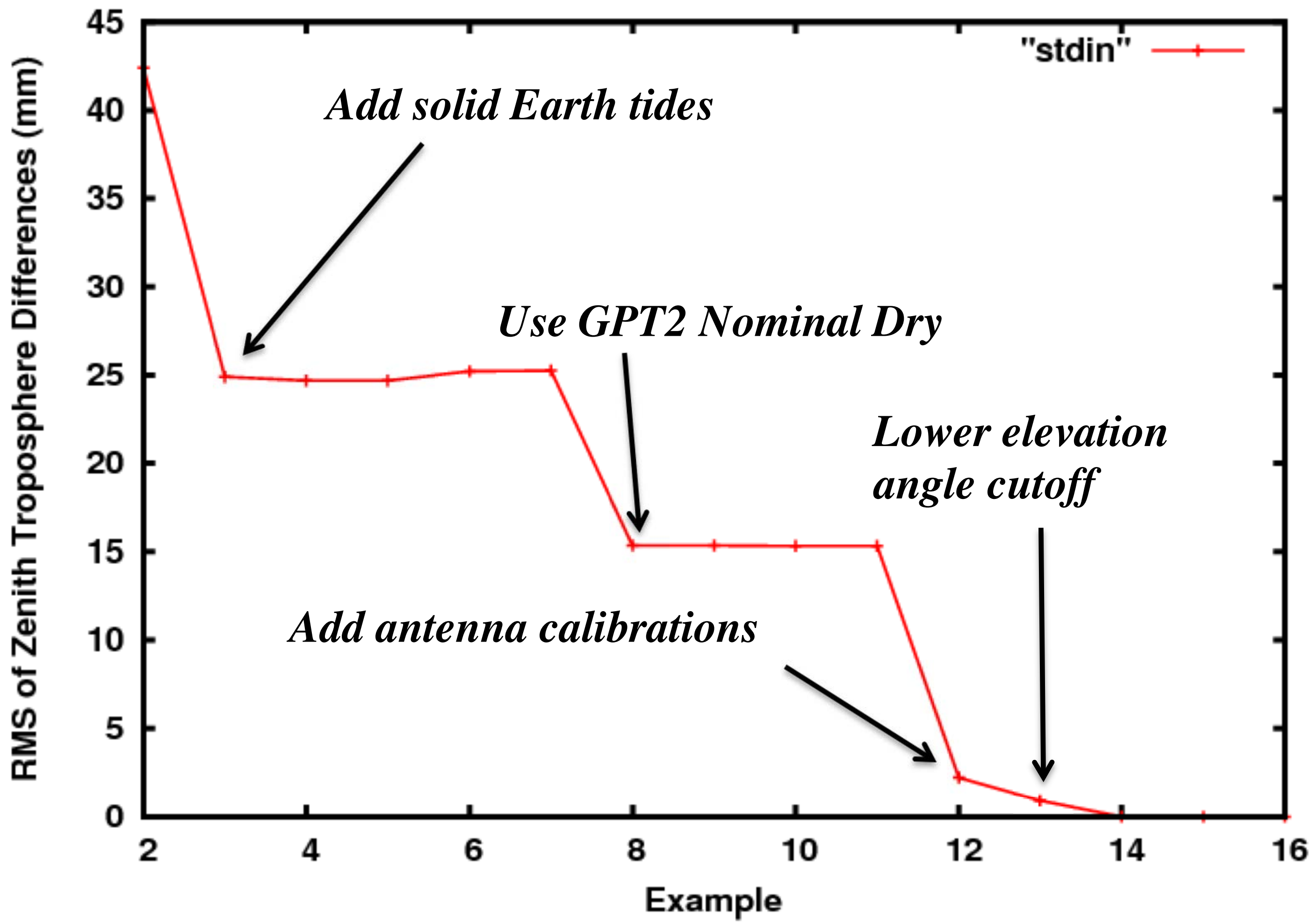
Effect of models/estimation approach on station position (Zoom, Relative to Example 16)



Effect of models/estimation approach on Clock Solutions (Relative to Example 16)

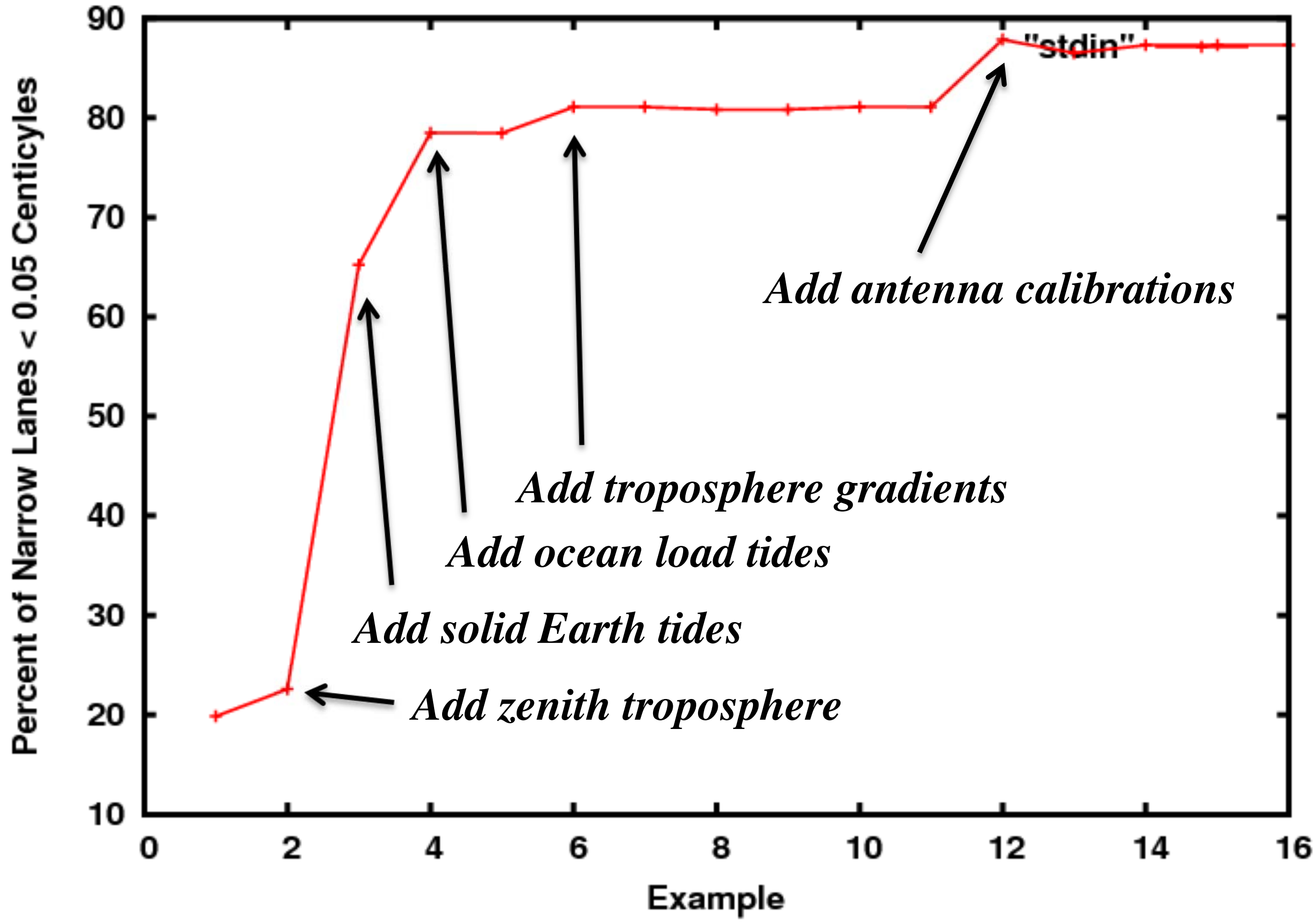


Effect of models/estimation approach on station position on Zenith Troposphere Solutions(Relative to Example 16)



Effect of models/estimation approach on station position on ambiguity resolution

NOTE: Number of narrow lanes < 0.05 centicycle also increased when elevation angle cutoff lowered to 7 degrees (3160 to 3510), and overall percentage increased slightly.



pr2p

- pr2p determines station position and clock from GPS pseudorange data alone.
  - No apriori information or models for receiver.
  - Only provide orbits/clocks of transmitters.
  - Useful when nominal station position not known, e.g. moving platforms.

pr2p –h | more

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pr2p - Example

NASA

cd ..

mkdir pr2p

cd pr2p

pr2p –i $GOA/class_gd2p/gol20100.10o –n GOL2 –orb_clk "flinnR *WORKDIR*/jplorbclk"

- Provides an average position in the log file (pr2p.log).

Average Position, (x,y,z), in km: -2353.614218 -4641.384766 3676.976173

Position Scatter, (x,y,z), in km: 0.001444 0.002298 0.001526

  – Could be used in follow-up gd2p run (-p option)

- Provides time series of receiver positions and clocks in output tdp_final.

  grep "STA [XYZ]" tdp_final

  grep "STA BIAS" tdp_final

  – Could be used in follow-up gd2p run (-tdp_in)

Kinematic Point Positioning

Kinematic Positioning
Apriori Positions and Troposphere

- Kinematic point positioning is more challenging than static positioning.
  - How fast is the platform moving?
    - For rapid movement, provide a nominal STA [XYZ] through input TDP file.
      - E.g., Solution from pr2p, prevous gd2p, or navigation solution.
      - Default is quadratic interpolation of positions in TDP file.
    - For rapid motion be careful with –amb_res. May be better not to use.
      - Check NLCUM statistics in smap_ambigon.log
  - Separating troposphere from position is more difficult.
    - Use apriori dry and preferably wet troposphere from tropnominal, or weather models (e.g., NCEP, ECMWF)
      - Provide through input TDP file.
  - If a TDP file with station position(s) is provided (STA [XYZ]), default:
    - Zenith dry troposphere: 1.013*2.27*exp(-0.116e-03*ht) meters.
    - Zenith wet troposphere: 0.1*exp(-ht/2000e0) meters.

Example 1

- Start with run_again from static point positioning example 15.

  cd ..

  mkdir kpp1

  cd kpp1

  cp ../spp15/run_again r1   # Copy run_again, and modify as needed.

  – Edit script r1:

  – Change positioning type to kinematic

  -type k \

  – **NOTE: We are already providing a nominal zenith dry and wet troposphere correction.**

    - **-tdp_in ../tropnominal/GOL2_GPT.TDPwetanddry**

  – Execute script

    ./r1

Example 1: First look at run

- No errors in gd2p.err.
- Postfit residuals significantly lower than corresponding static run.
  - Position has more freedom to follow data.

cat Postfit.sum

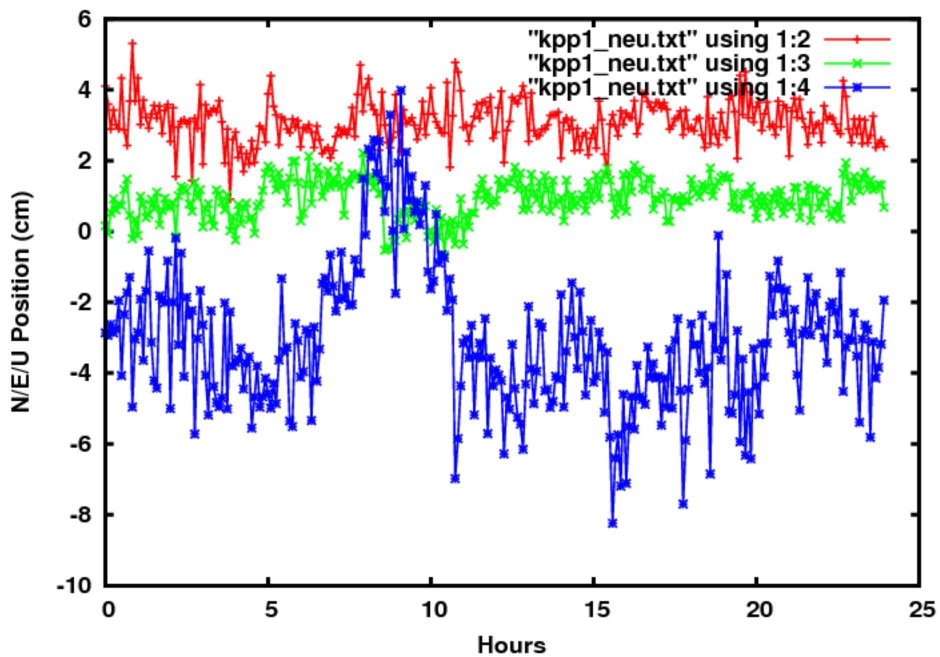
start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	5.9291E-06	2429	0
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0420E-04	2429	0

Example 1: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

  tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp1_neu.txt

  gnup -lp1:2 kpp1_neu.txt -lp1:3 kpp1_neu.txt -lp1:4 kpp1_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is standard deviation of time series?

cat kpp1_neu.txt | cl 2 | stats | cl 3
cat kpp1_neu.txt | cl 3 | stats | cl 3
cat kpp1_neu.txt | cl 4 | stats | cl 3

- North: 0.6 cm
- East: 0.5 cm
- Up: 2.0 cm

Example 2: Provide Wet Troposphere

- Provide wet troposphere from static solution instead of GPT2, and append to already used dry troposphere.

cd ..

mkdir kpp2

cd kpp2

grep -P 'TRP|WETZ' ../spp15/tdp_final > ../tropnominal/GOL2.TDPwetanddry
cat ../tropnominal/GOL2_GPT2.TDPdry >> ../tropnominal/GOL2.TDPwetanddry

cp ../kpp1/run_again r2 # Copy run_again, and modify as needed.

– Edit script r2:

– Change TDP input file:

-tdp_in ../tropnominal/GOL2.TDPwetanddry \

– Remove lines –trop_z_rw, and –wetzgrad (Still need –trop_map).

– Execute script

./r2

Example 2: First look at run

- No errors in gd2p.err.
- Check that troposphere parameters not estimated.

  diff wash.nml ../kpp1/wash.nml

  – WETZTROP and WETZGRAD are now both set to .FALSE.
- Postfit residuals are slightly lower, although 1 outlier.
  – Note: Fewer parameters being estimated, and less freedom for data.

  cat Postfit.sum

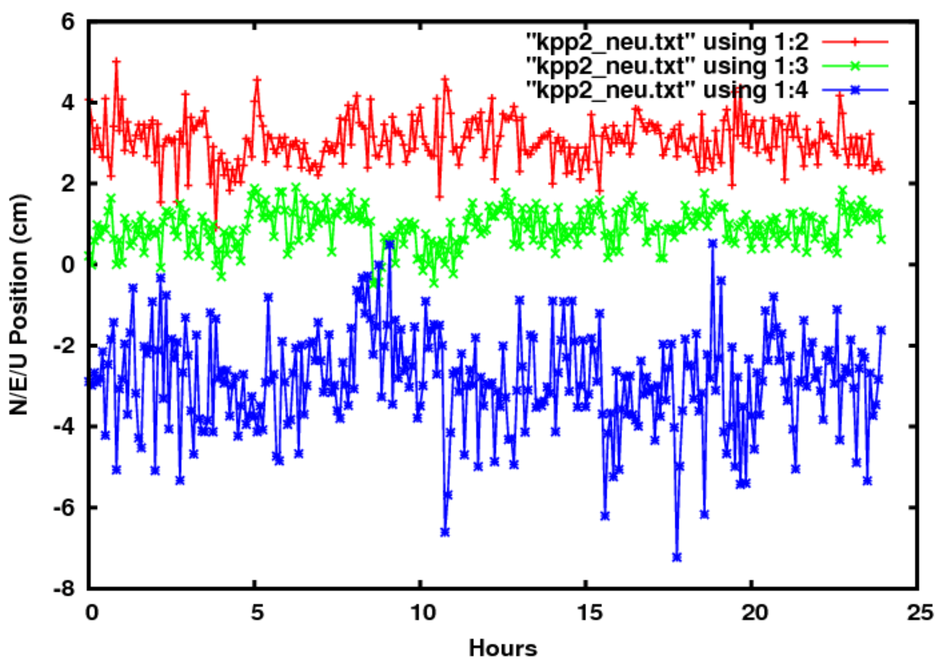
start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	5.6768E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0494E-04	2429	0

Example 2: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp2_neu.txt

gnup -lp1:2 kpp2_neu.txt -lp1:3 kpp2_neu.txt -lp1:4 kpp2_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is standard deviation of time series?

cat kpp2_neu.txt | cl 2 | stats | cl 3
cat kpp2_neu.txt | cl 3 | stats | cl 3
cat kpp2_neu.txt | cl 4 | stats | cl 3

- North: 0.6 cm
- East: 0.5 cm
- Up: 1.2 cm
- This is lower than when troposphere was estimated.
  - Improved result given station is not moving.

Example 3: Changing Random Walk Parameters

cd ..

mkdir kpp3

cd kpp3

cp ../kpp2/run_again r3 # Copy run_again, and modify as needed.

– Edit script r3:

– Add the following line:

-kin_sta_xyz 1.0e-3 5.7e-7 300 RANDOMWALK \

– gd2p's defaults are: 2.0e-3 1.0e-3 data_rate RANDOMWALK
  - In this example data rate = 300 seconds.
  - Defaults imply 1.0e-3*sqrt(300) km = 17.3 meters
    – Could just as well be white noise process for this type of station.
  - Changes imply 5.7e-7*sqrt(300) km = 10 mm

– Execute script

./r3

Example 3: First look at run

- No errors in gd2p.err.
- Postfit residuals are higher.
  - Tighter constraints on random walk mean less freedom for positions to follow data.

cat Postfit.sum

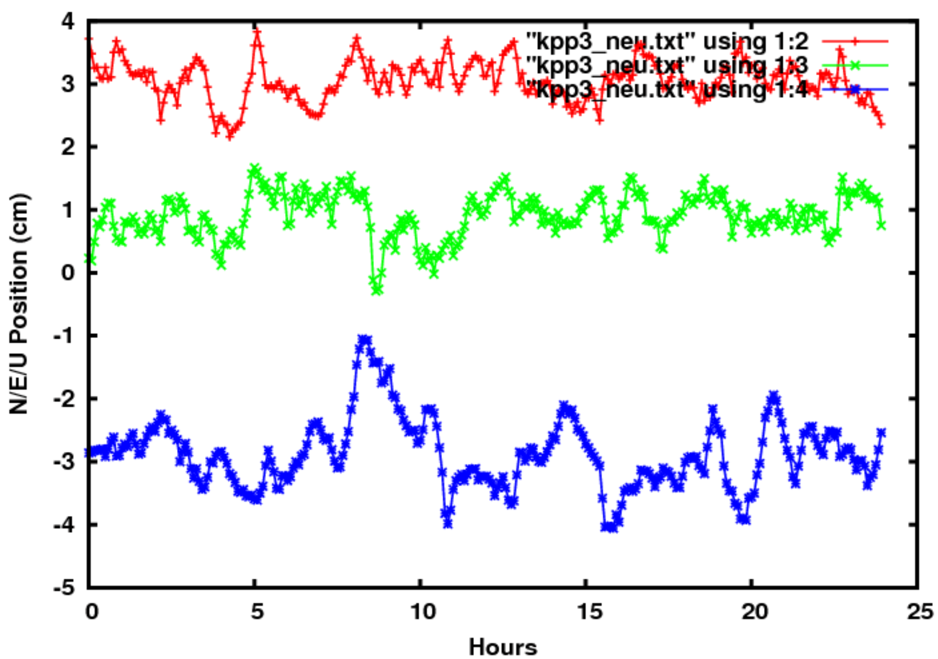
start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.7252E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0493E-04	2429	0

Example 3: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp3_neu.txt

gnup -lp1:2 kpp3_neu.txt -lp1:3 kpp3_neu.txt -lp1:4 kpp3_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is standard deviation of time series?

cat kpp3_neu.txt | cl 2 | stats | cl 3
cat kpp3_neu.txt | cl 3 | stats | cl 3
cat kpp3_neu.txt | cl 4 | stats | cl 3

- North: 0.3 cm
- East: 0.4 cm
- Up: 0.6 cm
- Lower scatter with tighter constraints on random walk.

Example 3: Comparing pre- and post-amb solutions

- Get the pre-amb position solutions:

  tdp2llh tdp_final_pre_amb GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp3_neu_pre_amb.txt

  cat kpp3_neu_pre_amb.txt | cl 2 | stats | cl 3

  cat kpp3_neu_pre_amb.txt | cl 3 | stats | cl 3

  cat kpp3_neu_pre_amb.txt | cl 4 | stats | cl 3

- Standard deviation of pre-amb versus post-amb time series.
  - Post-amb has slightly lower scatter.
    - Probably better since we know station is static.

	Pre-Amb	Post-Amb
North	0.4 cm	0.3 cm
East	0.4 cm	0.4 cm
Up	0.8 cm	0.6 cm

Example 4: Providing Nominal Station Position with TDP input

cd ..

mkdir kpp4

cd kpp4

cp ../kpp3/run_again r4   # Copy run_again, and modify as needed.

– Combine nominal troposphere (WET and DRY) and station positions in TDP input.
    - Use solution from previous example, i.e., iterate

cp ../tropnominal/GOL2.TDPwetanddry ../tropnominal/GOL2.TDPwetanddrysta

grep "STA [XYZ]" ../kpp3/tdp_final >> ../tropnominal/GOL2.TDPwetanddrysta
WARNING: -env_km is ignored when providing STA [XYZ] in TDP input file.

– Edit script r4:

– Change the following line:

-tdp_in ../tropnominal/GOL2.TDPwetanddrysta \

– Execute script

./r4

Example 4: First look at run

- No errors in gd2p.err.
- Postfit residuals are slightly lower.
  - Better nominal solution provided.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:54:45	LC	GOL2	6.4449E-06	2428	1
10JAN09 23:59:45	10JAN10 23:54:45	PC	GOL2	4.0494E-04	2429	0

- Verify that the nominal station positions are time-varying in this example.
  - Look at column 2 of tdp_final

grep "STA X" tdp_final

  - In previous examples the nominal was constant.

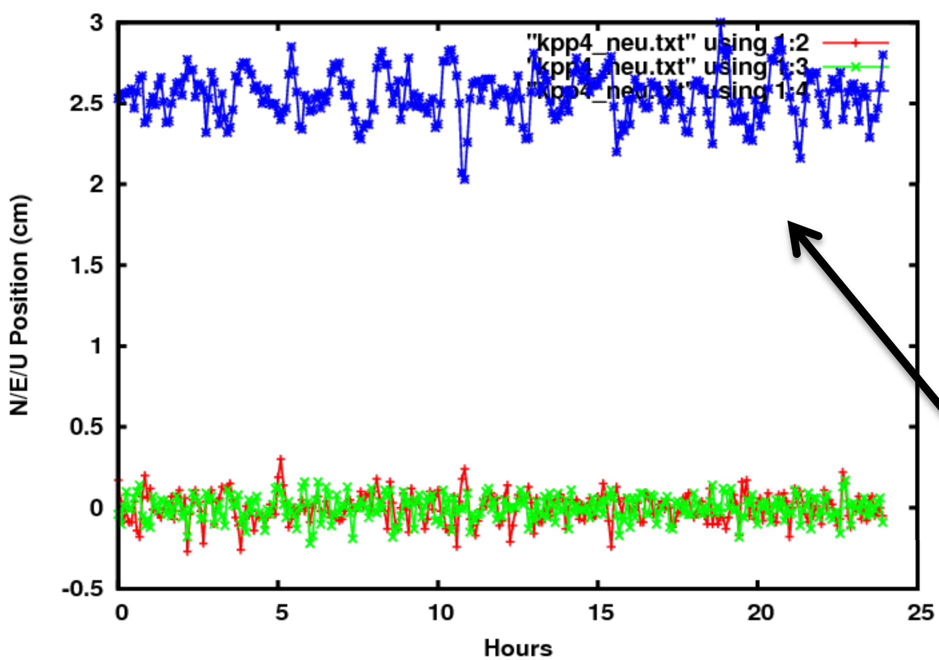
grep "STA X" ../kpp3/tdp_final

Example 4: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp4_neu.txt

gnup -lp1:2 kpp4_neu.txt -lp1:3 kpp4_neu.txt -lp1:4 kpp4_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is scatter of time series?

cat kpp4_neu.txt | cl 2 | stats | cl 3
cat kpp4_neu.txt | cl 3 | stats | cl 3
cat kpp4_neu.txt | cl 4 | stats | cl 3

- North: 0.1 cm
- East: 0.1 cm
- Up: 0.1 cm
- Using "est" from tdp2llh means we are looking at the change relative to the provided time varying nominal.
- **Bias in UP component results from –env_km information being ignored when providing STA [XYZ] in input.**

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Example 5: Using High Rate Data

cd ..

mkdir kpp5

cd kpp5

cp ../kpp4/run_again r5 # Copy run_again, and modify as needed.

– Edit script r5:

– Change data rate, and update rate of station positions to 30 seconds:

-r 30 \

-kin_sta_xyz 1.0e-3 5.7e-7 30 RANDOMWALK

– Execute script

./r5

NOTE: Takes much longer to run with more data.

Example 5: First look at run

- No errors in gd2p.err.
- Number of data points increased by factor of 10.
- Post-fit PC residuals increase significantly.
  - PC data are not carrier smoothed if –r option is same as original data rate.

cat Postfit.sum

start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:59:15	LC	GOL2	7.2019E-06	23883	14
10JAN09 23:59:45	10JAN10 23:59:15	PC	GOL2	1.0627E-03	23690	207

Example 5 – More checks

- Verify that the input transmitter clocks are high-rate (30-second) clocks.
  - Look at gd2p.log to verify that high-rate clock product was found.

  2010-01-10_hr.tdp.gz

  - Look at column 1 of tdp_clk_yaw

  more tdp_clk_yaw

- If high-rate transmitter clocks not available, could also use low-rate (5-minute) clocks and add –interp_300 option to gd2p command.
  - Expect higher postfit residuals and accuracy of solution to be worse.
- Verify that station position estimates are also at high-rate.
  - See column 1 of tdp_final file.

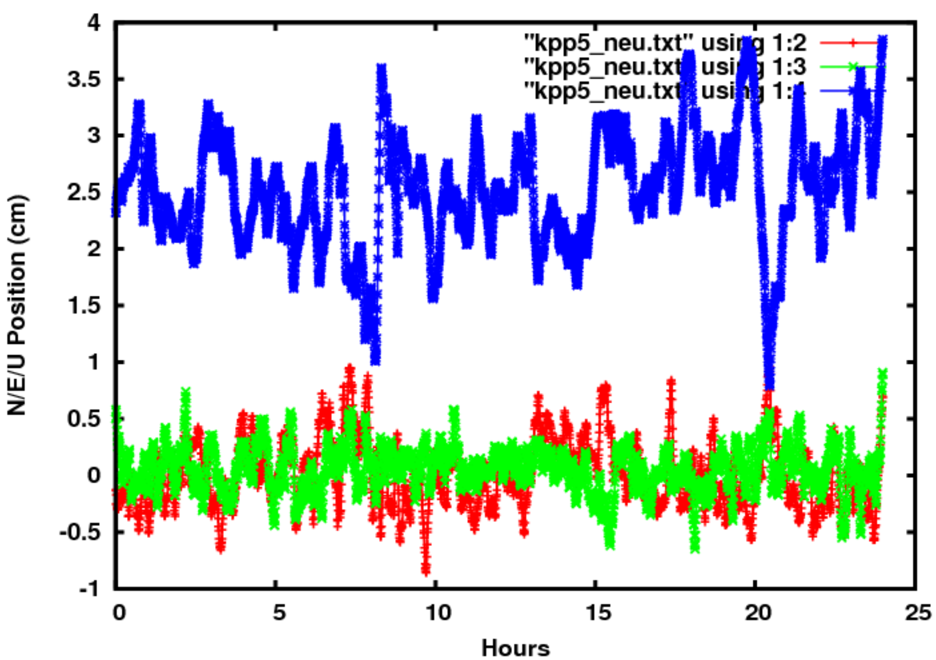
  grep "STA X" tdp_final | more

Example 5: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp5_neu.txt

gnup -lp1:2 kpp5_neu.txt -lp1:3 kpp5_neu.txt -lp1:4 kpp5_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is scatter of time series?

cat kpp5_neu.txt | cl 2 | stats | cl 3
cat kpp5_neu.txt | cl 3 | stats | cl 3
cat kpp5_neu.txt | cl 4 | stats | cl 3

- North: 0.3 cm
- East: 0.2 cm
- Up: 0.5 cm
- Larger scatter than low-rate run, as expected.

Example 6: Using Whitenoise Process

cd ..

mkdir kpp6

cd kpp6

cp ../kpp5/run_again r6 # Copy run_again, and modify as needed.

- Edit script r6:
- Switch to a white noise process to give kinematic solution freedom to follow the data. Useful for following cases:
  - Platform moving rapidly (e.g., airplane)
  - Motion is not known (could use pr2p to provide apriori information).
    - Might use as first attempt before "smoothing" with RANDOMWALK.
  - To capture rapid "jumps" in station position.

-kin_sta_xyz 1.0e3 1.0e3 30 WHITENOISE

- Execute script

  ./r6

Example 6: First look at run

- No errors in gd2p.err.
- Post-fit PC residuals decrease significantly.
  - Positions have significant freedom to follow the data.

cat Postfit.sum

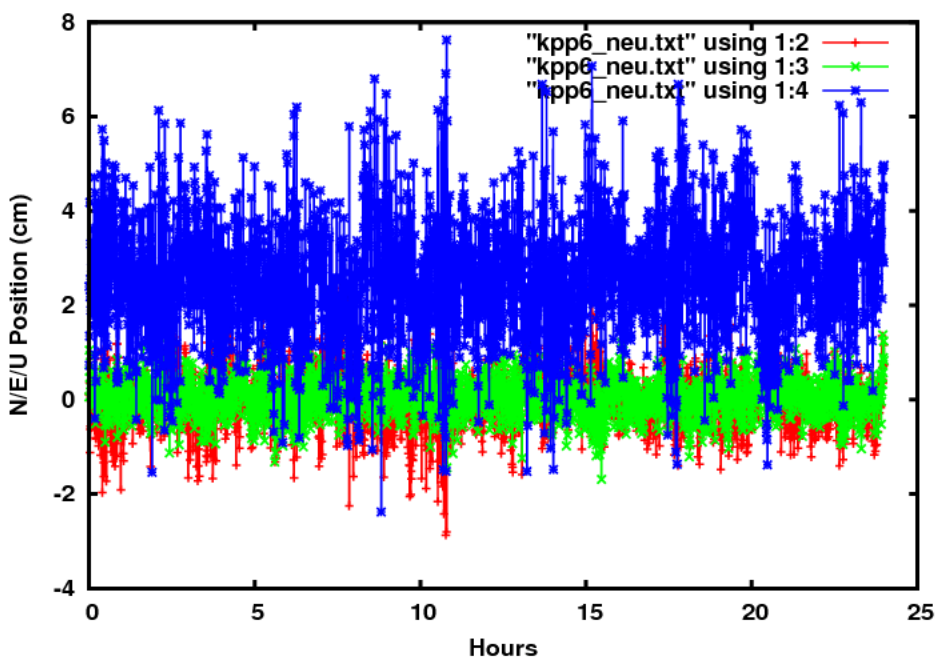
start time	stop time	type	user	postfit sigma	npts	outliers
10JAN09 23:59:45	10JAN10 23:59:15	LC	GOL2	5.9111E-06	23896	1
10JAN09 23:59:45	10JAN10 23:59:15	PC	GOL2	1.0622E-03	23689	207

Example 6: Position solution relative to nominal

- Use tdp2llh to compare the solution to the nominal.

  tdp2llh tdp_final GOL2 | grep est | cl h1 '1e2*c2' '1e2*c3' '1e2*c4' > kpp6_neu.txt

  gnup -lp1:2 kpp6_neu.txt -lp1:3 kpp6_neu.txt -lp1:4 kpp6_neu.txt -xl 'Hours' -yl 'N/E/U Position (cm)'



- What is standard deviation of time series?

cat kpp6_neu.txt | cl 2 | stats | cl 3
cat kpp6_neu.txt | cl 3 | stats | cl 3
cat kpp6_neu.txt | cl 4 | stats | cl 3

- North: 0.6 cm
- East: 0.4 cm
- Up: 1.2 cm
- Significantly larger scatter as expected.
- Represents extreme limit of positioning accuracy achievable from available data.
  - Random walk effectively smooths this solution.

Kinematic Positioning Suggestions

- Troposphere and clock are more correlated with position.
  - Provide nominal troposphere.
  - Use an atomic clock.
- Be more careful of bad data.
- Default gd2p.pl model is random walk model on STA [XYZ]
  - See flags –type, -kin_sta_xyz
  - If random walk (or white noise) update rate is different than the data rate, and nominal positions are provided through an input TDP file, positions will be interpolated to measurement times.
- Iterate on solution unless you have a good nominal.
  - Depends on speed of platform.