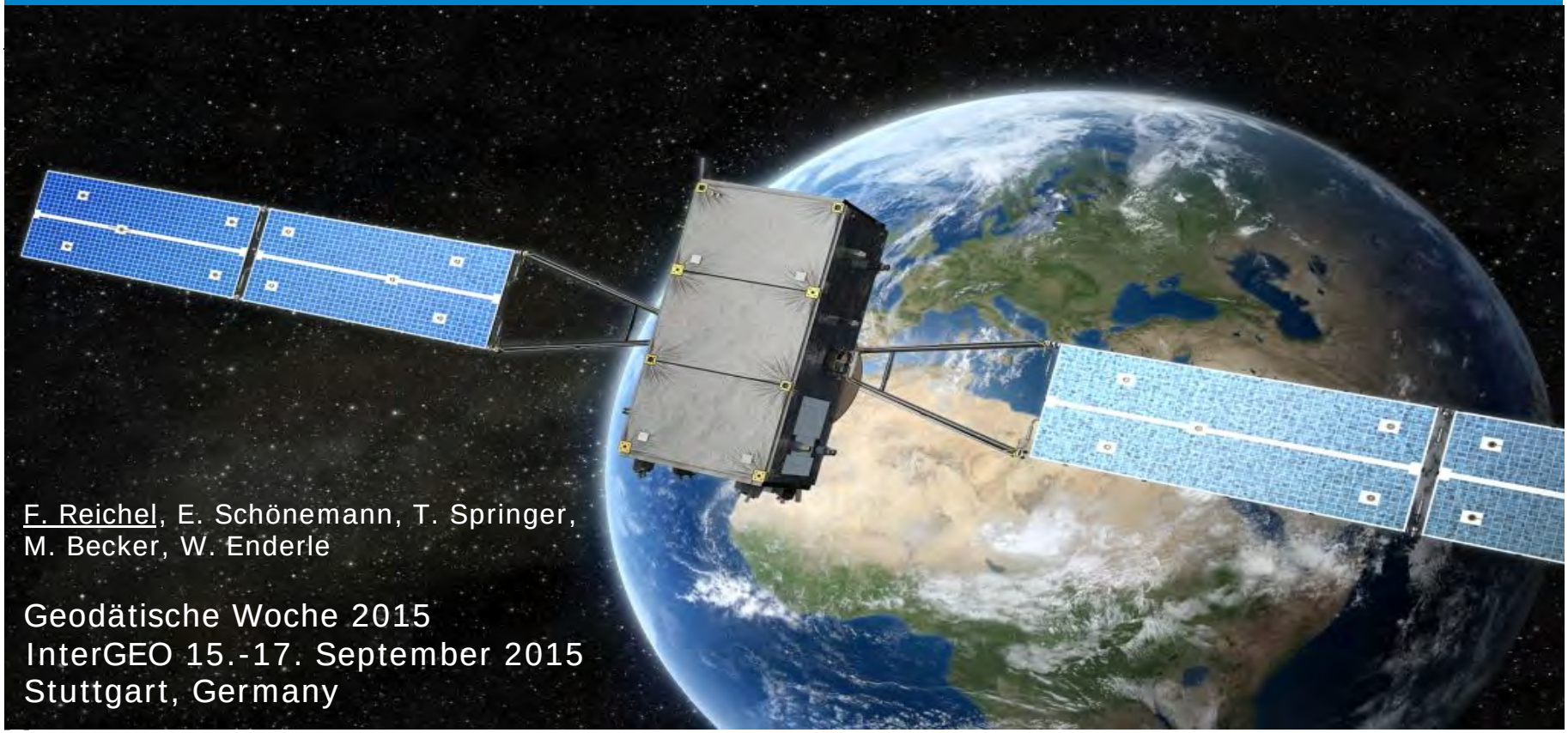
Benefits and Challenges of Multi-GNSS Observation Combinations



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Content

Introduction

- RINEX 3 format offers vast number of observations to process

System	Freq. Band	Frequency	Channel or Code	Observation Codes			
				Pseudo Range	Carrier Phase	Doppler	Signal Strength
GPS	L1	1575.42	C/A	C1C	L1C	D1C	S1C
			P	C1P	L1P	D1P	S1P
			Z-tracking and similar (AS on)	C1W	L1W	D1W	S1W
			Y	C1Y	L1Y	D1Y	S1Y
			M	C1M	L1M	D1M	S1M
			codeless	--	L1N	D1N	S1N
	L2	1227.60	C/A	C2C	L2C	D2C	S2C
			L1(C/A)+(P2-P1) (semi-codeless)	C2D	L2D	D2D	S2D
			L2C (M)	C2S	L2S	D2S	S2S
			L2C (L)	C2L	L2L	D2L	S2L
			L2C (M+L)[1]	C2X	L2X	D2X	S2X
			P	C2P	L2P	D2P	S2P
			Z-tracking and similar (AS on)	C2W	L2W	D2W	S2W
			Y	C2Y	L2Y	D2Y	S2Y
			M	C2M	L2M	D2M	S2M
			codeless	--	L2N	D2N	S2N
	L5	1176.45	I	C5I	L5I	D5I	S5I
			Q	C5Q	L5Q	D5Q	S5Q
			I+Q	C5X	L5X	D5X	S5X

- Huge increase of processing complexity

Galileo	E1	1575.42	A PRS	C1A	L1A	D1A	S1A
			B I/NAV OS/CS/SoL	C1B	L1B	D1B	S1B
			C no data	C1C	L1C	D1C	S1C
			B+C	C1X	L1X	D1X	S1X
			A+B+C	C1Z	L1Z	D1Z	S1Z
	E5a	1176.45	I F/NAV OS	C5I	L5I	D5I	S5I
			Q no data	C5Q	L5Q	D5Q	S5Q
			I+Q	C5X	L5X	D5X	S5X
	E5b	1207.140	I I/NAV OS/CS/SoL	C7I	L7I	D7I	S7I
			Q no data	C7Q	L7Q	D7Q	S7Q
			I+Q	C7X	L7X	D7X	S7X
	E5 (E5a+E5b)	1191.795	I	C8I	L8I	D8I	S8I
			Q	C8Q	L8Q	D8Q	S8Q
			I+Q	C8X	L8X	D8X	S8X
	E6	1278.75	A PRS	C6A	L6A	D6A	S6A
			B C/NAV CS	C6B	L6B	D6B	S6B
			C no data	C6C	L6C	D6C	S6C
			B+C	C6X	L6X	D6X	S6X
			A+B+C	C6Z	L6Z	D6Z	S6Z

The Receiver Independent Exchange Format (RINEX v. 3)

- Even bigger number of possible signal combinations

→ How to combine all these observations?

Processing Approach

- Two different processing approaches are compared in this work

1. Conventional Ionosphere-Free Linear Combination Processing
   - Standard approach and current main processing strategy
2. Raw signal processing (see [1])
   - Raw processing of signals ‚as they are' without forming linear combinations
   - Reduces carrier noise wrt. IonoFree-LC by a factor of ~3 (relative to L1)
   - Need to estimate additional parameters (ionosphere)
   - Exploit the advantages of each individual GNSS system and not make reference to one specific system
   - More complex approach

- Performed PPP to compare processing approaches

[1] Schönemann, E., Becker, M., & Springer, T. (2011). A new approach for GNSS analysis in a multi-GNSS and multi-signal environment. Journal of Geodetic Science, 1(3), 204–214. doi:10.2478/v10156-010-0023-2

Data and Products

- Shown results are based on orbit & clock products derived from MGEX data
- RINEX 3 data from stations at Wettzell and ESA/ESOC were used for the analysis (days 165 & 245 of year 2015)
- Data selection for Wettzell was based on maximum visibility of Galileo satellites, to be able to process ‘Galileo only‘

GPS	1C	2W
WTZR	X	X

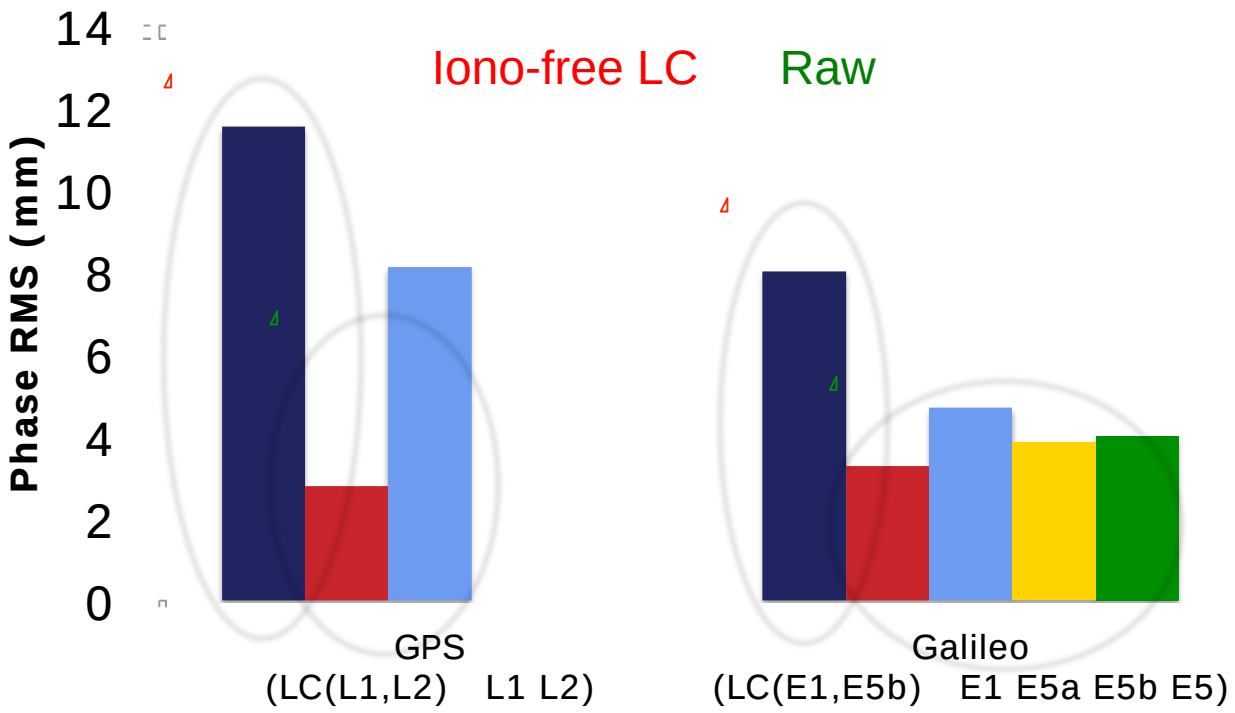
Galileo	1C	1X	5Q	5X	7Q	7X	8Q	8X
WTZR	X		X		X		X	
ESO1	X		X		X		X	
ESO2	X		X		X		X	
ESOB		X		X		X		X

Analysis

- Carrier Phase RMS
  - Compare Iono-Free LC and ‘Raw‘ Approach
- Code Multipath, derived from RINEX observations
  - Different observation characteristics
  - Receiver dependent characteristics
- Parameter Estimation (Iono-Free LC vs. Raw Approach)
  - Uncalibrated Code Delays
  - Clock estimation
  - Distinguish signal effects (ZPD vs. Clock)

Ion-Free LC vs. Raw Approach

- Carrier phase rms of iono-free LC & raw observation processing

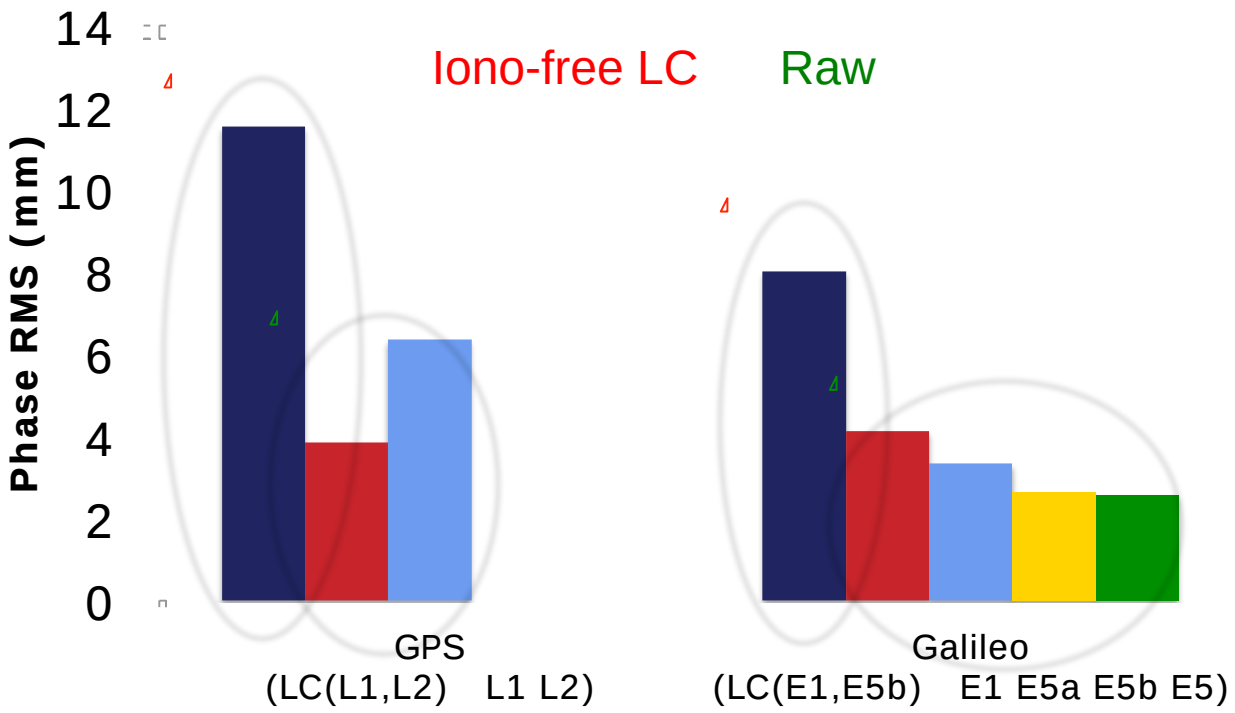


- Raw approach:
  - Applied frequency dependent weighting (factor = f(L1)^2/f^2)
  - Applied additional wave lentgh dependent weighting

→ Correct weighting remains active research area

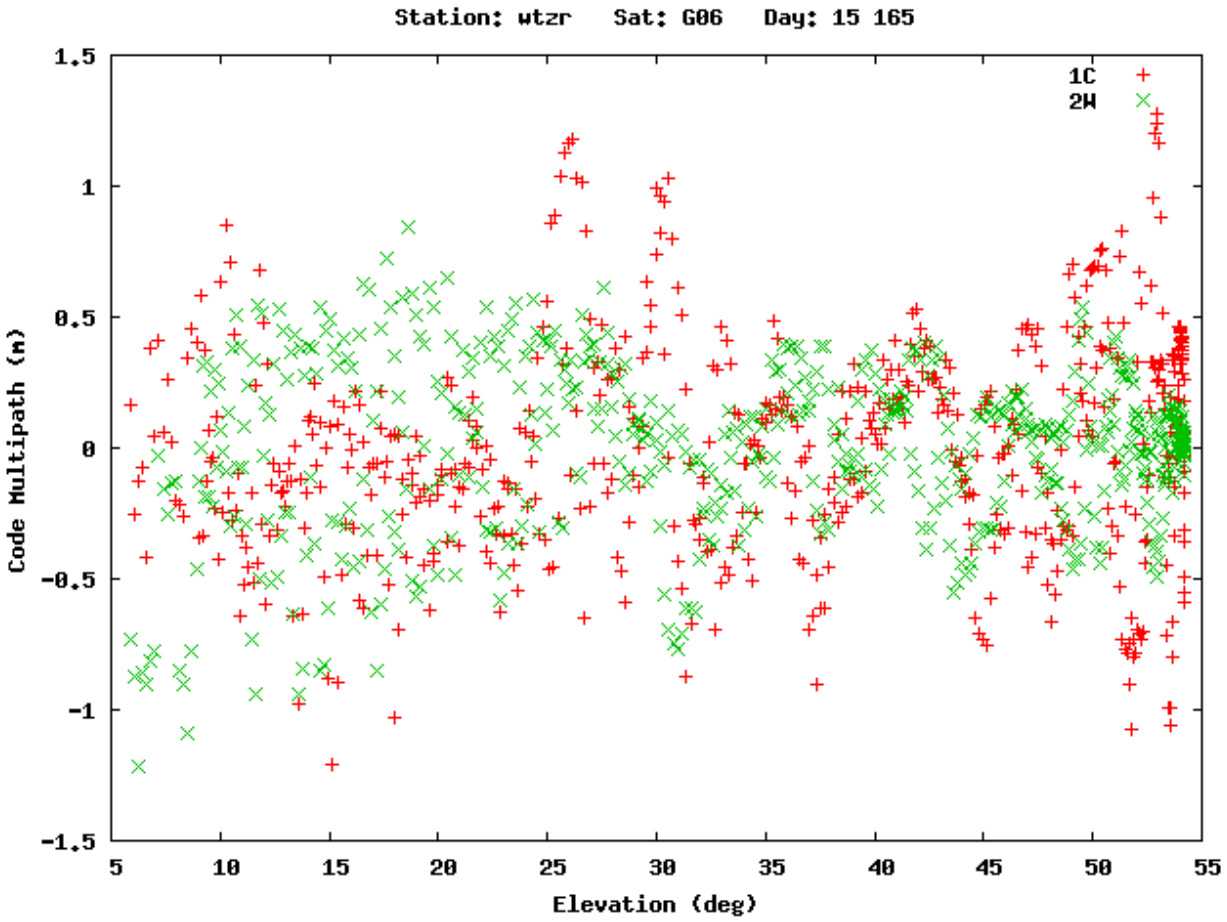
Ion-Free LC vs. Raw Approach

- Carrier phase rms of iono-free LC & raw observation processing



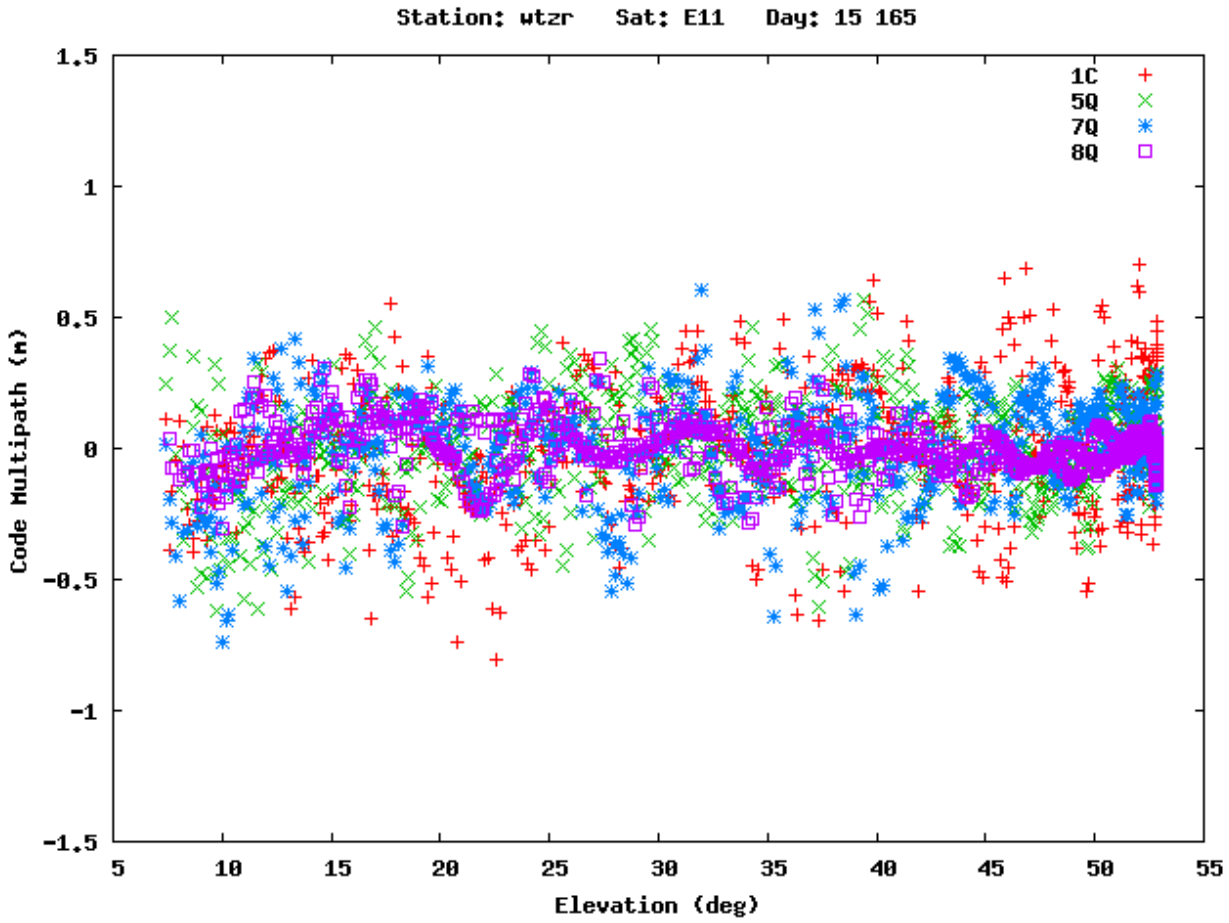
- Raw approach:
  - Applied frequency dependent weighting (factor = f(L1)^2/f^2)
  - No additional weighting applied
  - Galileo weighting:
    - Smaller RMS expected for E1
    - Higher weighting of E5 band since:
      - E1 band: 1 obs
      - E5 band: 3 obs

Code Multipath – WTZR G06



- Code multipath combination from RINEX 3 observations
- GPS (G06) code multipath as seen from station WTZR for observations:
  - 1C
  - 2W

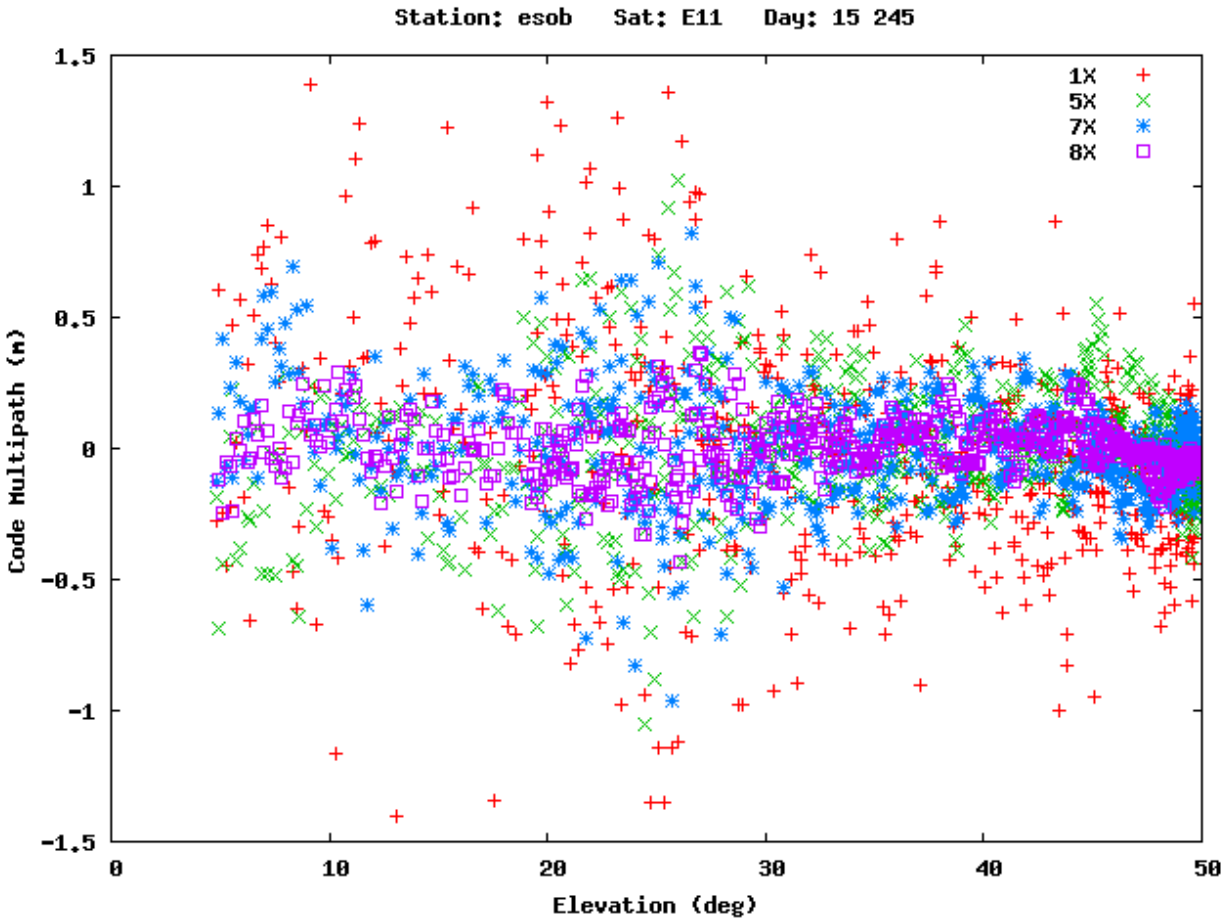
Code Multipath – WTZR E11



- Code multipath combination from RINEX 3 observations
- Galileo (E11) code multipath as seen from station WTZR for observations:
  - 1C
  - 5Q
  - 7Q
  - 8Q
- Low E5 code noise!

→Signal characteristics need to be taken into account in processing

Code Multipath – ESA / ESOC



- Code multipath combination from RINEX 3 observations
- Galileo (E11) code multipath as seen from stations at ESA/ ESOC (all connected to the same antenna) for observations:
  - 1C / 1X
  - 5Q / 5X
  - 7Q / 7X
  - 8Q / 8X

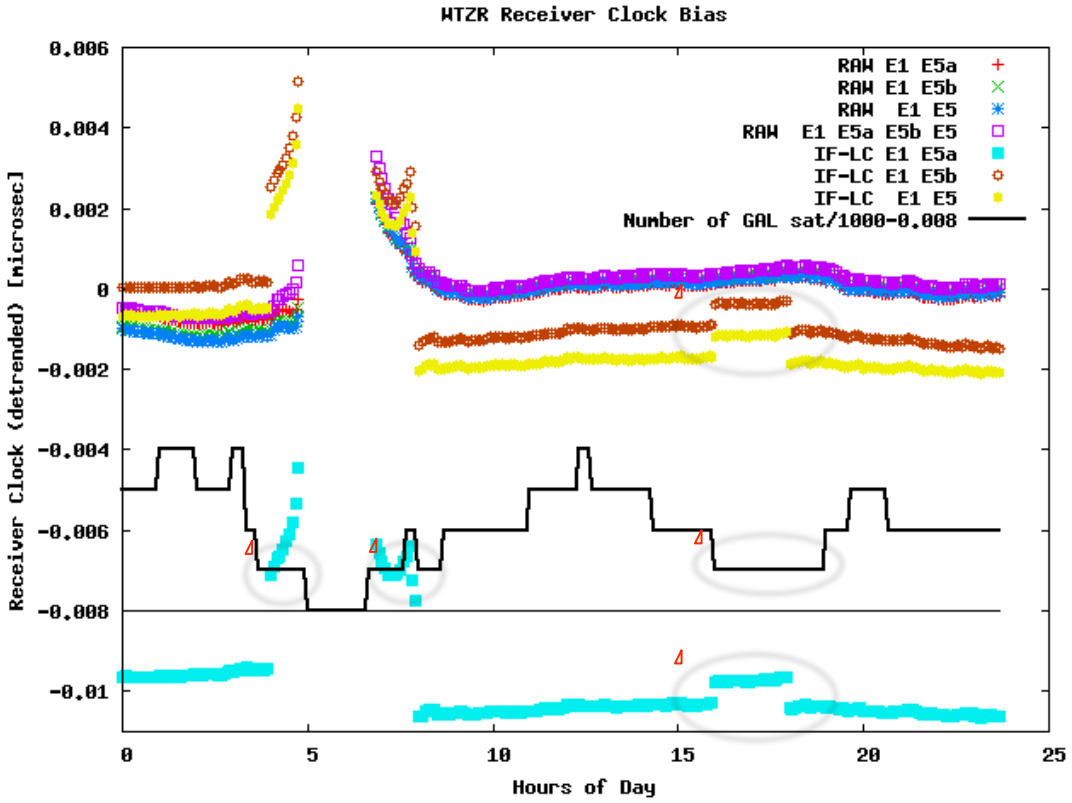
→ Different receiver characteristics!

Uncalibrated Code Delays

- Similar to Differential Code Biases (DCBs), ‘raw‘ approach estimates UCDs for individual signals
- Problem: UCDs are not only signal dependent, but also receiver, receiver settings and antenna (chain) dependent
- A deficit in the UCD estimation leads to offsets in the clock
  - This is also true for DCBs and Iono-Free LC!

Clock estimation (GAL only)

- Epoch wise clock estimates of different signal combinations
  (offset and trend of 'RAW E1 E5a' removed from estimates)



Different signal combinations may lead to different clocks

Low Number of Sat.

Ion-Free LC
2 hours jump in clock (ZPD estim. Interval)

Lack of distinguishing ZPD (elevation effect) and clock

Summary and Conclusion

- The increasing number of GNSS satellites and signals offers great potential to improve positioning and navigation solutions
- However, there is a huge increase of the GNSS processing complexity, when the vast number of observations is used, future GNSS will offer and already offer today
- The challenge is to combine observations and select the optimal combination depending on the application

Questions?

Thank you for your attention!