Aircraft kinematic positioning

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Overview

- Examine two application areas:
  - LIDAR altimetry measurements
  - Airborne Gravity
- Data cleaning and ambiguity resolution. Low multipath base stations and antenna calibration critical.
- Approaches to Atmospheric delay modeling
- Gravity surveys: Reducing short period noise using smoothed line-of-sight ionospheric delays and L1+L2 data.
- GPS receiver tracking loops and effects on kinematic positioning.

Cycle slip detection

- Multiple techniques are used to detect cycle slips:
  - Ln phase - Ln range (n=1,2). Removes geometry but affected by ionospheric delay (opposite sign on phase and range) and noise in range measurements
  - L1 phase - L2 phase. Some times called a wide-lane. Affected by ion-delay but is a common detector if gaps are small.
  - Double difference phase residuals: On short baselines, removes ionosphere and if good apriori positions are known, should be a smooth function of time. Often used to estimate number of cycles in sip and resolve to integer value. Limited use for aircraft and fast moving vehicles.
  - Melbourne-Wubena wide lane (ML-WL) (see over)

MW Wide lane

- From the equations for range and phase with the phase offsets for cycle offsets you can derive:

$$MW-WL = N_1 - N_2 = \phi_{L2} - \phi_{L1} + (P_1 + P_2)\frac{f_{L1} - f_{L2}}{f_{L1} + f_{L2}}$$

- The MW-WL should be constant if there are no cycle slips. When the phase and range values are double differences, N_2-N_1 should be integer.
- The factor for range is ~0.1 and so range noise is reduced.
- Average values of the MW-WL are used to estimate L1/L2 phase difference independent of ion-delay and geometry changes.

Ambiguity resolution

- The MW-WL is often used to get N1-N2 and then N1 is estimated, as non-integer value, from the least-squares fit to the phase data.
- If the sigma of the N1 estimate is small, and the estimate is close to an integer then it can be resolved to an integer values. There are various methods for deciding if an N1 estimate or a group of N1 estimates can be fixed to integers (e.g., LAMBDA method)
- Fixing ambiguities, improves the sigma of the east position estimate by typically a factor of two and makes it similar to the North sigma.
- With a forward backwards smoothing filter, non-resolved ambiguities are fixed non-integer values although resolving to integers does seem to improve results.
- Often incorrectly resolved or non-resolved ambiguities introduce slopes into time series. Easy to see with stationary sites but difficult to assess for moving vehicles.

Magnitudes of effects of ambiguities

- Basic changes in phase with ambiguities: LC ion-free combination; LG proportional to ion delay

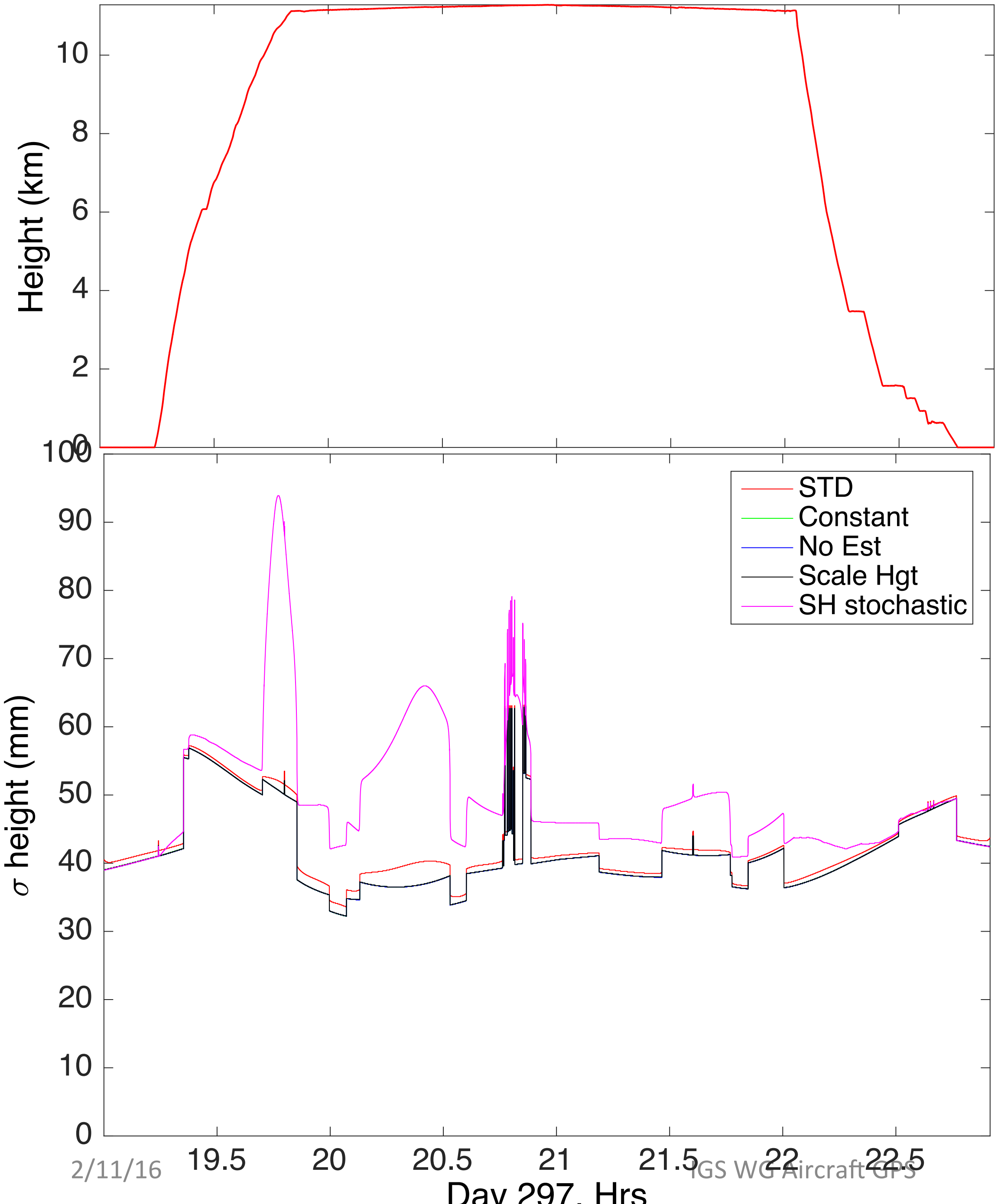
$$\Delta LC = \frac{1}{1-(f_2/f_1)^2} N_1 - \frac{f_2/f_1}{1-(f_2/f_1)^2} N_2 = 2.54 N_1 - 1.98 N_2$$

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

- 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).

Atmospheric delay estimates

- Multiple approaches are possible.
- In track, the options are:
  - Standard random walk (RW) process. Default RW 10 cm/sqrt(day). Setting the apriori sigma and/or RW process noise allows constant offset or no estimate (good for static short baselines).
  - Scale height estimates: Delay is proportional to height difference between aircraft and primary base station. Process noise model depends on rate of change of height.

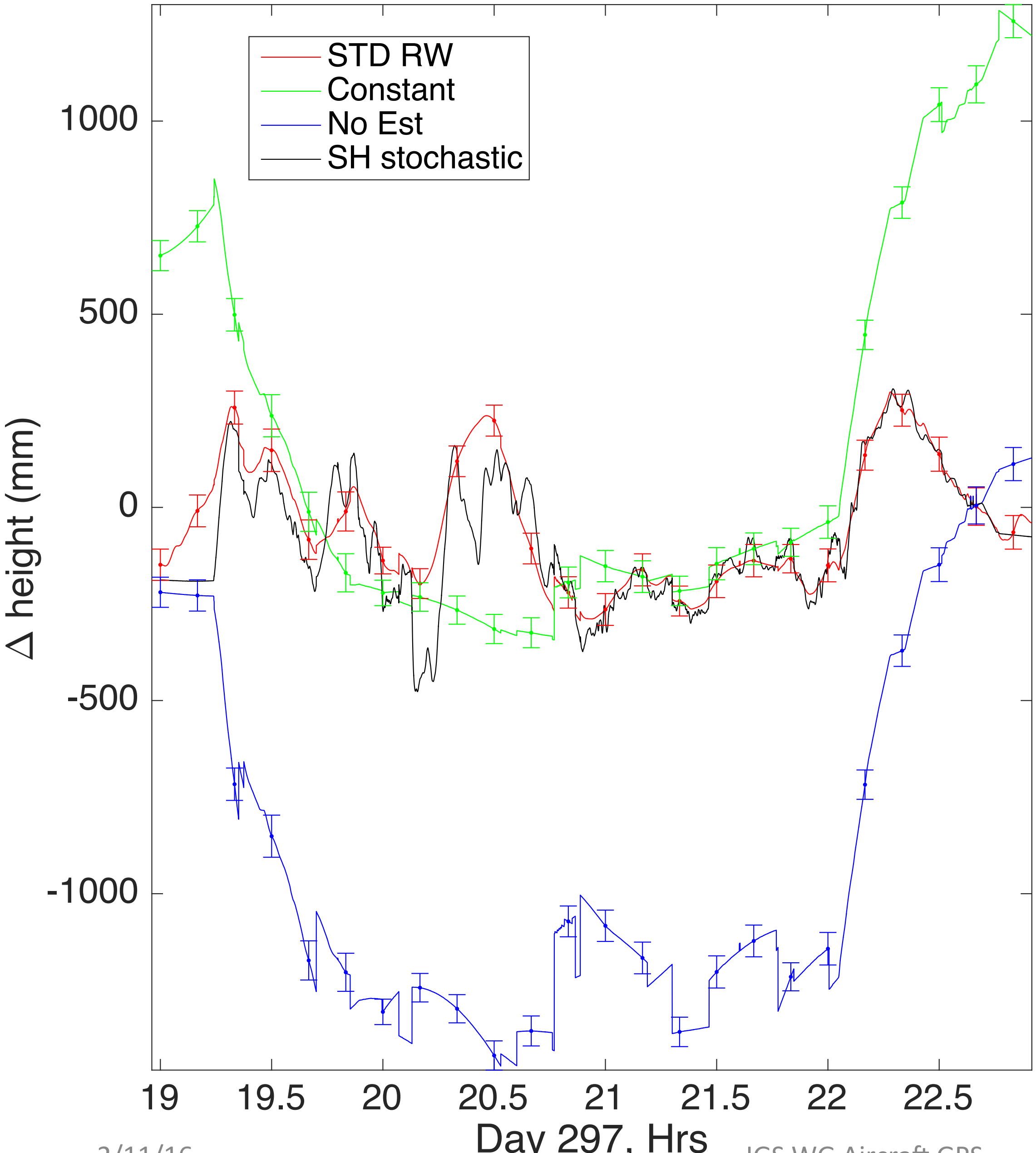


Effects of atmospheric delay estimates

Treatment of atmospheric delay has large effect on height sigmas.

RMS scatters of stationary periods

Soln	Start	End (mm)
Std R	25.5	20.5 mm
Constant	15.7	23.1 mm
No Est	9.4	9.1 mm
Scale Hgt	10.1	11.8 mm
SH stoc	9.7	12.9 mm

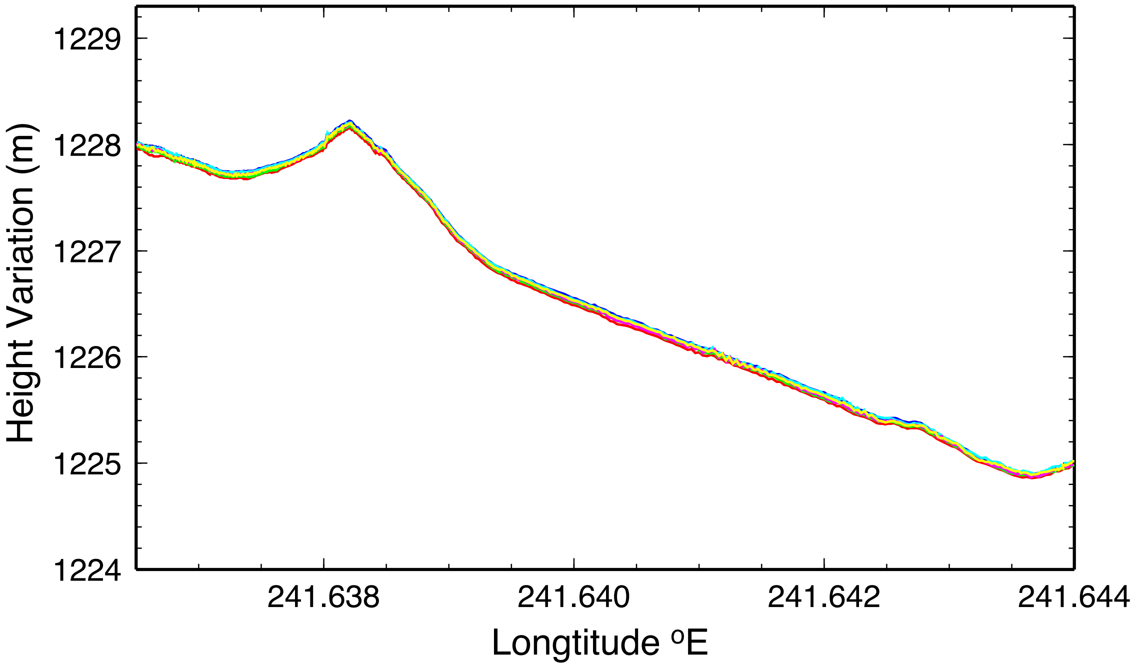


Impact on height estimates

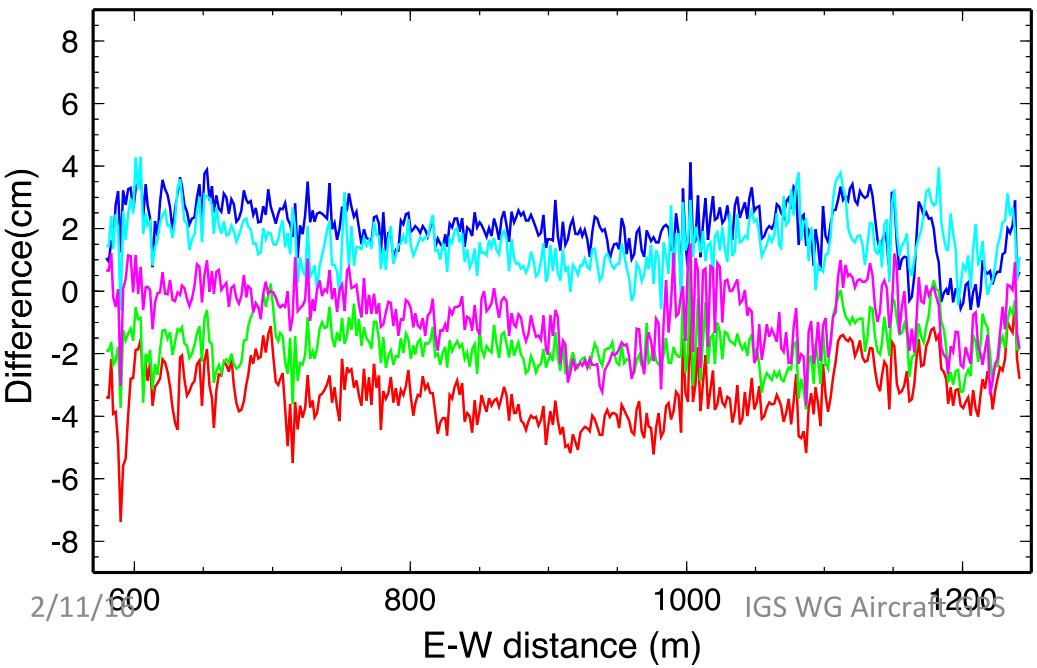
Differences for different analysis from the non-stochastic scale height estimates

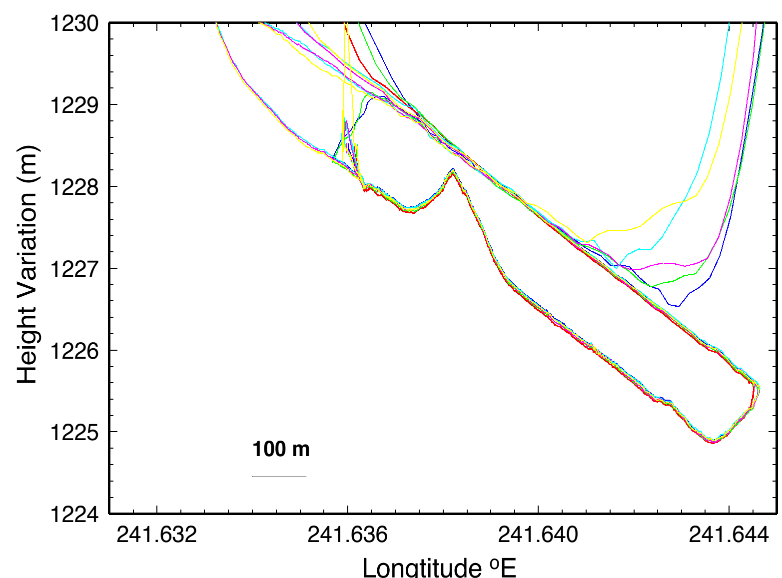
Soln	RMS (mm)
Std RW	163.6 mm
constant	504.1 mm
No Est	484.4 mm
SH stochastic	182.0 mm

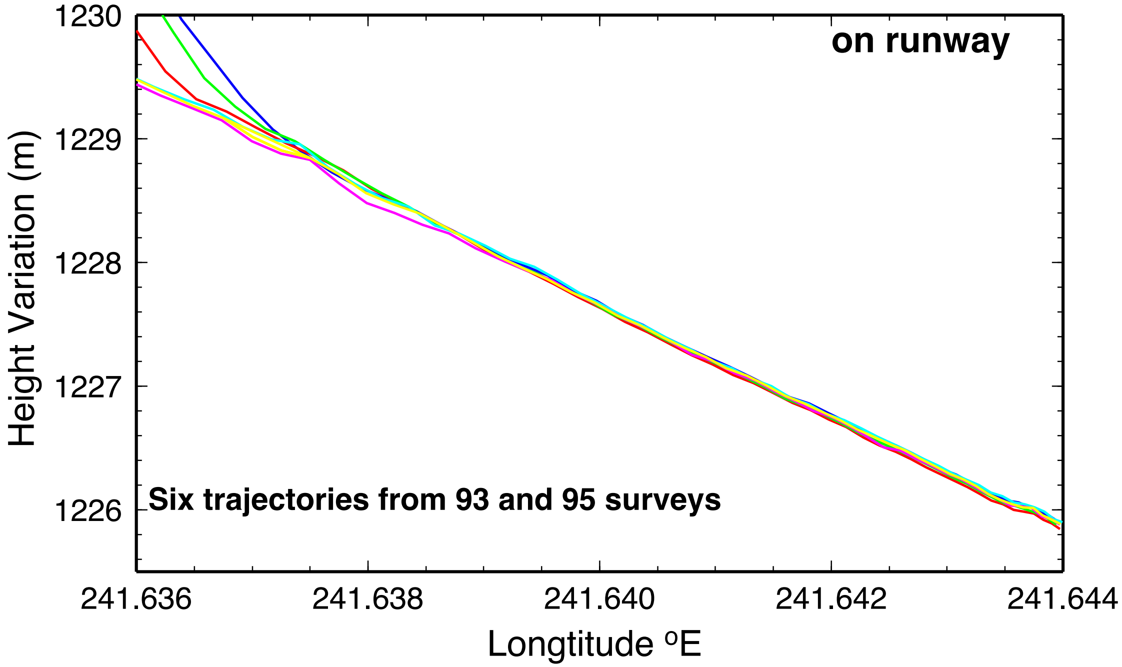
Assessment of kinematic positioning quality

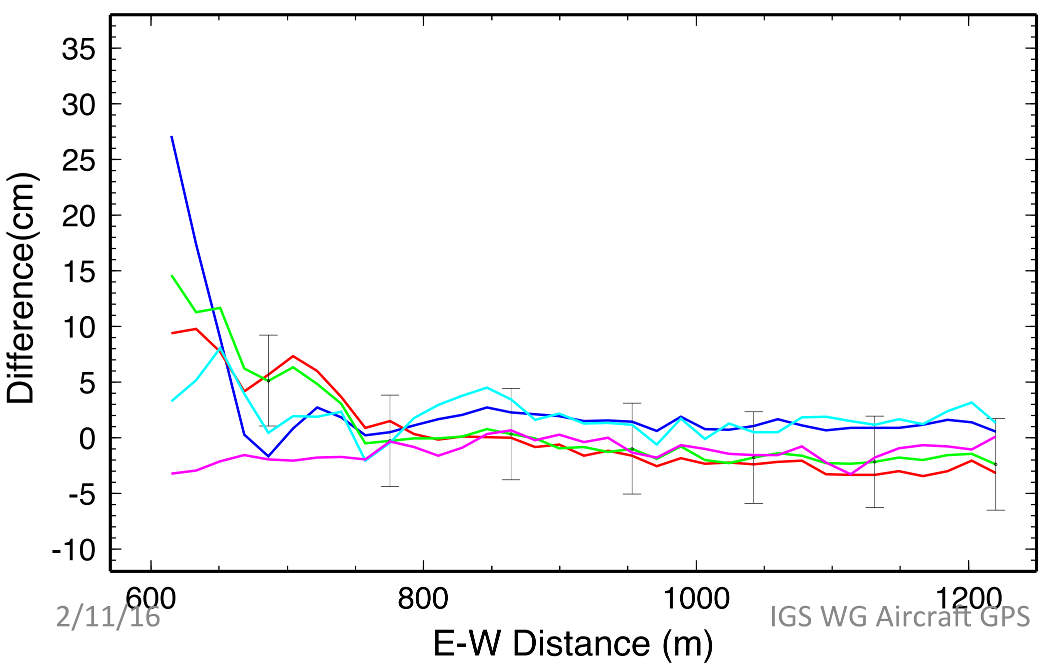


Taxiing
Lower left shows repeats.
Note aircraft weight might be different on different days and before and after.
Ghang Chen Ph. D thesis MIT



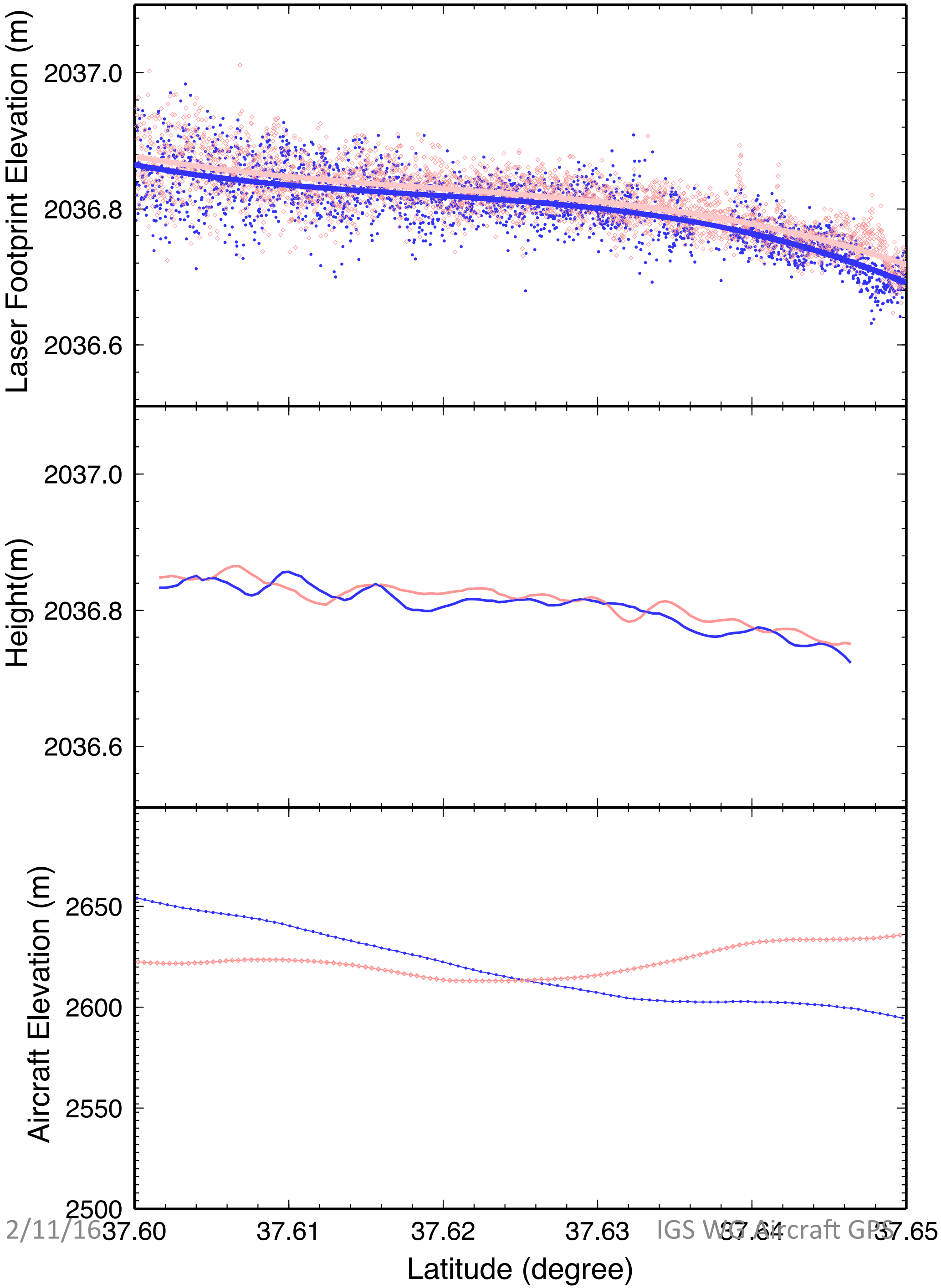






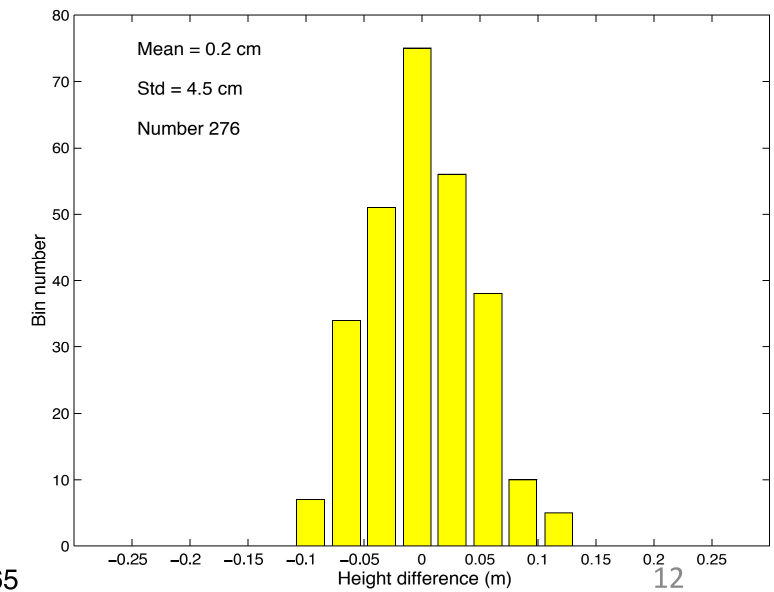
Details of landing (multiple years)

Mean differences vary between 1.2 and 3.1 cm (same aircraft but different years). Error bars is 4 cm; RMS differences ~2 cm.

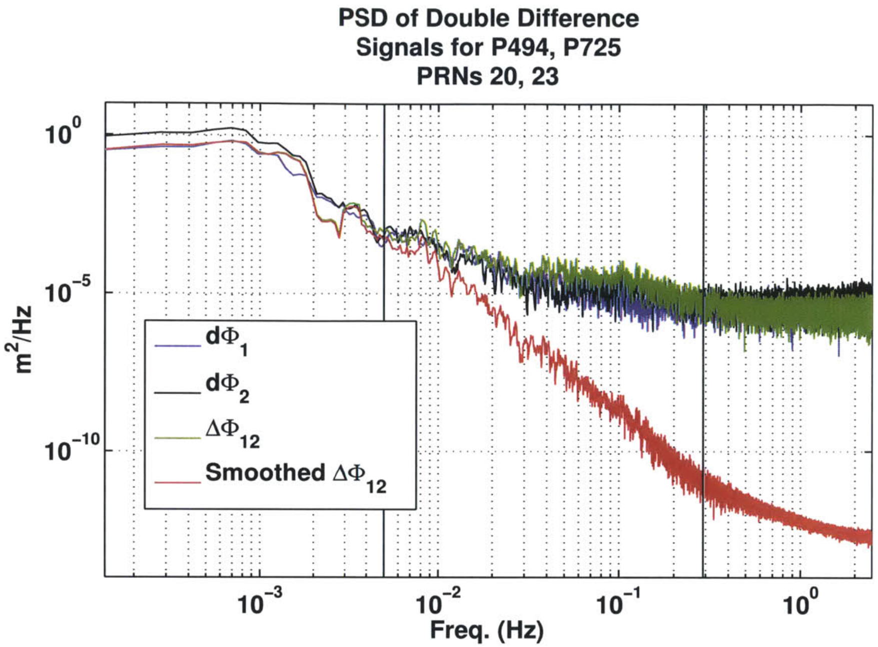


Lake Crowley over flight with laser altimeter

Histogram of differences. RMS 4.5 cm.

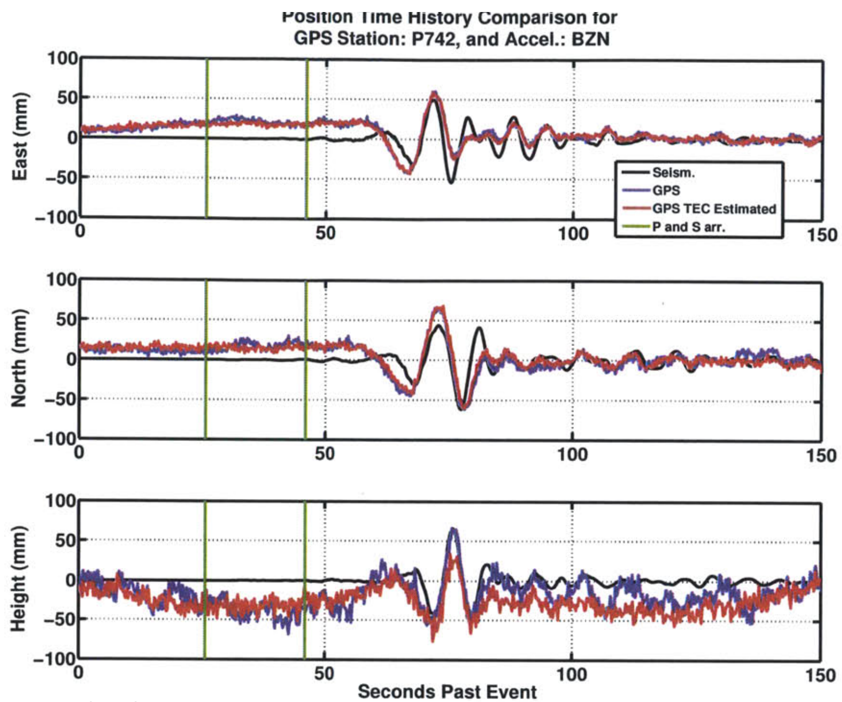


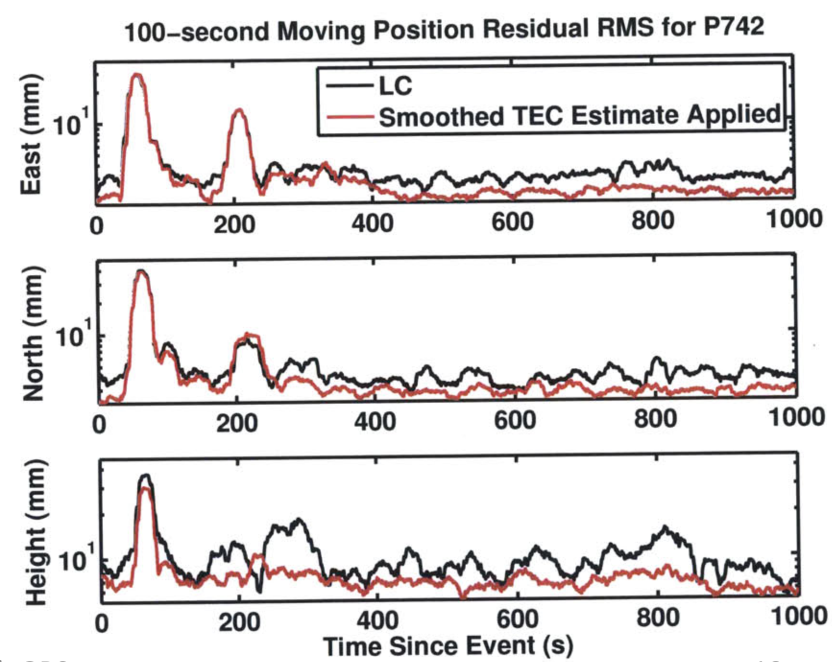
LC versus smoothed ionospheric delay model



Evaluating using smoothed ionospheric delay applied to L1+L2 to reduce short period noise. Example here is for seismic wave arrivals.

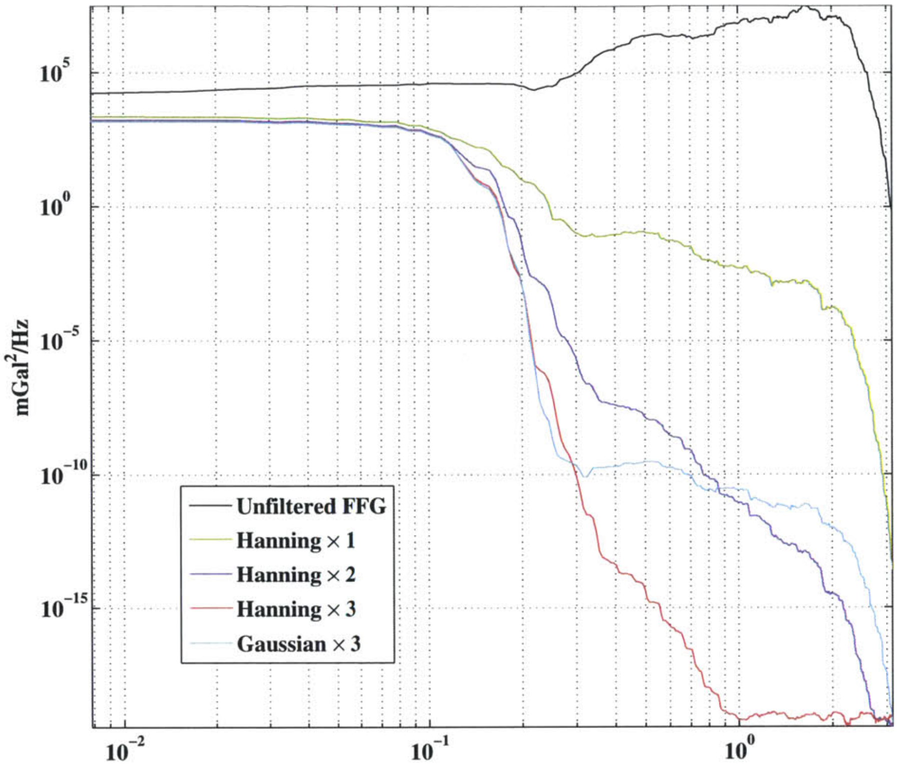
Frank Centinello Ph D. thesis MIT, 2015

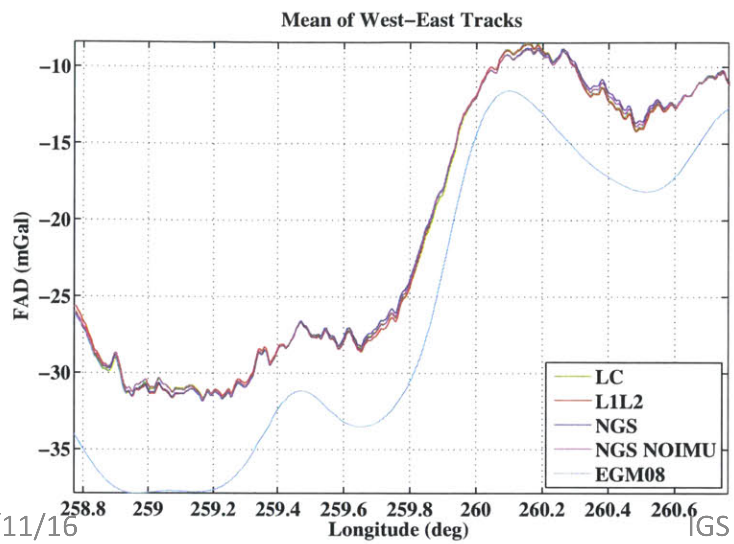


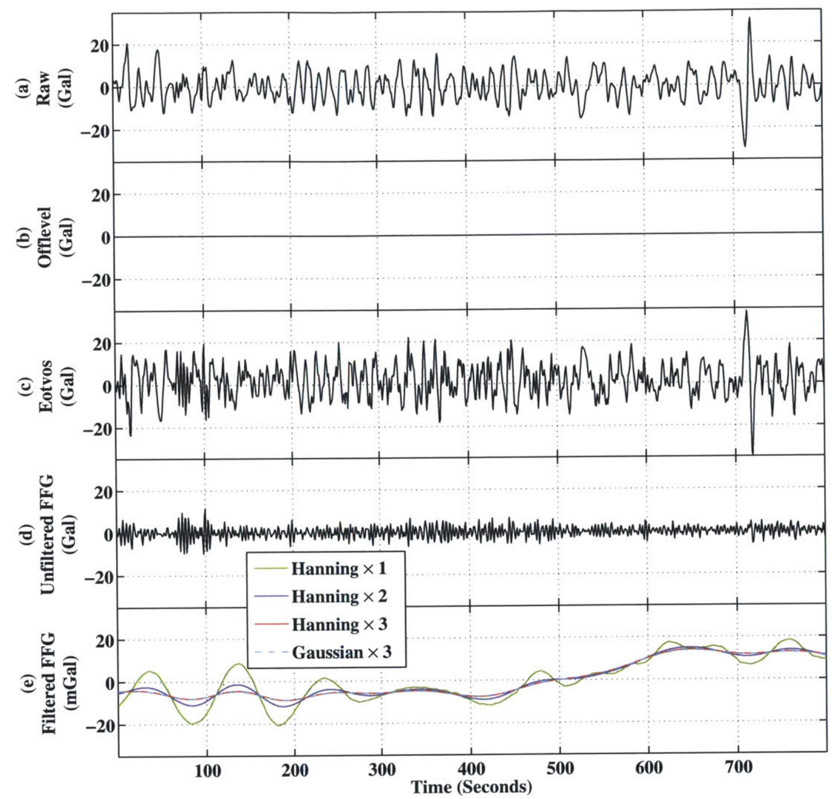


Gravity processing

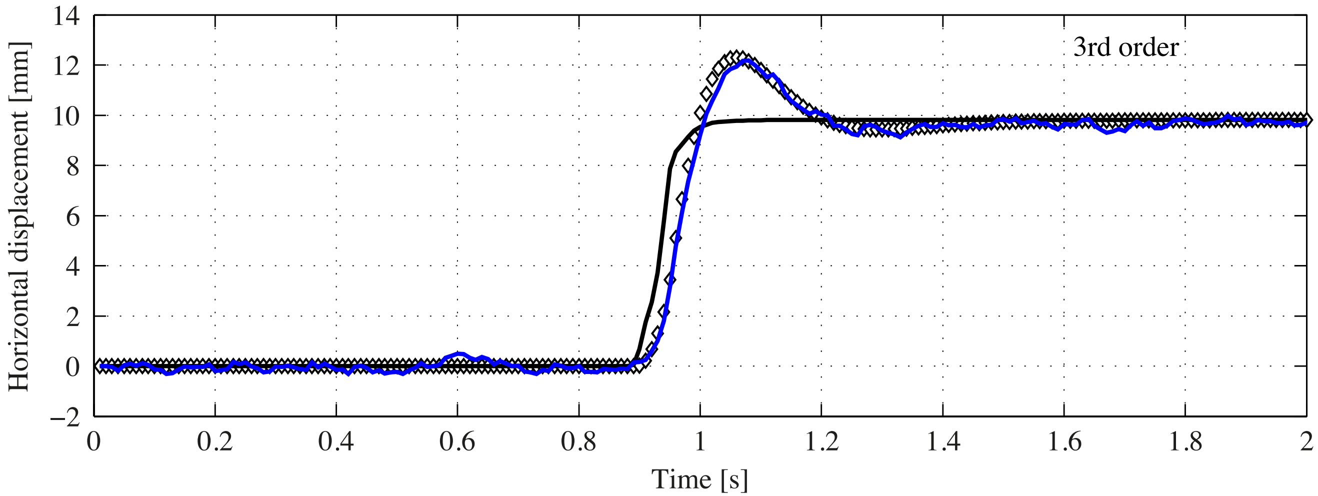
Smoothed ionospheric delay applied to L1+L2 data for airborne gravity. Frank Centinello Ph D. thesis MIT, 2015



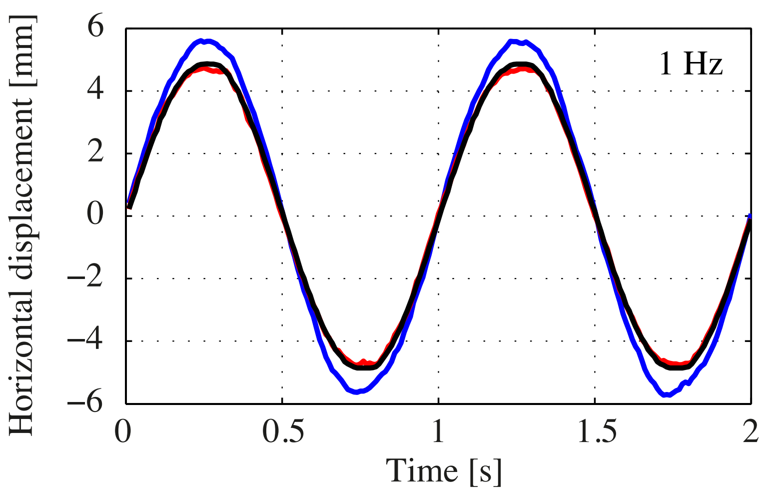


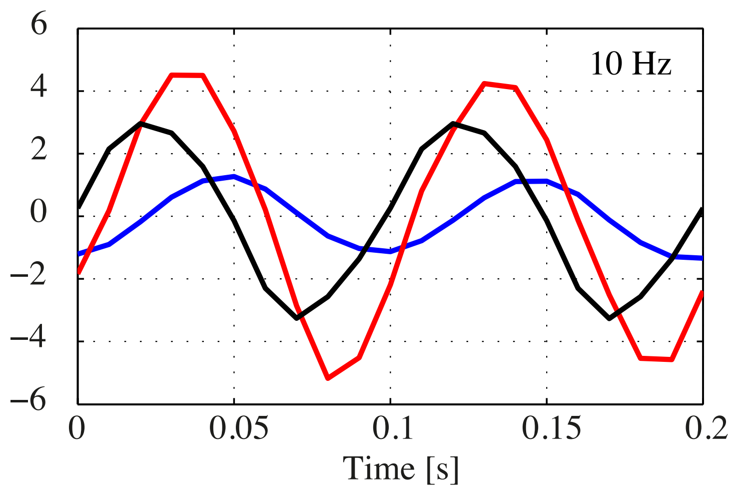


Instrument response



Step response dependent on tracking loop parameters. If tracking loop is known (rare), blue shows expected response, diamonds are data, black is actual





Similar but now for periodic. At 1 Hz OK, but at 10 Hz can be over or under estimated. Black is truth)

From: Simon Haberling Ph. D., , ETH Zurich “Theoretical and Practical Aspects of High-Rate GNSS Geodetic Observations “

Conclusions

- Treatment of atmospheric delay have a major impact of kinematic aircraft position.
- Assessment of in-flight accuracy is difficult.
- Potential reduction of short period noise using smoothed line-of-sight ionospheric delay. Not really useful for airborne gravity because of heavy filters that are needed.
- GPS instrument response may not be small.
- Aircraft antenna calibration should ideally be performed. Use two different orientations to fill the hole around the pole.