Innovative **N**avigation using new GNSS **SIG**nals with **H**ybridised **T**echnologies

iNsight

The impact of new signals and constellations for centimetre level positioning

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Overview

- What are the problems?
- What are the theoretical benefits?

- More satellites
  - GPS+GLONASS PPP example
- Different signals
  - Characteristics of GPS, GLONASS and Galileo
  - E5altboc positioning example
- More frequencies
  - Multiple frequency PPP

Introduction

“Why can’t I have centimetre level positioning everywhere?!”

- Need good geometry
  - Need lots of satellites in all directions; use long occupation times
- Need low noise and multipath
  - Use good antenna; keep away from buildings
- Need high accuracy orbits and clocks
  - Broadcast ephemeris improving; real-time PPP services
- Ionosphere and troposphere
  - Spatially variable; need dense network of reference stations; need at least two frequencies

Benefits of new constellations

1. More satellites in space
   - Better availability
   - Better DOP?
   - Better modelling of the troposphere
     - More signals sampling the troposphere
   - Better integrity
     - e.g. more satellites to check consistency
   - Faster convergence?

Benefits of new constellations

2. Different signals
   - Better noise characteristics
   - Better multipath characteristics
   - Faster convergence?
3. More frequencies
   - Better sampling of the ionosphere
     - Frequency dependence of ionosphere
   - Linear combinations of observations
     - Easier to fix ambiguities?
   - Faster convergence?

More satellites

More satellites

- PPP GPS+GLONASS ambiguity resolution test
  - Already two full constellations in space
  - CNES real-time products
    - GPS and GLONASS satellite ephemeris and clocks
    - Uses ~ 50 stations
    - Latency ~ 5 seconds
    - Real-time product but use off-line for testing
  - Insight Software Suite (ISS)
    - PPP and RTK positioning software developed in iNsight project
    - Ionosphere free measurements
    - Estimate troposphere wet delay using Kalman filter state
  - Expect more satellites will result in faster convergence

More satellites

- PPP ambiguity resolution
  - Fix GPS wide-lane ambiguities with Melborne-Wubbena combination
    - Wide-lane carrier phase minus narrow-lane pseudorange
  - Estimate ionosphere-free ambiguities in Kalman filter
    - Calculate narrow-lane ambiguities based on fixed wide-lane and float ionosphere-free ambiguities
  - LAMBDA ambiguity search

$$L_{IF} = \frac{f_1^2}{f_1^2 - f_2^2} L_1 - \frac{f_1 f_2}{f_1^2 - f_2^2} L_2 = \varsigma + \lambda_1 N_{IF}$$

$$N_{IF} = \frac{f_1}{f_1^2 + f_1^2} N_{NL} - \frac{f_1 f_2}{f_1^2 - f_2^2} N_{WL}$$

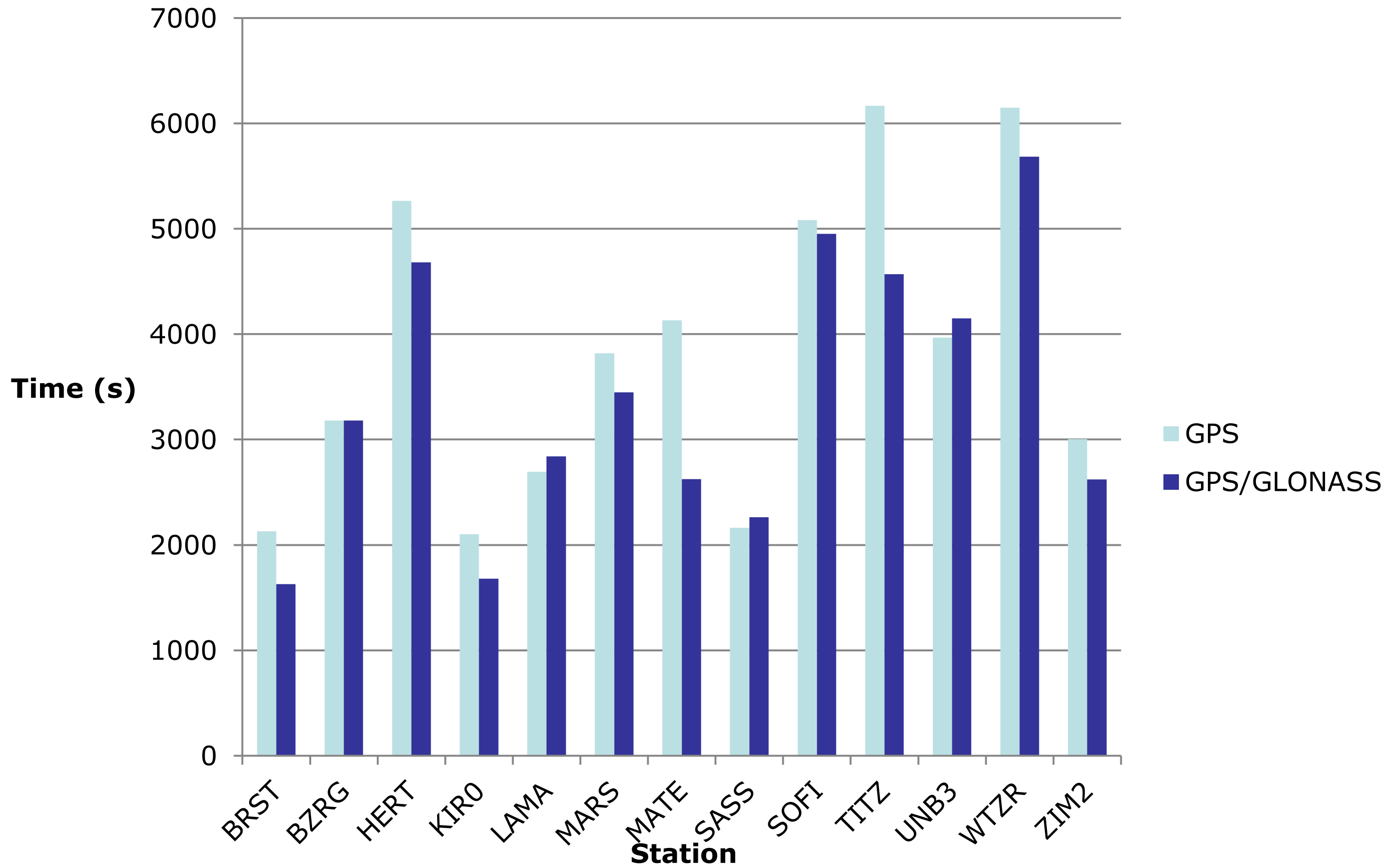
More satellites

- To test the impact of GPS+GLONASS:
- 13 IGS stations tested
  - BRST, BZRG, HERT, KIRO, LAMA, MARS, MATE, SASS, SOFI, TITZ, UNB3, WTZR, ZIM2
- Leica, Trimble, Javad receivers
- 10 days
  - 30-31 December 2011
  - 2-6 January 2012
  - 10-12 February 2012
- 5 second data rate
- Determine time to first fix
  - "at least four narrow-lane integer ambiguities"

IGS HERT station

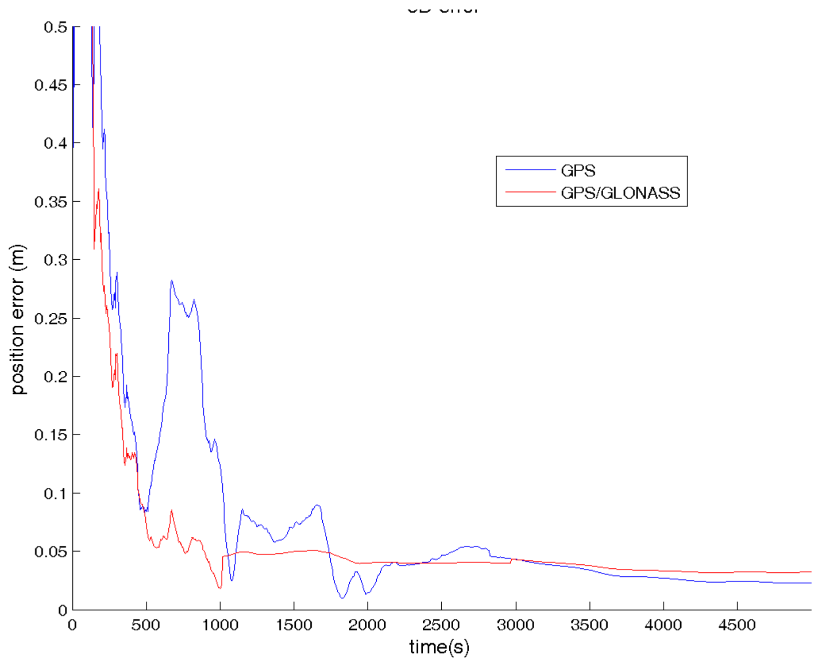
More satellites

Average time to fix ambiguities for different stations



More satellites

- Convergence example
  - Data recorded on 30 December 2012 at BRST IGS station
  - Ambiguities were fixed at the epoch 2825s (GPS only) and 1015s (GPS/GLONASS)



More satellites

- Using GLONASS shown to improve time to first fix
  - Improvement of 9% to fix ambiguities
- Impact of GLONASS diminished because of:
  - FDMA signal structure
  - Pseudorange inter-frequency biases
    - Receiver dependent, impacts Melborne-Wubbena
  - Increased noise of GLONASS observables
  - Carrier phase inter-frequency biases
    - Compensate using frequency and receiver manufacturer dependent corrections
  - Above result in less weight to GLONASS observations

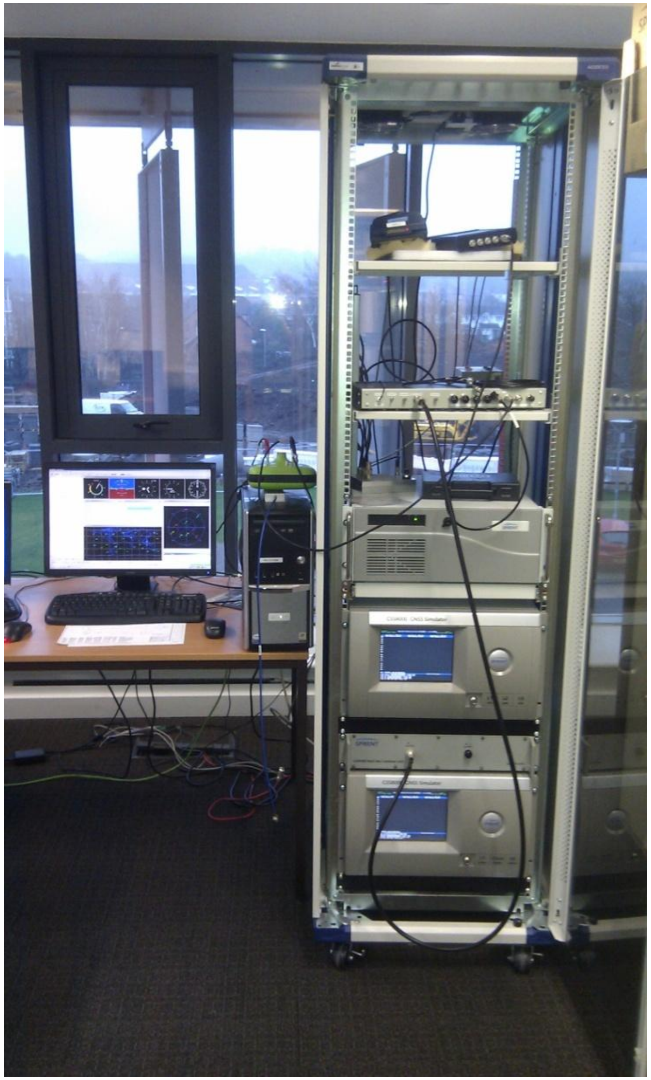
More satellites

- Currently we don't have two complete CDMA satellite systems
- Galileo has 4 satellites in space
  - 2 x GIOVE, 2 x Galileo IOV
  - Only limited ephemeris and clock products available (e.g. CONGO)
- Instead can use simulation to determine expected impact

More satellites

- Simulation

  - Spirent GSS8000 simulator
    - GPS L1/L2/L5
    - Galileo E1/E5a/E5b
  - Septentrio PolaRxS Pro
    - L1/L2/L5
    - R1/R2
    - E1/E5a/E5b/E5AltBoc
    - 136 channels
    - Up to 100Hz output
    - RINEX 3.0



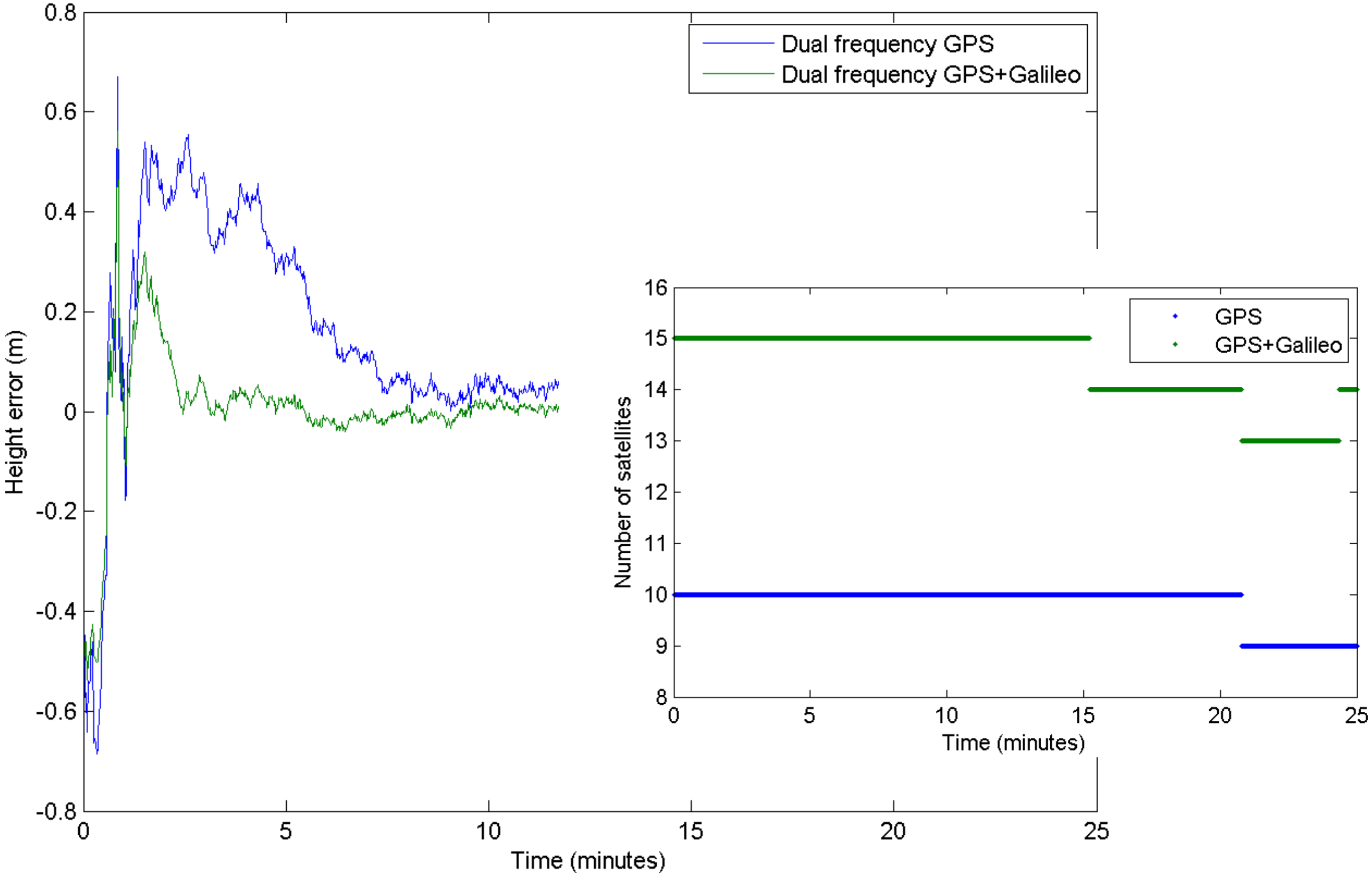
More satellites

- Simulation

Model	Simulation
Ephemeris	Broadcast, no error
Satellite clocks	Broadcast, no error
Troposphere	STANAG, add ZTD
Ionosphere	Klobuchar
Satellite phase centre correction	x
Phase wind-up correction	x
Antenna phase centre correction	x
Solid Earth tide	x
Ocean tide loading	x
Pole tide	x
Satellite hardware delays	x
Multipath	Model reflector, attenuation

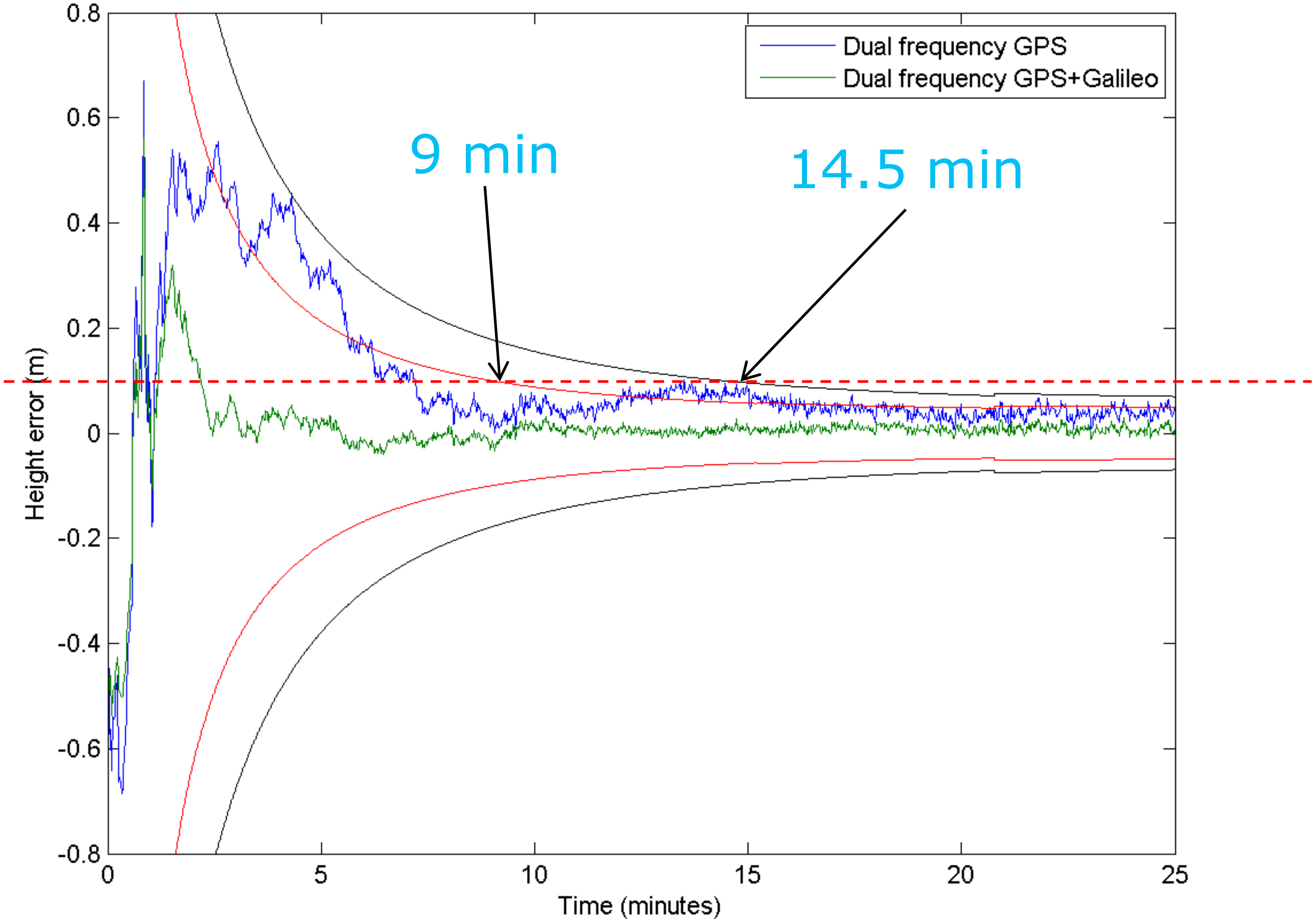
More satellites

Height convergence for 1) GPS L1+L2 ionosphere free and 2) GPS (L1+L2) with Galileo (E1+E5a)



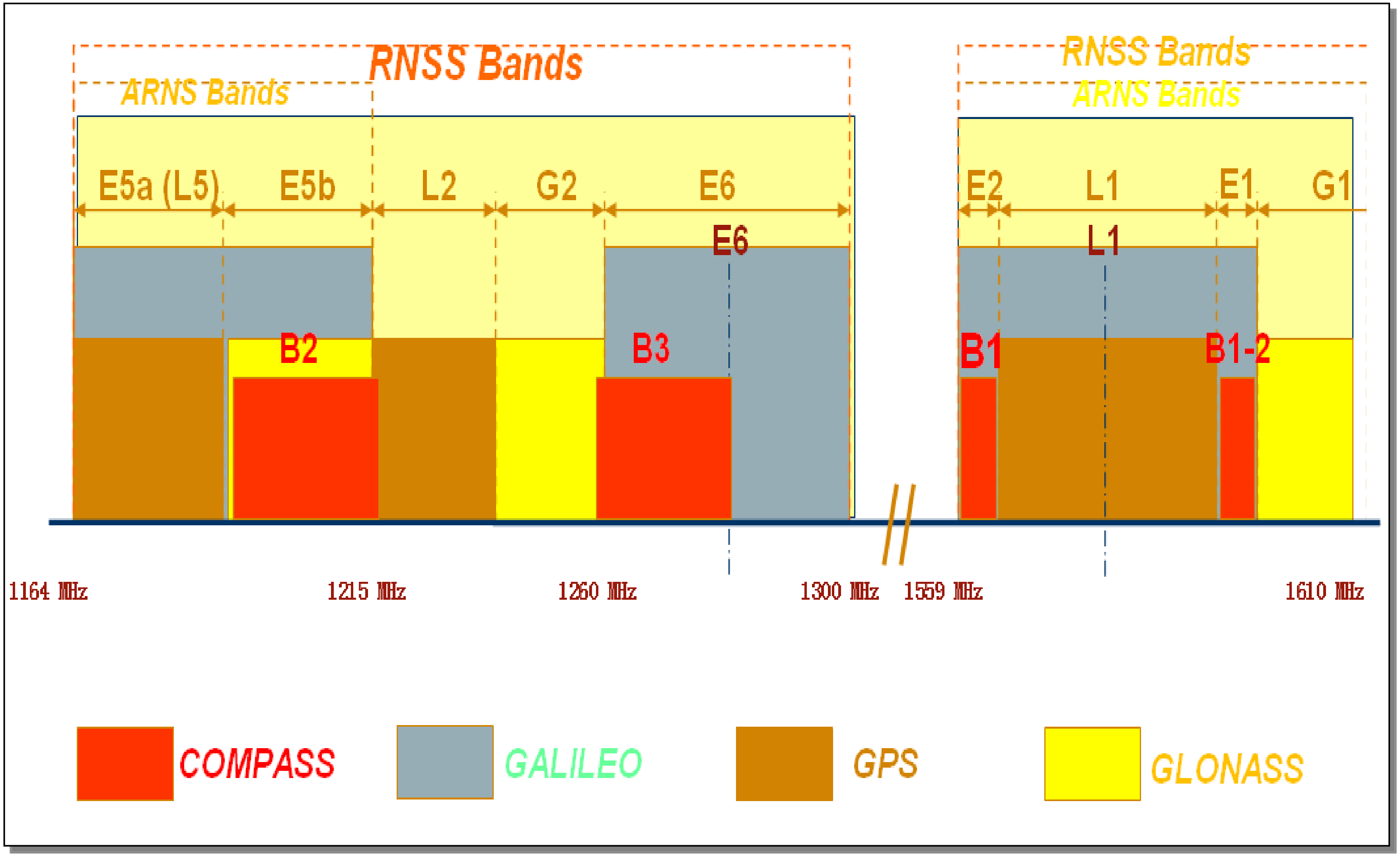
More satellites

Height convergence for 1) GPS L1+L2 ionosphere free and 2) GPS (L1+L2) with Galileo (E1+E5a)



New signals

New signals


RNSS Bands
ARNS Bands
E5a (L5)
E5b
L2
G2
E6
E6
B2
B3
RNSS Bands
ARNS Bands
E2
L1
E1
G1
L1
B1
B1-2
1164 MHz
1215 MHz
1260 MHz
1300 MHz
1559 MHz
1610 MHz
COMPASS
GALILEO
GPS
GLONASS

New signals

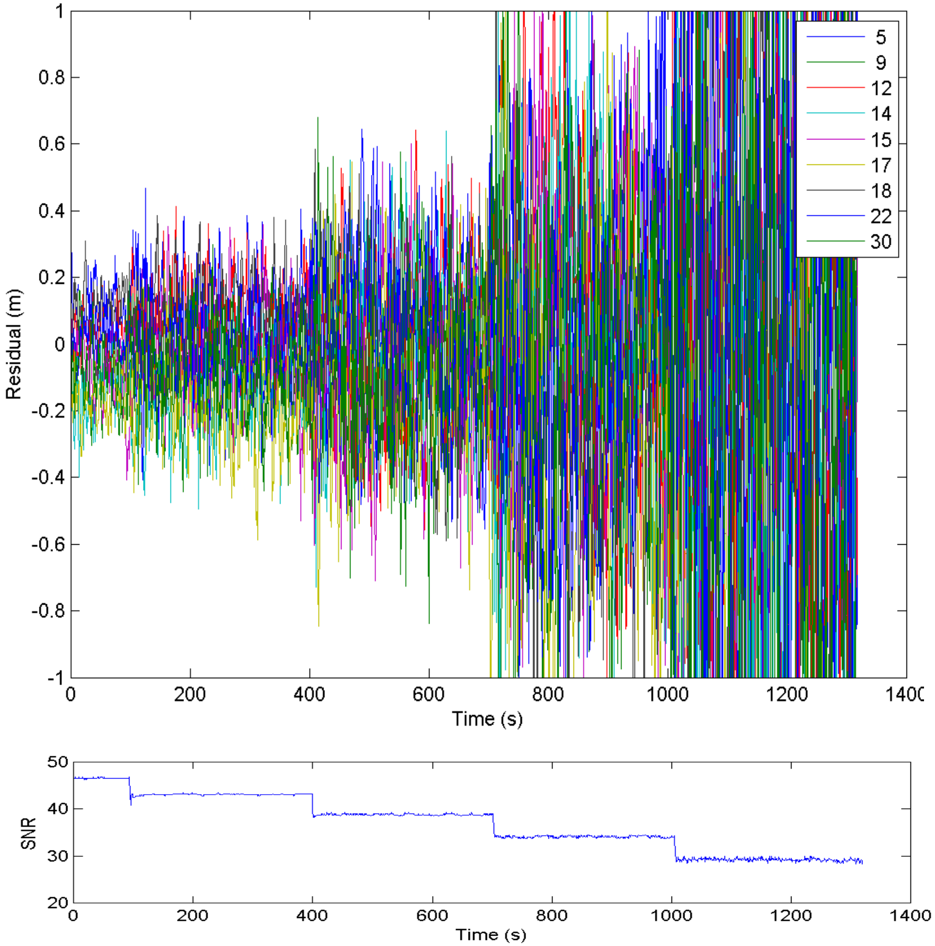
iNsight

Constellation	Frequency	0dB	-5dB	-10dB	-15dB	-20dB
GPS	L1	0.076	0.130	0.223	0.433	0.735
	L2	0.045	0.124	0.102	0.173	N/A
	L5	0.022	0.037	0.065	0.116	0.208
Galileo	E1	0.036	0.063	0.105	0.192	N/A
	E5a	0.025	0.042	0.074	0.136	0.224
	E5b	0.023	0.036	0.063	0.116	0.199
	E5altboc	0.005	0.008	0.014	0.026	0.044

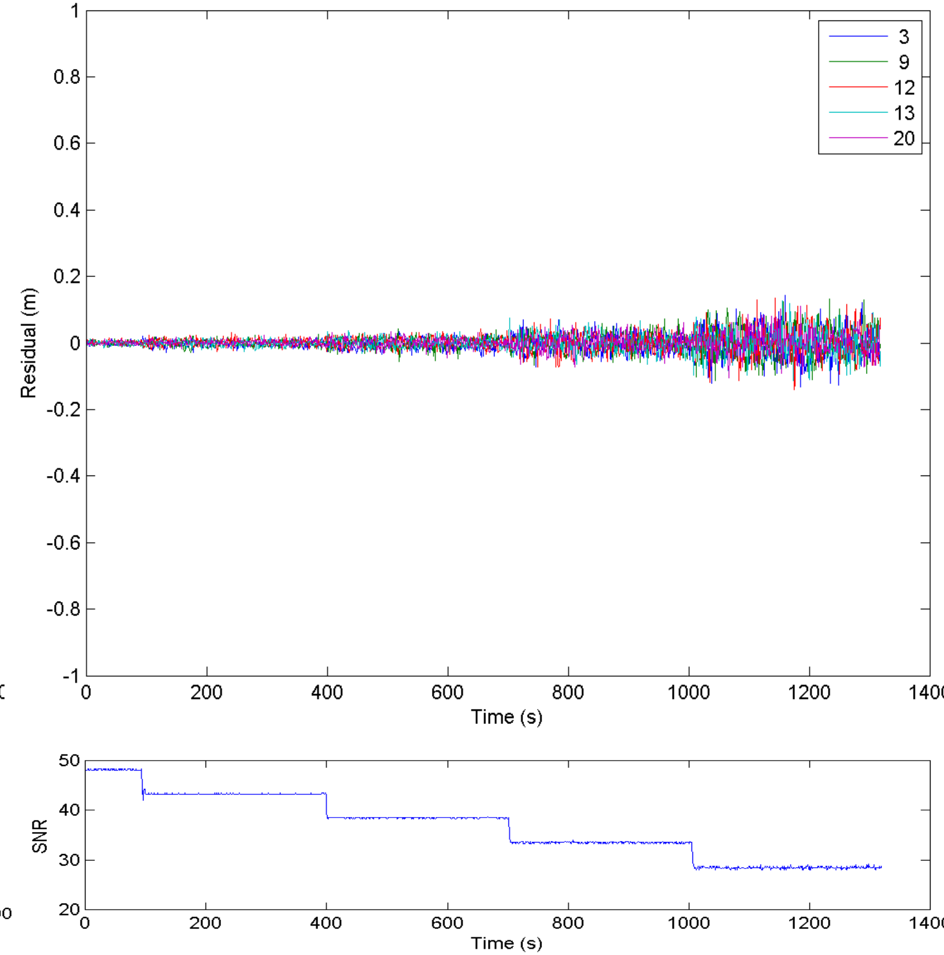
Pseudorange tracking noise using Spirent GSS8000 and Septentrio PolaRxS (m)

New signals

GPS L1 residuals



Galileo E5altboc residuals



New signals

- Simulated data difficult to make more like the real world
- Current signals in space:
  - 31 GPS healthy
  - 24 GLONASS (+2 maintenance, 4 spares, 1 test)
  - 2 Galileo IOV + GIOVE-A + GIOVE-B
  - also COMPASS and QZSS but don't have receiver capable of tracking

New signals

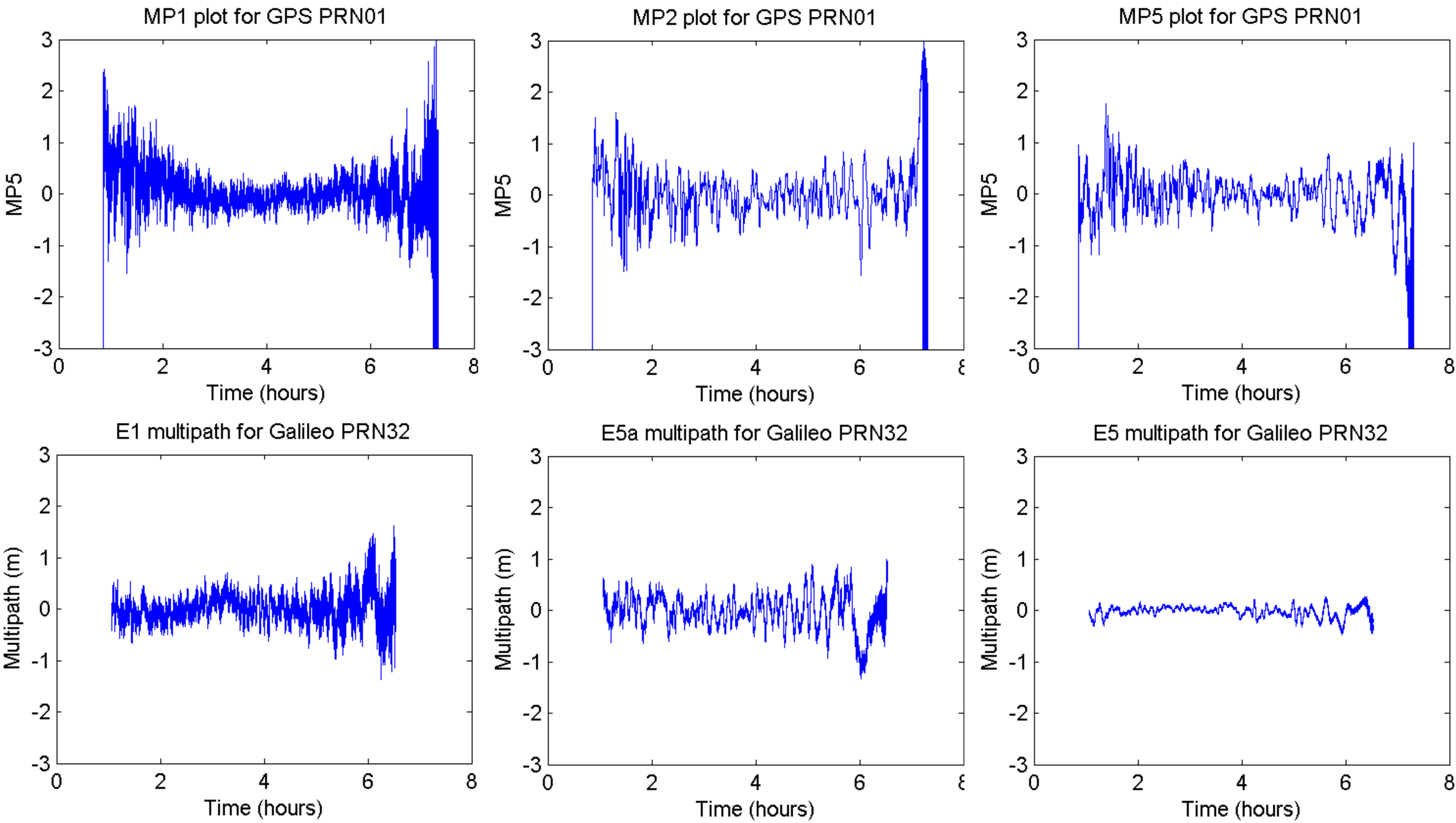
- Observables to investigate real data
  - MP1, MP2, MP5, i.e.

$$M_{P1} = P_1 - \Phi_1 + 2\lambda_1^2 \frac{\Phi_2 - \Phi_1}{\lambda_2^2 - \lambda_1^2}$$

- For three frequency satellites we have

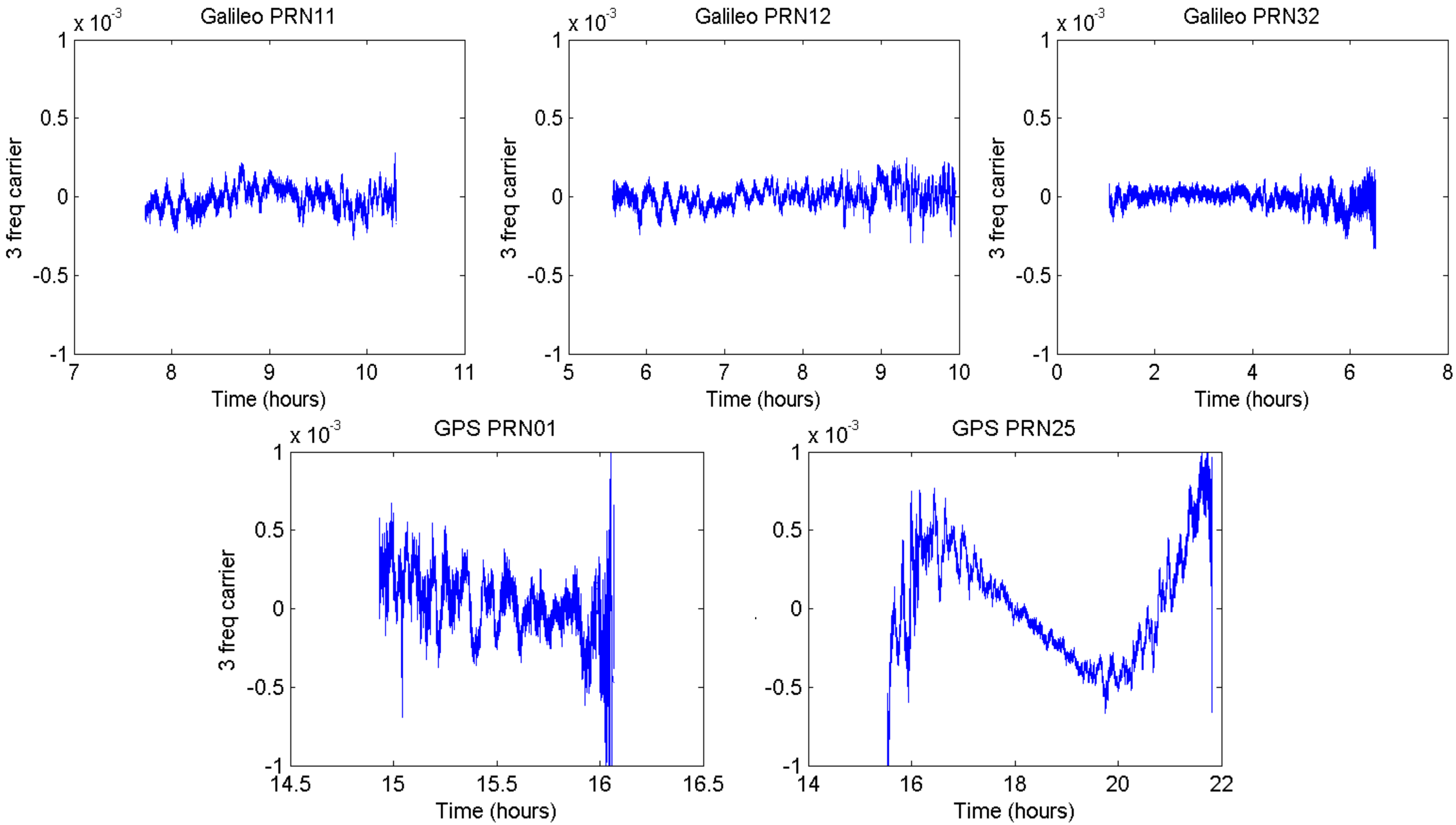
$$M_{\Phi 123} = \lambda_3^2(\Phi_1 - \Phi_2) + \lambda_2^2(\Phi_3 - \Phi_1) + \lambda_1^2(\Phi_2 - \Phi_3)$$

New signals



MP1 plot for GPS PRN01
MP2 plot for GPS PRN01
MP5 plot for GPS PRN01
MP5
Time (hours)
E1 multipath for Galileo PRN32
E5a multipath for Galileo PRN32
E5 multipath for Galileo PRN32
Multipath (m)
Time (hours)
3
2
1
0
-1
-2
-3
0
2
4
6
8

New signals


Galileo PRN11
Galileo PRN12
Galileo PRN32
GPS PRN01
GPS PRN25
x 10^-3
3 freq carrier
Time (hours)
1
0.5
0
-0.5
-1

New signals

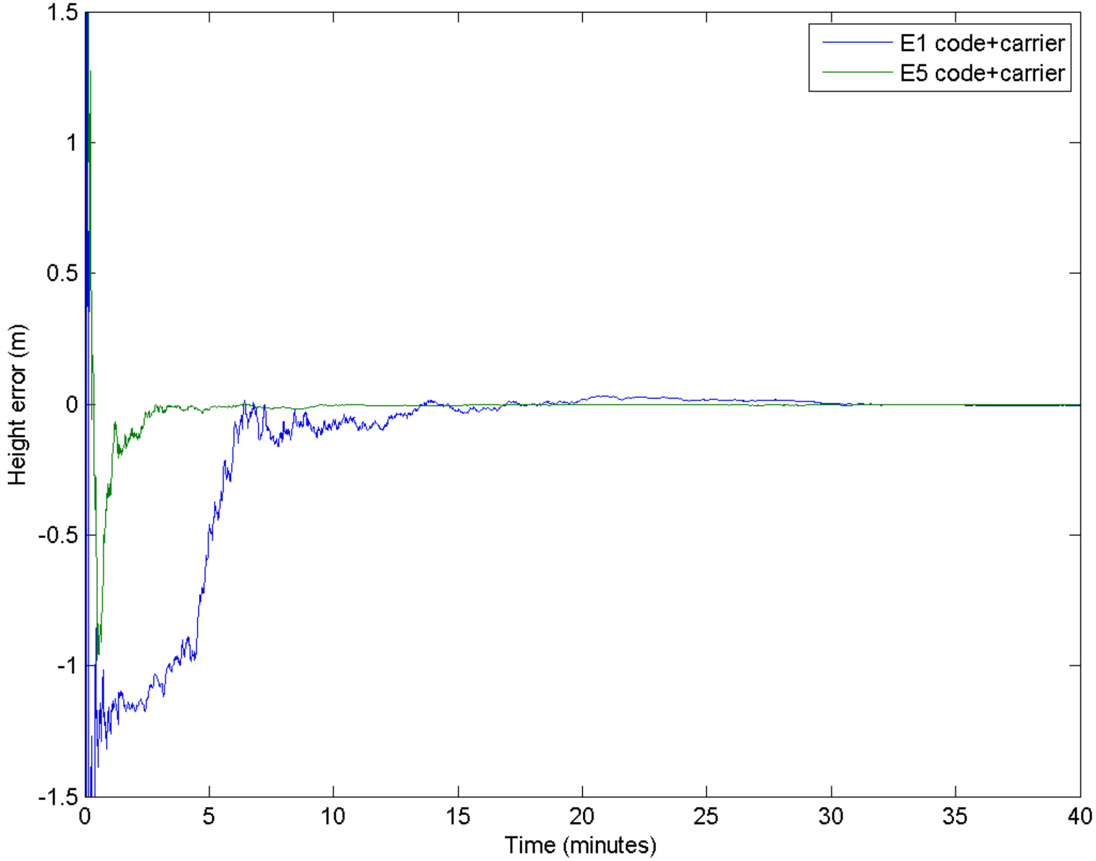
- How to make the most of a single high accuracy pseudorange?
- Significant impact for short baseline RTK
- PPP and long baseline RTK both affected by ionosphere and troposphere
- One possible method is code plus carrier
  - cancels 1st order ionosphere but adds ambiguity

$$\frac{P+\phi}{2} = \rho + \frac{\lambda N}{2} + dtrop + dT + m_{P+\phi} + e_{P+\phi}$$

New signals

Code+carrier static height error (5 Galileo satellites)

E1 compared to E5altboc



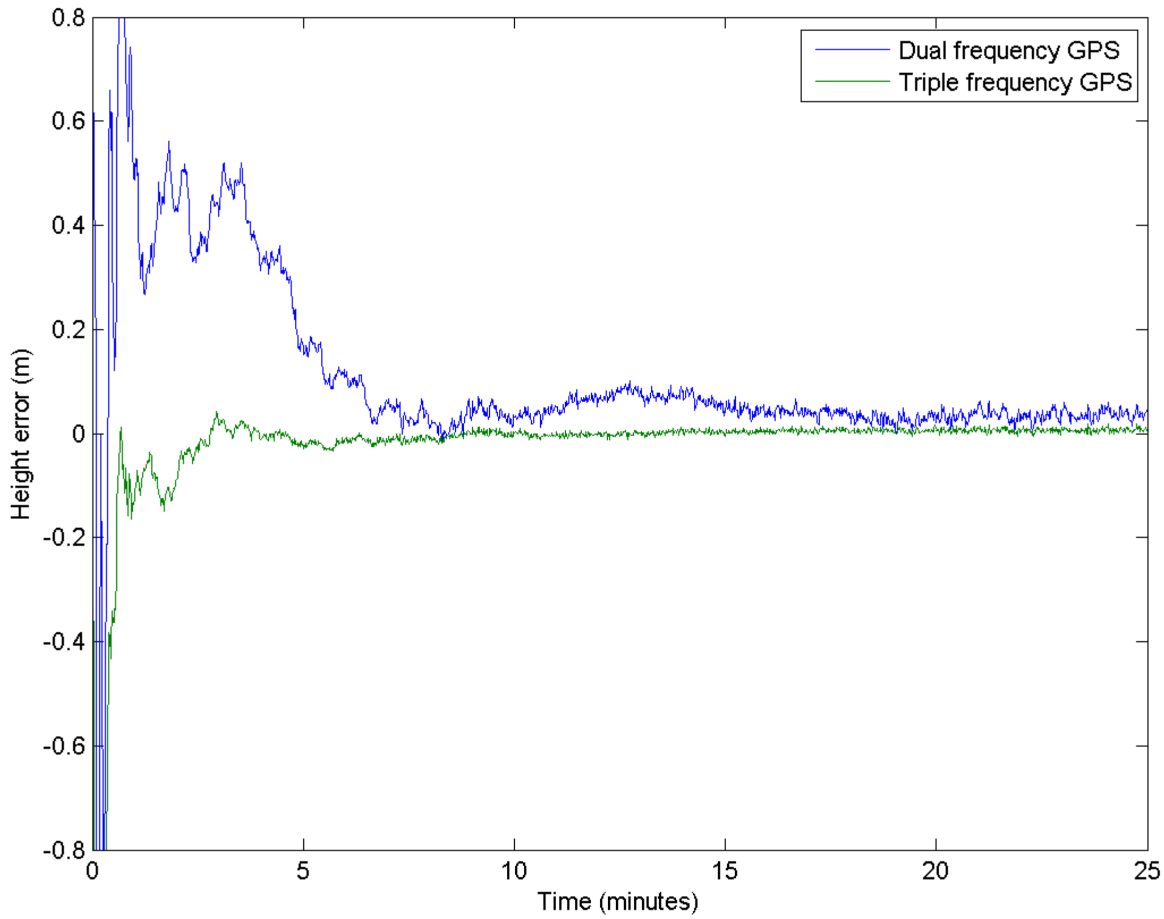
More frequencies

More frequencies

- All future plans for new or updated constellations include 3 frequencies
- Benefits
  - 1^{st} order ionosphere can be removed
  - Can form linear combinations
  - Can aid ambiguity resolution e.g. cascading ambiguity resolution
    - extra-widelane -> wide-lane -> L1
  - Faster convergence
- Issues
  - Satellite hardware delays need to be determined and cannot be separated from clocks
  - Ionosphere needs to be removed for PPP

More frequencies

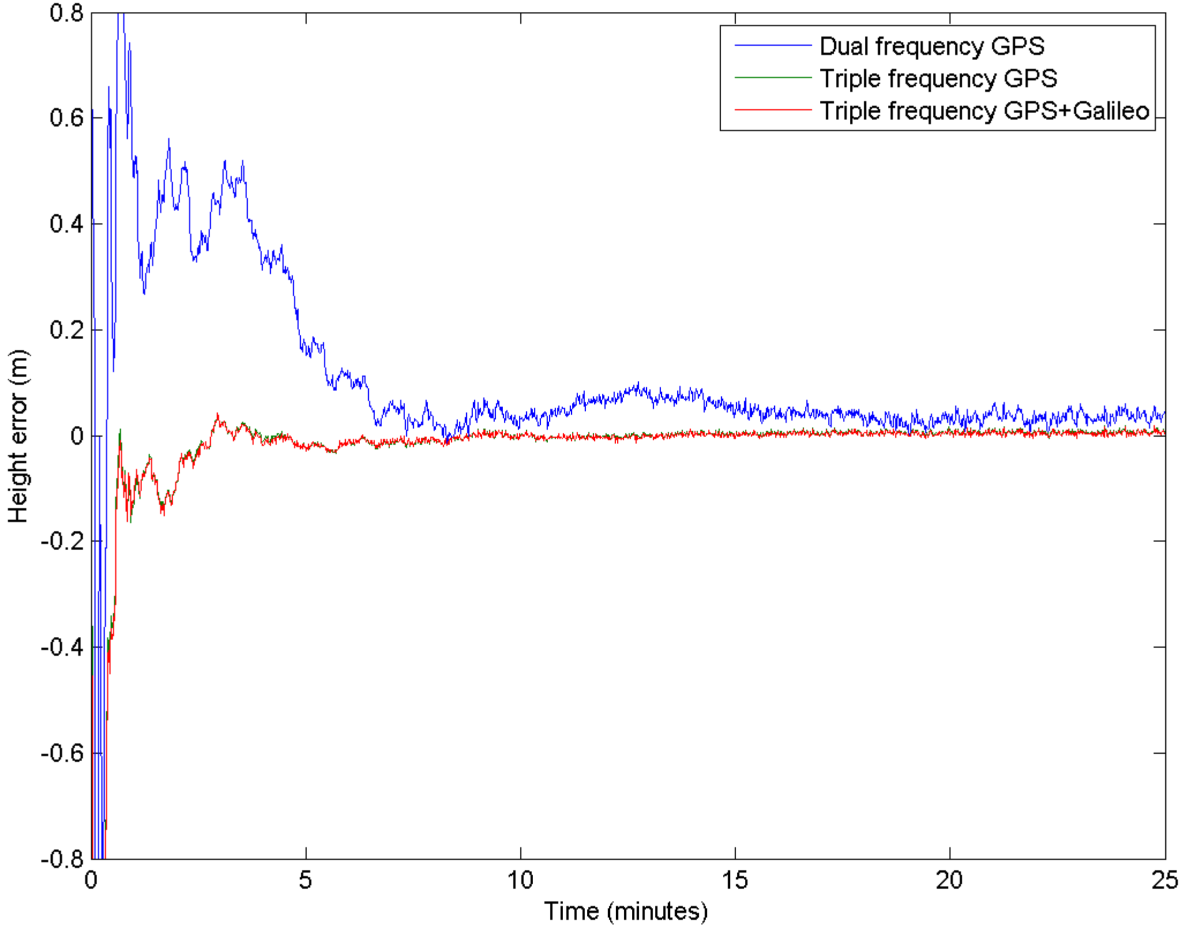
L1/L2 GPS PPP compared to L1/L2+L1/L5 GPS PPP



More frequencies

L1/L2+L1/L5 GPS PPP compared to

L1/L2+L1/L5 GPS with E1/E5a+E1/E5 Galileo



Conclusions

- More satellites
  - Not seeing the full benefit of a new constellation with GLONASS due to FDMA
  - Difficult to quantify improvement until satellites are in space
- New signals
  - Significant improvement with E5altboc
- New frequencies
  - Additional frequencies will improve convergence and aid with ambiguity resolution

Thanks for attention!

Questions?