Analysis of Multi-GNSS Observations and the Challenges of their Combination

TECHNISCHE UNIVERSITÄT DARMSTADT

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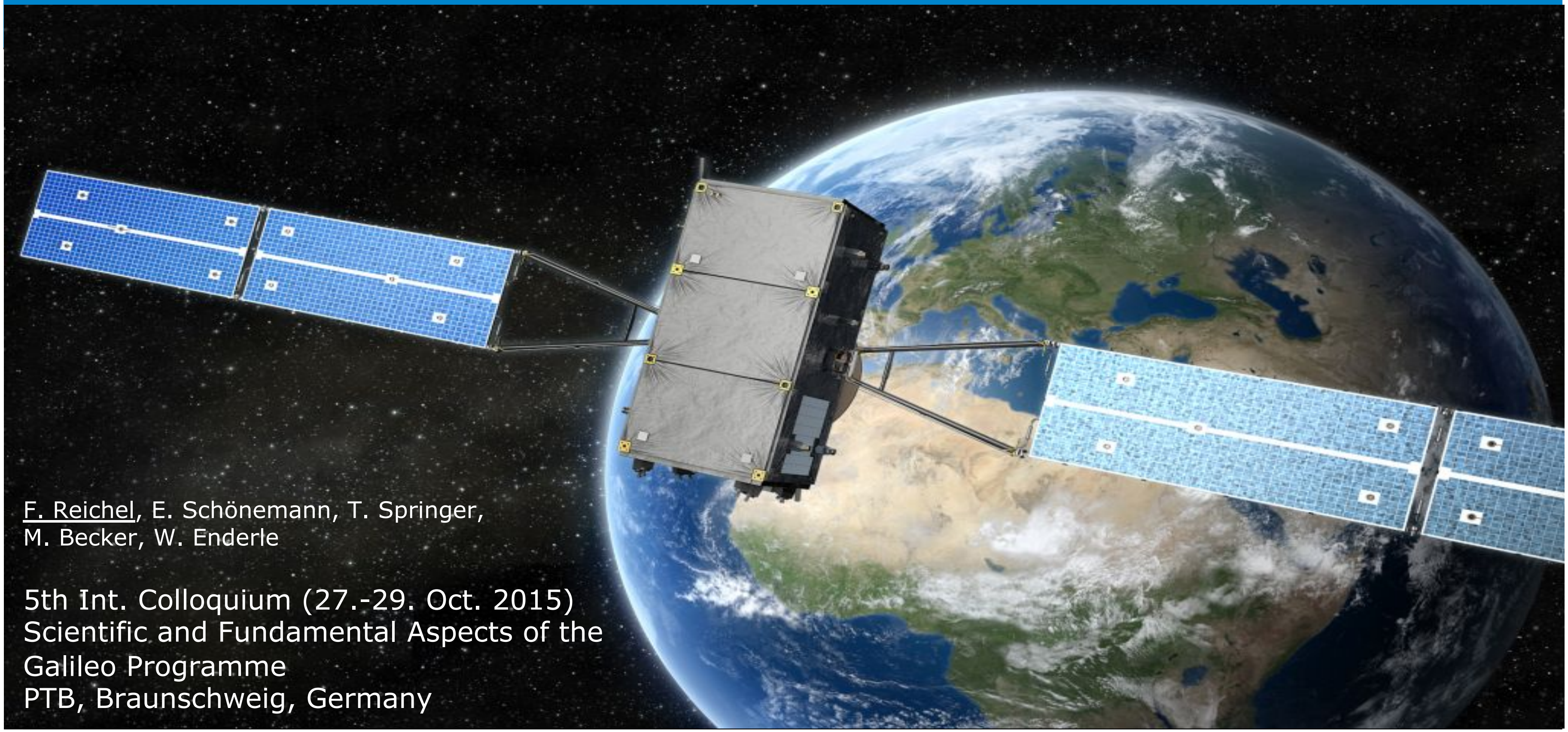

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5th Int. Colloquium (27.-29. Oct. 2015)
Scientific and Fundamental Aspects of the Galileo Programme
PTB, Braunschweig, Germany

PSGD

Content

Introduction

- The RINEX 3.02 format offers a factor of ~4 more observation types than RINEX 2.11 for Galileo and a factor of ~6 for GPS (not taking into account Glonass, Beidou, QZSS)
  - Significant increase in number of frequencies and signals
  - Increase in number of GNSS systems
- Huge increase of observation processing complexity
- Generation of mixed observation type ‘X‘ is not clearly defined

All 5 GNSS (RINEX 3.02)
~70 code & ~70 phase observation types

GNSS 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
		L1C (D)	C1S	L1S	D1S	S1S
		L1C (P)	C1L	L1L	D1L	S1L
		L1C (D+P)	C1X	L1X	D1X	S1X
		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)	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

GNSS System	Freq. Band /Frequency	Channel or Code	Observation Codes			
			Pseudo Range	Carrier Phase	Doppler	Signal Strength
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 3.02)

Introduction/Motivation

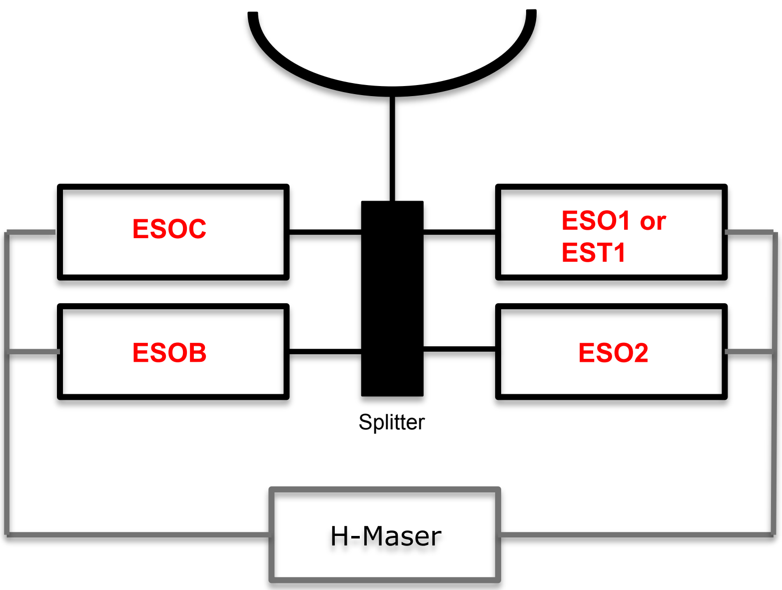
Motivation

- Observation type selection and joint processing of multi-frequency/multi-GNSS observation types

Questions

- What are the characteristics of the different observation types and different receivers?
- How stable and correlated are observation types of the same frequency?
- How to jointly process observation types from multiple frequencies and GNSS?
  - Processing approach
  - Observation type weighting
  - Bias handling

Zero-Baseline setup at ESA/ESOC



- Shown PPP results are based on ESOC orbit & clock products
- RINEX 3.02 data from the ESOC site were used for the analysis (days 248/290 of year 2015)

Galileo	1C	1X	5Q	5X	7Q	7X	8Q	8X
ESO1	X		X		X		X	
ESO2	X		X		X		X	
ESOB		X		X		X		X
ESOC/ EST1	X		X		X		X	

GPS	1C	1W	2W	2L	2X
ESO1	X	C only	X	X	
ESO2	X	C only	X	X	
ESOB	X	X	X		X
ESOC/ EST1	X	C only	X	X	

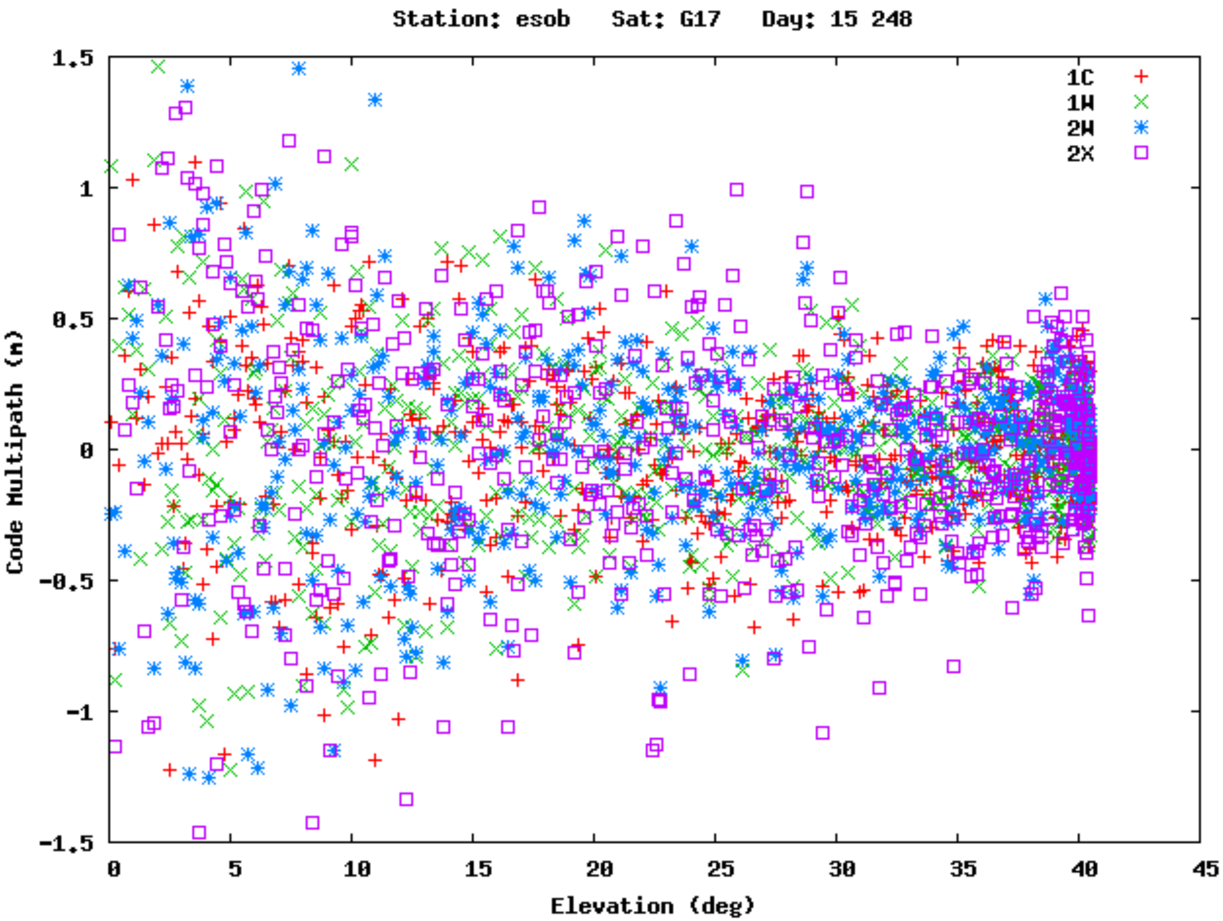
RINEX 3.02 Observation Analysis

- Comparison of observation types within a GNSS system

1. Code multipath combination from RINEX 3.02 observation types
   - $$MP_i = Pr_i - \left(\frac{\gamma+1}{\gamma-1}\right)\cdot Ph_i + \left(\frac{2}{\gamma-1}\right)\cdot Ph_j, \qquad \gamma = \left(\frac{f_i}{f_j}\right)^2$$
   - Assumptions
     - Zero mean
     - Phase multipath + noise << code multipath

2. Direct comparison of observation types by forming differences (Ph_k – Ph_l and Pr_k – Pr_l)

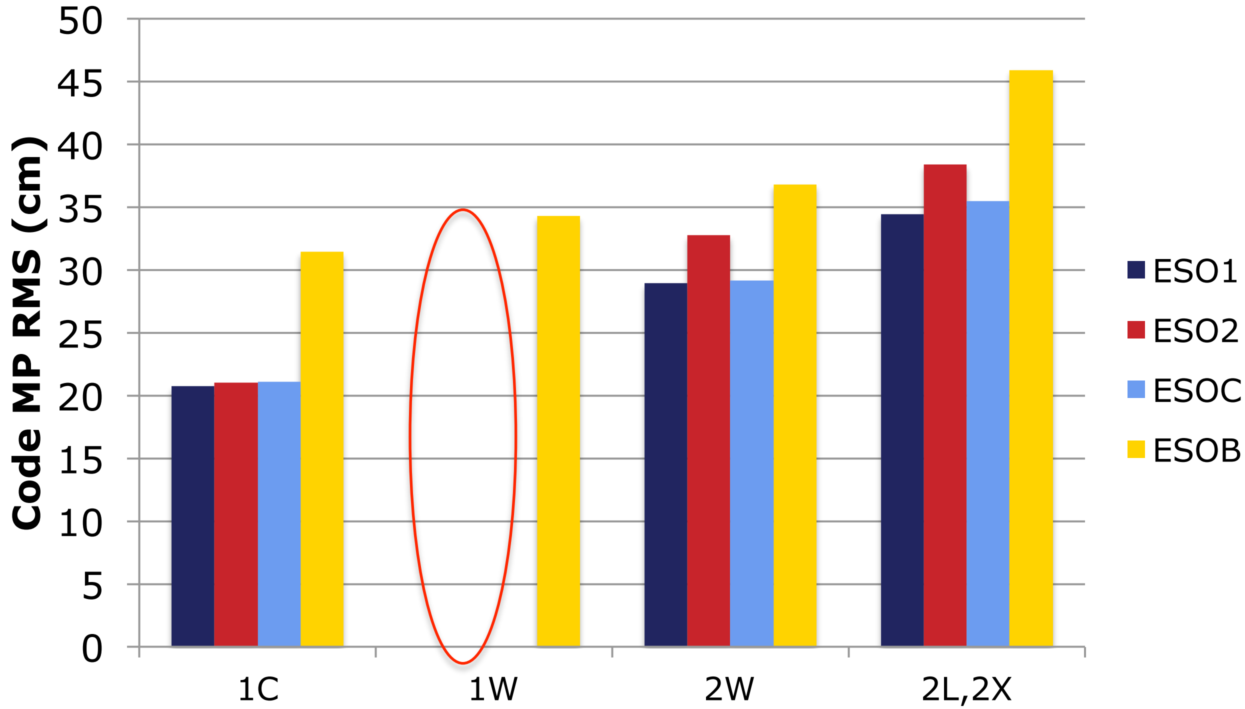
Code Multipath – GPS



- Code multipath combination from RINEX 3.02 observations
- GPS (G17) code multipath as seen from station ESOB for observations:
  - 1C
  - 1W
  - 2W
  - 2X

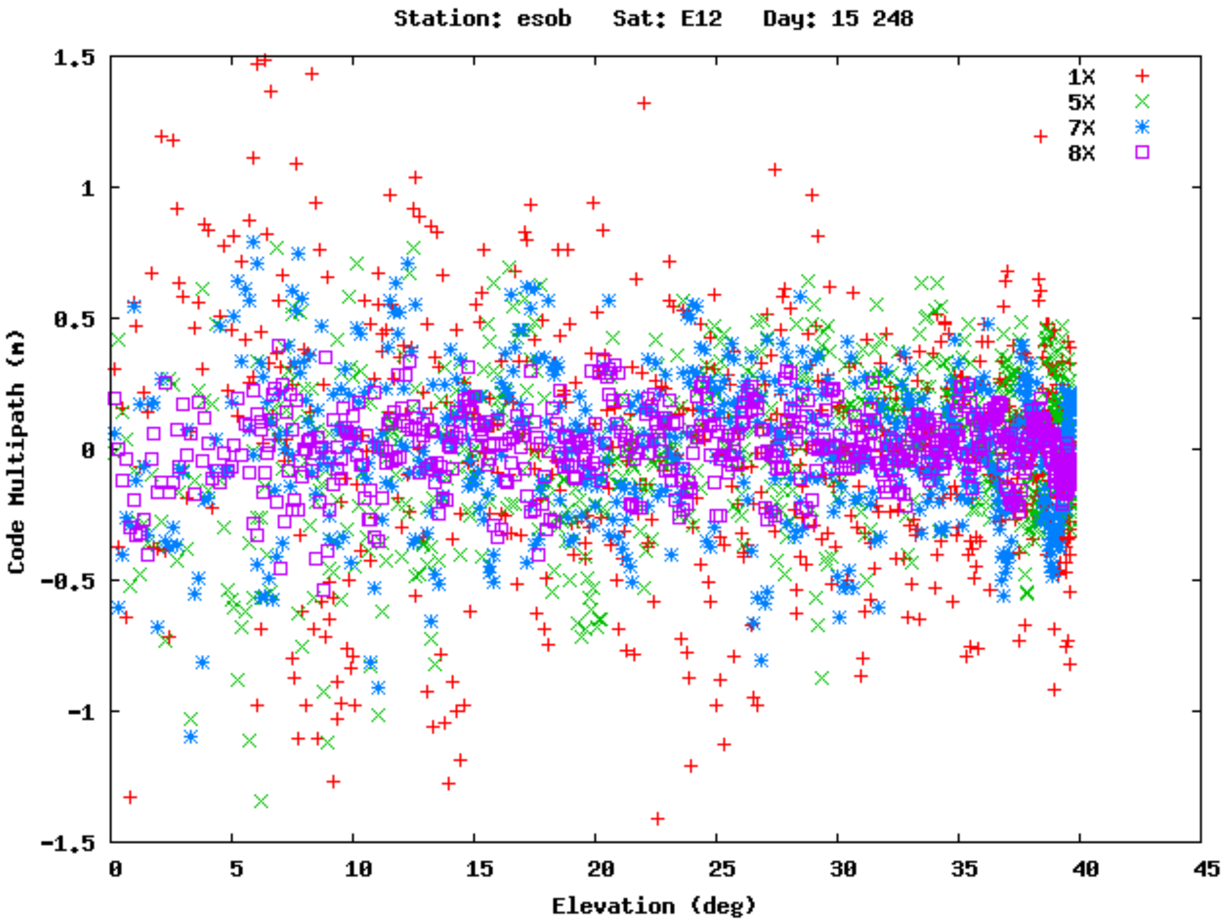
Code Multipath RMS - GPS

- Code multipath RMS for GPS satellite G17 on day 15 248 without elevation cutoff → high MP environment



- ESOB tracks 2X component, whereas the other receivers track 2L
- No 1W value for ESO1, ESO2, ESOC since phase measurement is not available
- Observation type and receiver dependent characteristics visible

Code Multipath – Galileo

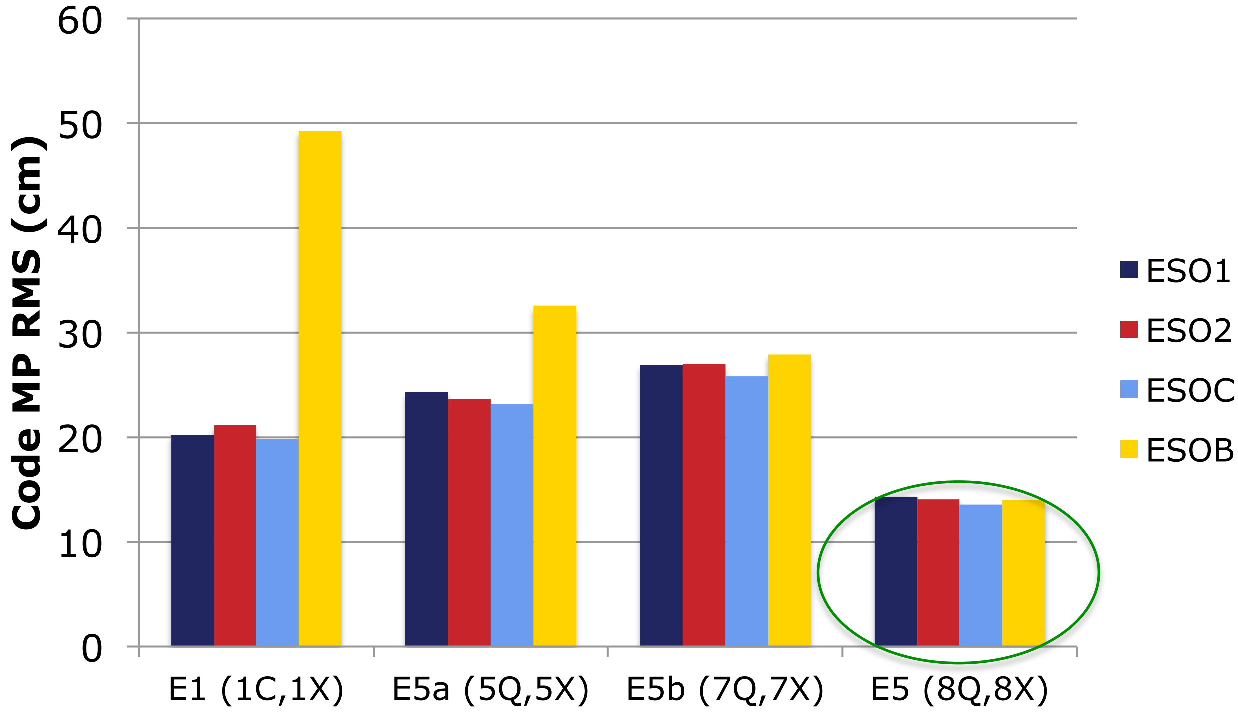


- Code multipath combination from RINEX 3.02 observations
- Galileo (E12) code multipath as seen from stations at ESA/ESOC for observations:
  - 1C (ESOB: 1X)
  - 5Q (ESOB: 5X)
  - 7Q (ESOB: 7X)
  - 8Q (ESOB: 8X)

→ Different observation type and receiver characteristics

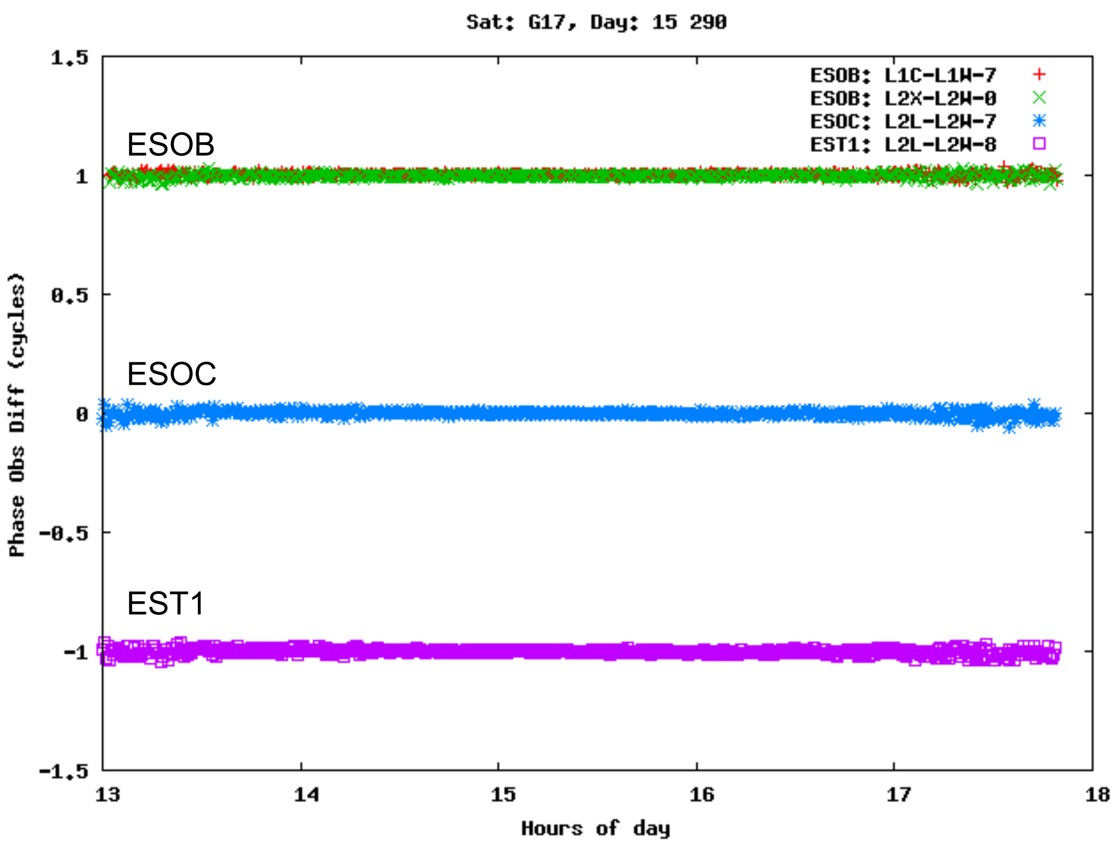
Code Multipath RMS - Galileo

- Code multipath RMS for Galileo satellite E12 on day 15 248 without elevation cutoff → high MP environment



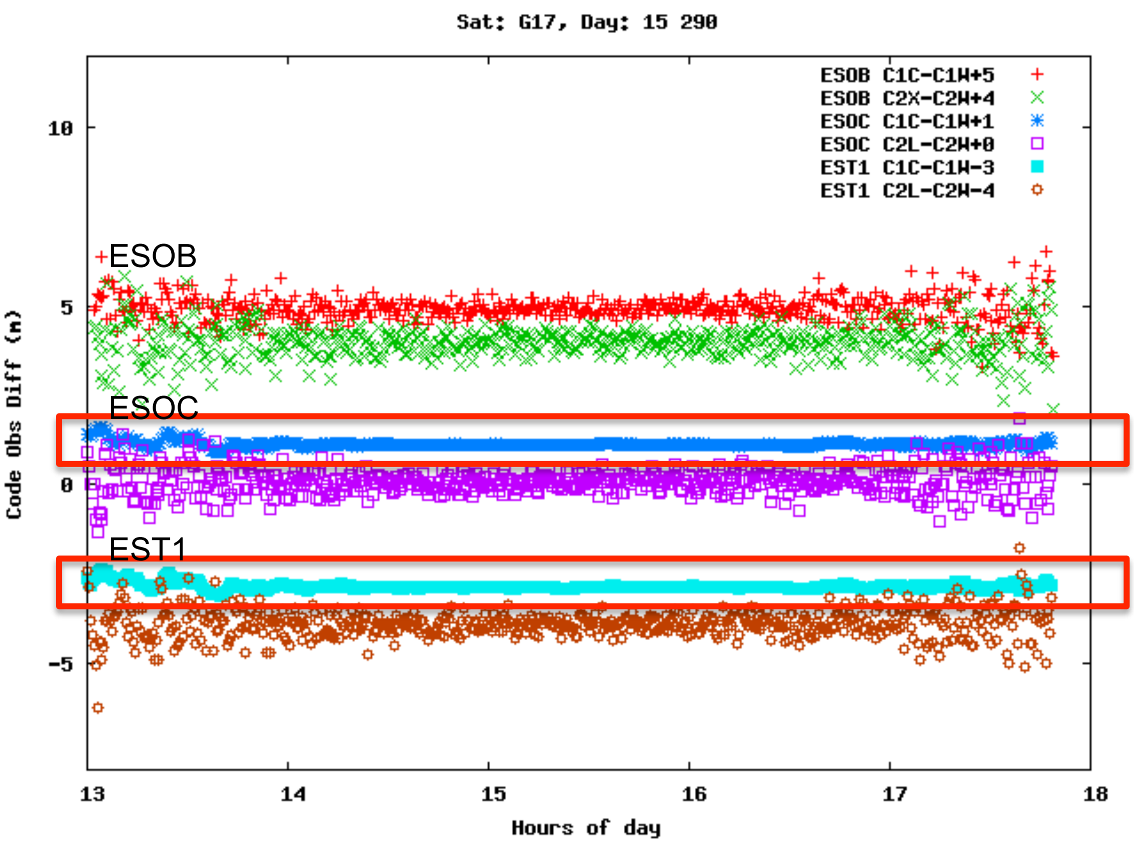
- ESOB tracks X component, whereas the other receivers track C and Q
- Low code noise/multipath visible on E5 AltBOC
- Frequency and observation type/receiver dependent characteristics
- These characteristics should be taken into account for processing (observation weighting)

Phase Observation Differences



- GPS phase observation differences on the same frequency
- No observations available for Galileo
- No drift between different observation types
- Fix cycle offset between phase observation types

Code Observation Differences



- GPS code observation differences on the same frequency
- Zero mean difference and no drift between observation types
- ESOC/EST1: 1C and 1W signals are not independently tracked → High correlation of code observation types

Processing Approaches

- Two different processing approaches are analysed:

1. Conventional Ionosphere-Free Linear Combination
   - Standard approach and current main processing strategy

2. Raw signal processing (see [1])
   - Raw processing of signals, ‘as they are‘ without forming any combinations
   - Need to estimate additional parameters (eg. Ionosphere)
   - Exploit the advantages of each individual GNSS system and not make reference to one specific system
   - More physical approach

[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

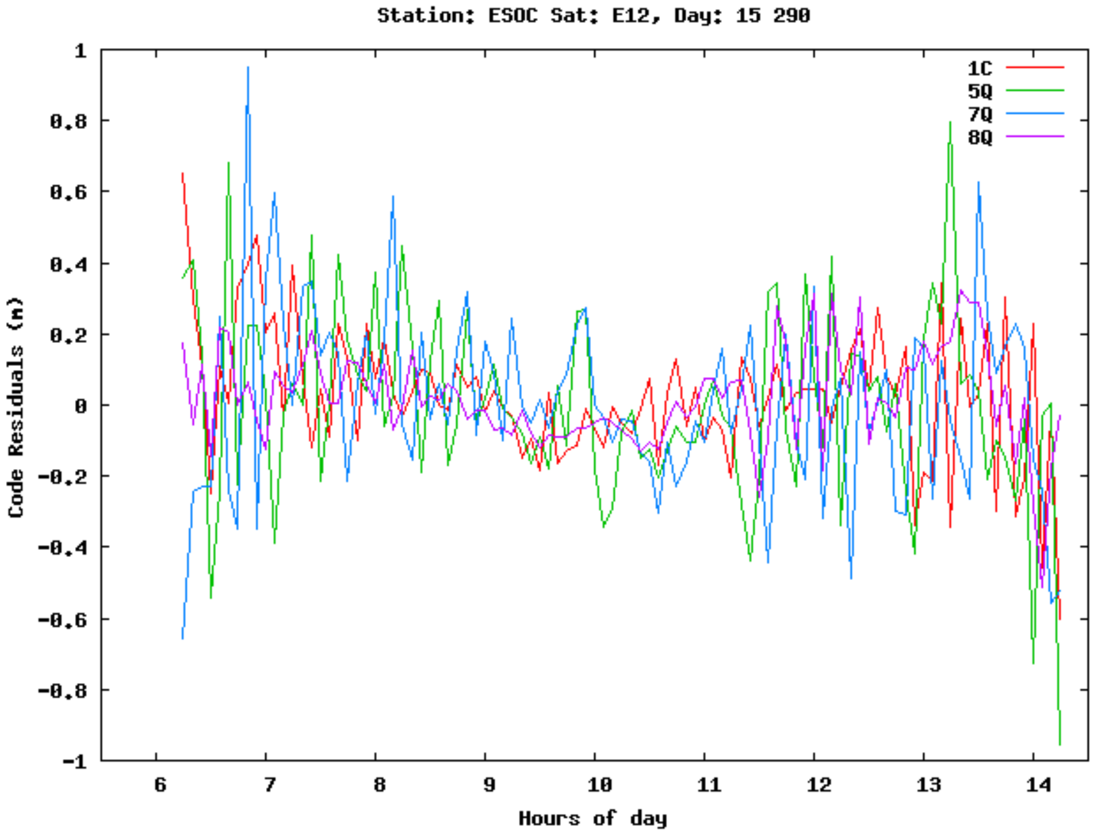
Static PPP Analysis using raw signal processing

- Signal Noise
  - Carrier noise is reduced by a factor of ~3 wrt. Iono-Free LC (theory)
  - Wavelength dependency of signal noise and other factors, like signal power can be taken into account

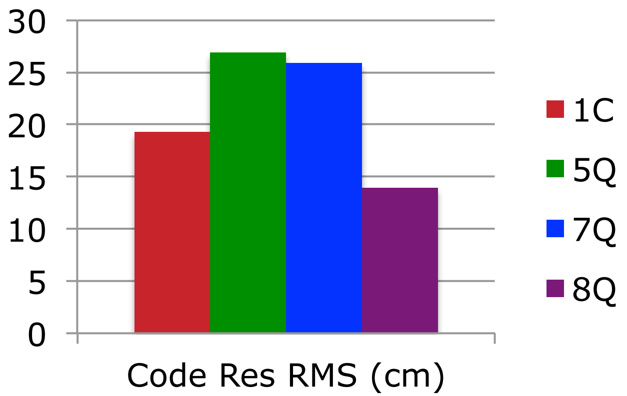
- Weighting
  - Weighting can be chosen individually for each frequency and observation type, whereas for Iono-Free linear combination, the weighting is given by the LC itself

- Processing
  - Process all observations to estimate all parameters jointly in a single run

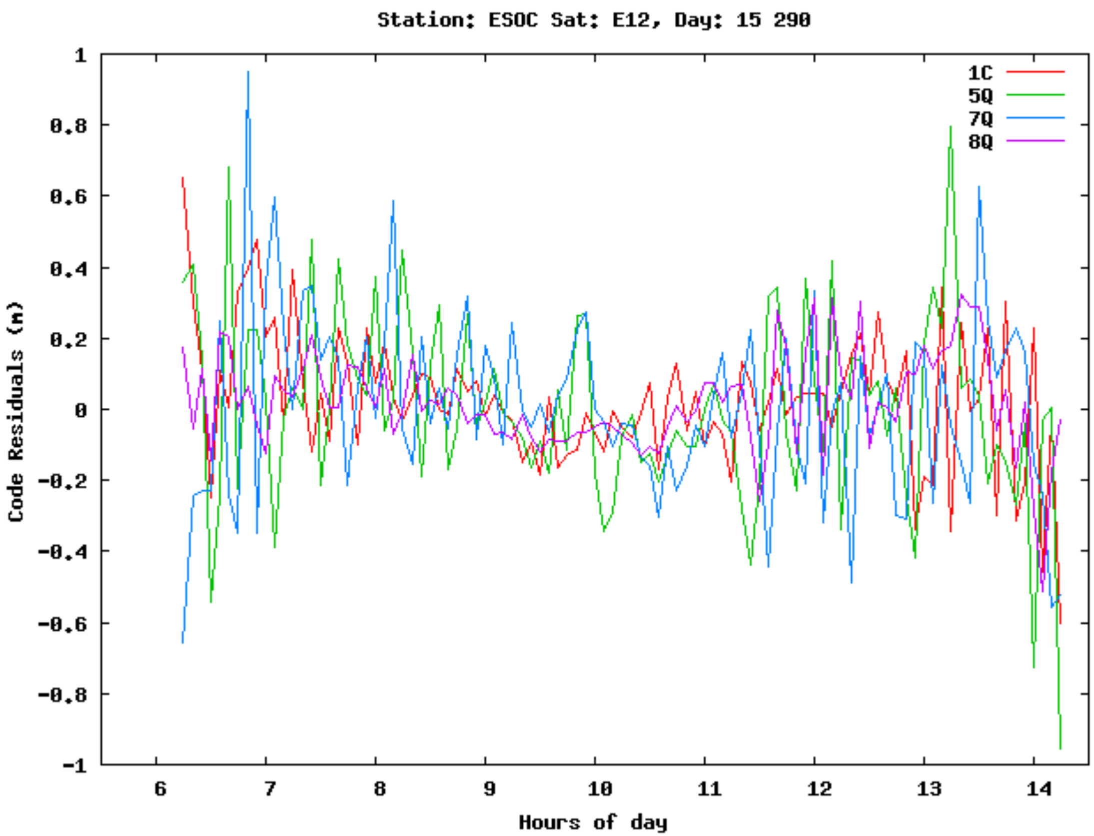
Code Residuals



- Code residuals from static PPP
- Observations weighting:
  - elevation dependent
  - frequency dependent



Code Residuals



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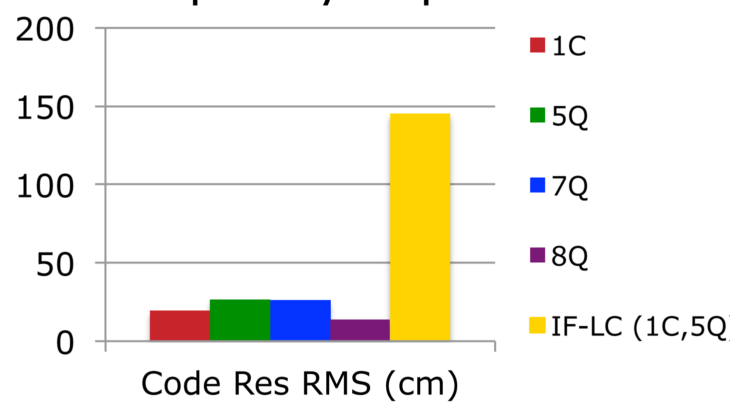
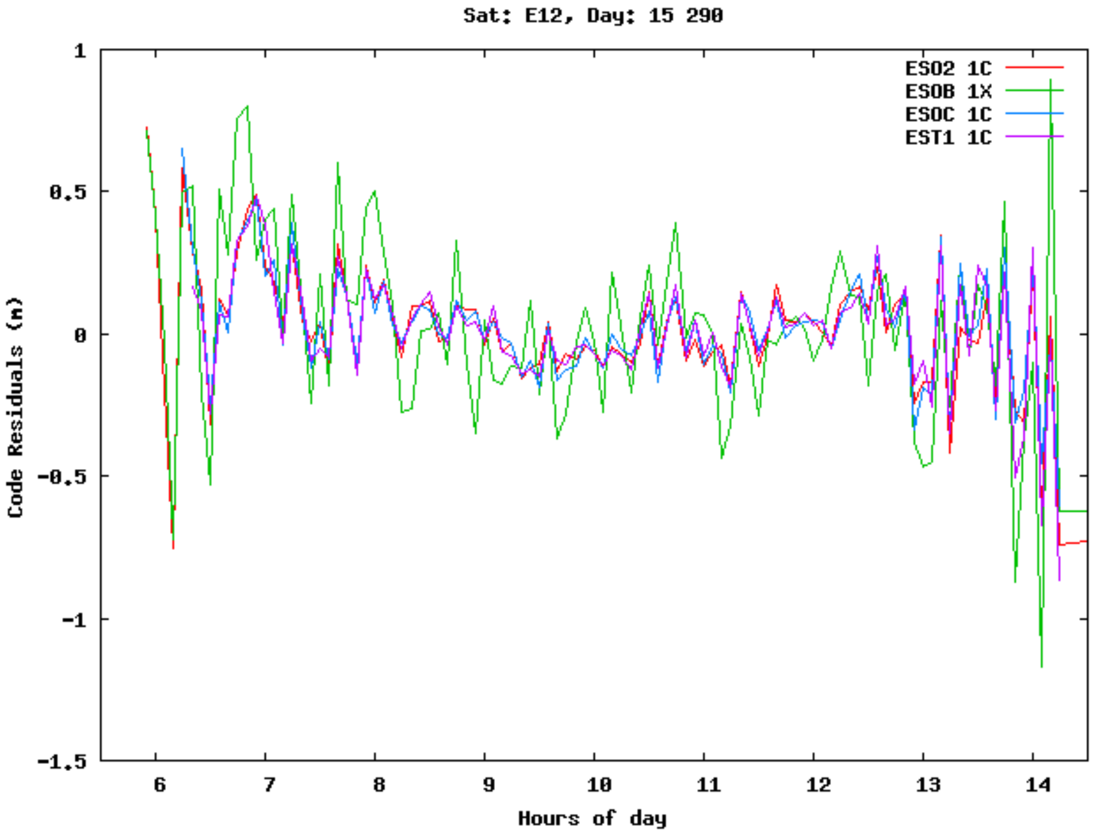


Code Residuals



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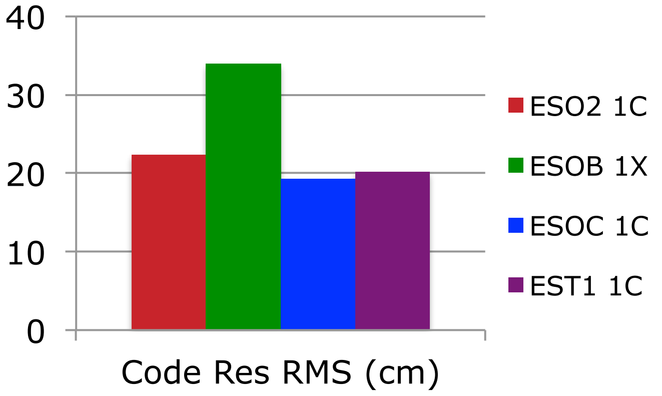

Smaller 8Q code residuals
Larger 1X code residuals
Large IF-LC residuals

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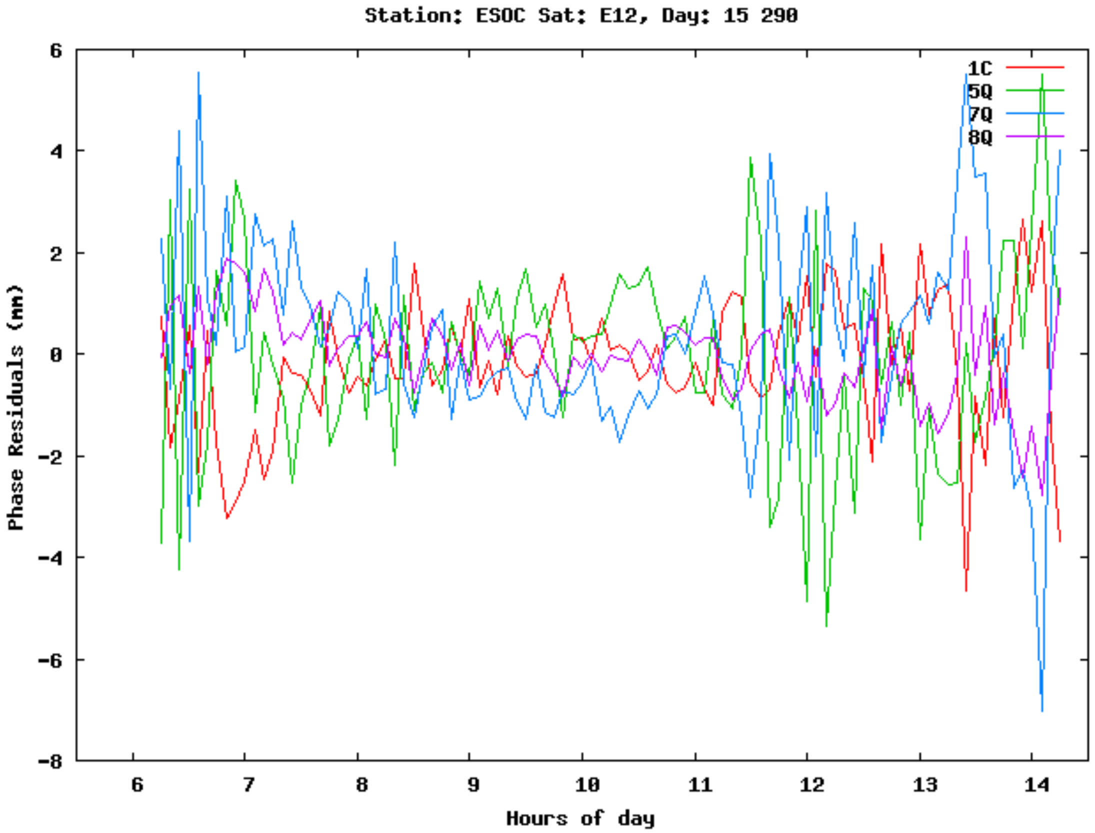
Phase Residuals



- Phase residuals from static PPP
- Observations weighting:
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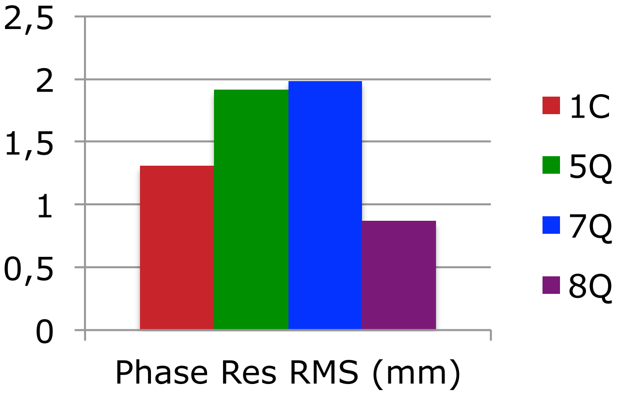
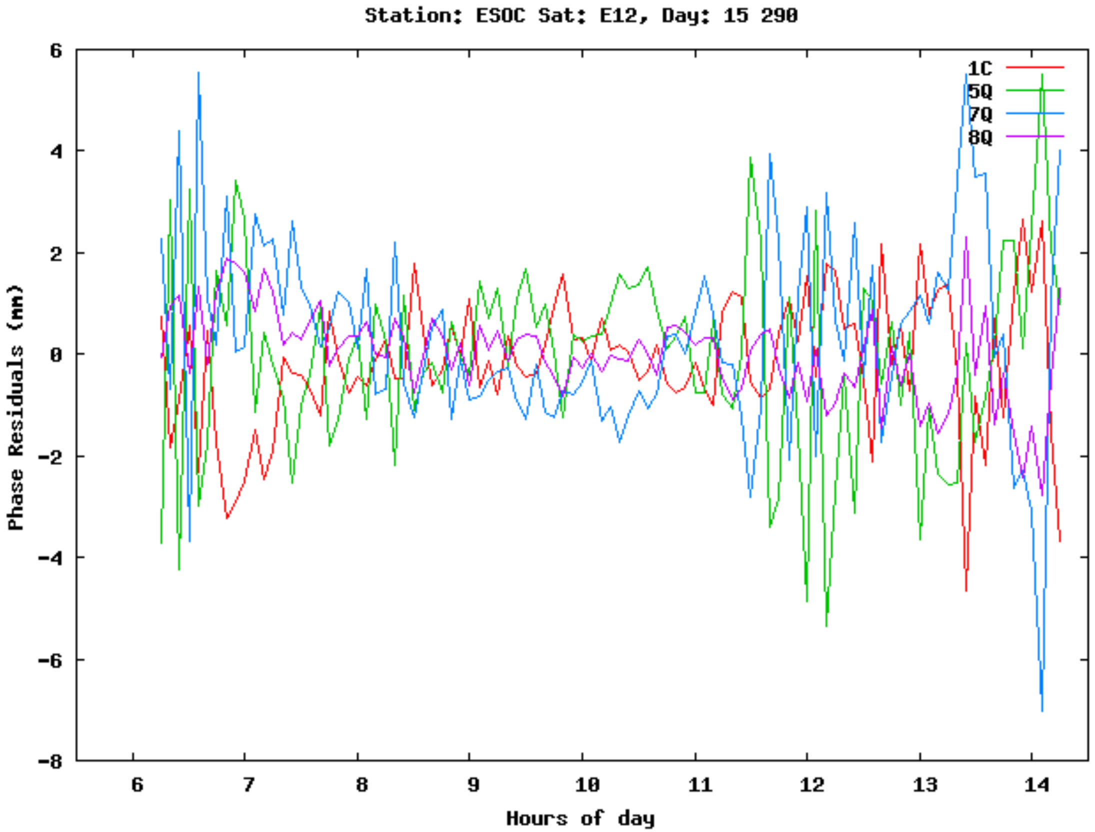
  - frequency dependent



Phase Residuals



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- Observations weighting:
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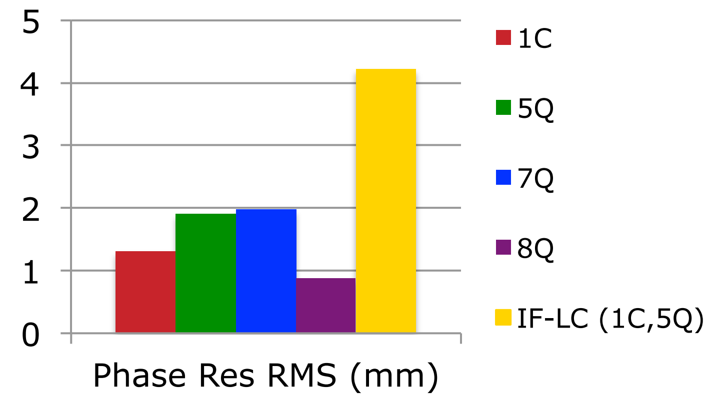
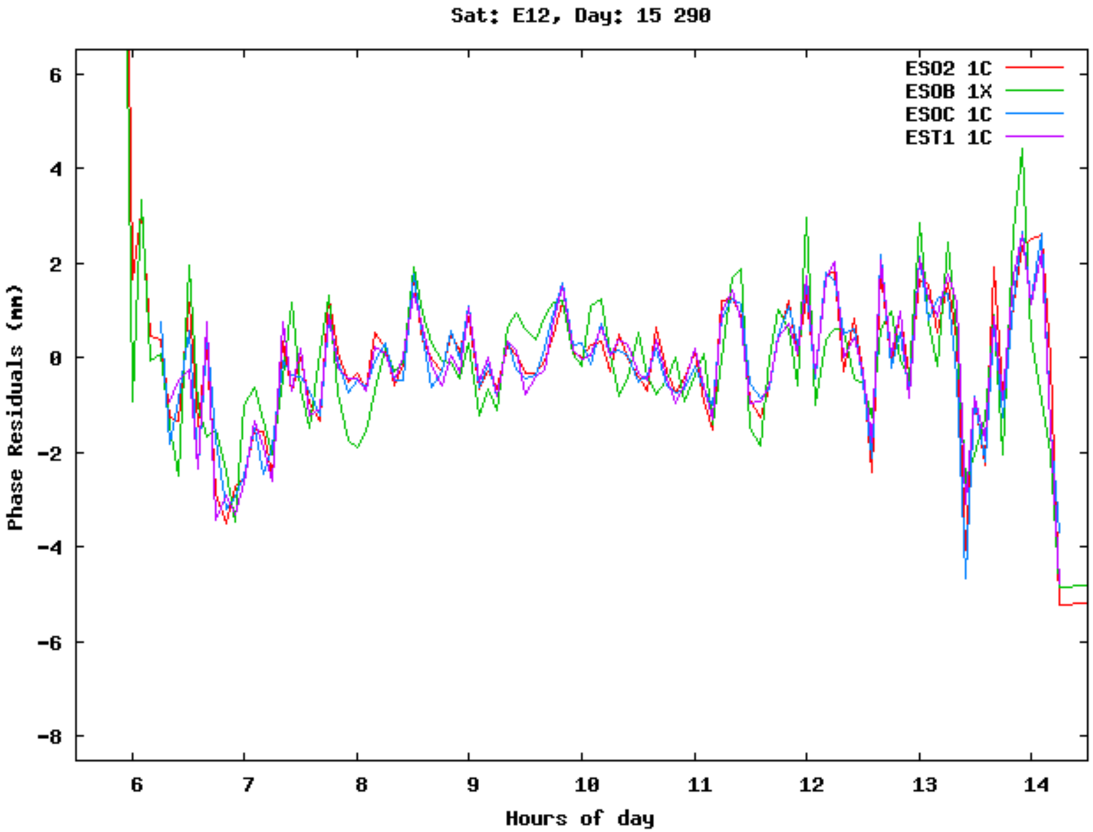


Phase Residuals



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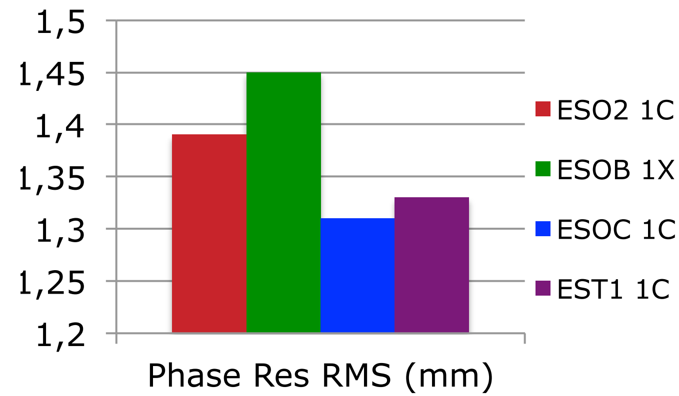

Smaller 8Q phase residuals
Larger 1X phase residuals
Large IF-LC residuals

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 observation types and combinations of observation types is used
- The observation type selection and level of complexity is mainly driven by the application itself
- There is a need to discuss new processing approaches to exploit the full potential of multi-frequency multi-GNSS processing
- Open questions/issues remain:
  - How to handle the large number of (code and phase) biases, when jointly processing mulitple frequencies and different GNSS?
    → Reference signal selection
  - How stable are these biases?