



Performance of Galileo for geodetic positioning under challenging signal reception conditions

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Outline



- **Introduction**
- **Characteristics of GNSS signals**
- **Case studies**
- **Data analysis**
- **Conclusions**



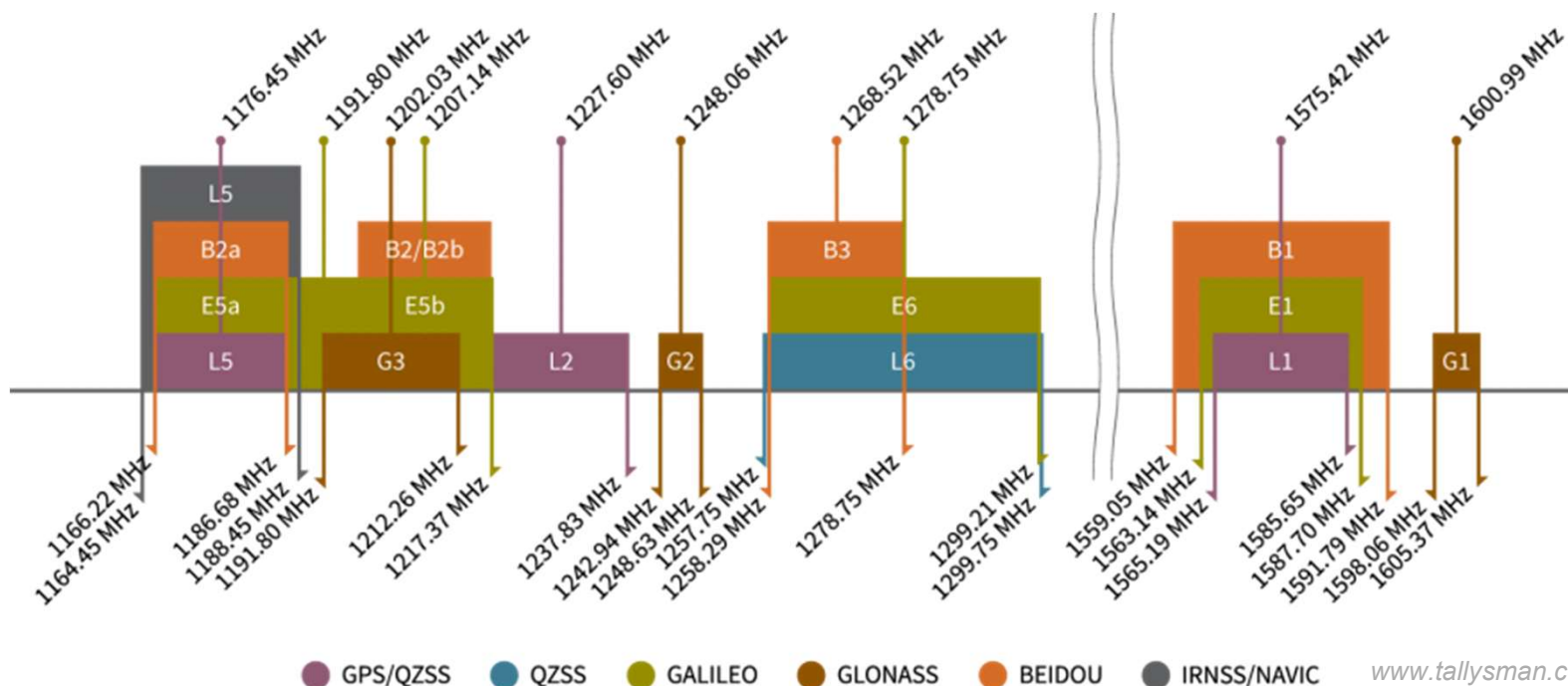
Introduction



- Galileo's design is promising enhanced performance
- Advanced techniques are used in its signal design (BOC, AltBOC etc.)
- Several studies demonstrated superior signal tracking performance
- Here we focus on Galileo's performance under unfavorable signal reception conditions

Characteristics of GNSS signals

GNSS frequencies



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Characteristics of GNSS signals

GNSS (civil) signals

GNSS	Block	Signals	Modulations used
GPS	IIR IIR-M IIF III	L1 C/A, L1/L2 P(Y) L1 C/A, L1/L2 P(Y), L2C , L1 C/A, L1/L2 P(Y), L2C, L5 L1 C/A, L1/L2 P(Y), L2C, L5, L1C	BPSK, BPSK mux, TMBOC
GLN	M K1 K2	L1OF, L1SF , L2OF, L2SF L1OF, L1SF , L2OF, L2SF, L3OC L1OF, L1SF , L2OF, L2SF, L1OC, L1SC, L2OC, L2SC, L3OC	BPSK, BOC
BDS-2		B1-2, B2, B3	BPSK
BDS-3		B1-2, B1, B2, B3ab	BPSK, TMBOC, BOC, TMBOC
GAL		E1, E6, E5a, E5b, E5a+b	CBOC, BPSK-BOC, AltBOC

based on Montenbruck et al., 2017

Characteristics of GNSS signals

Power of main GNSS signals

GNSS	Band	Signal	Power (dBW)
GPS	L1	C/A	-158.5
		P(Y)	-161.5
		L1C-P	-158.25
	L2	P(Y)	-161.5 ^a
		L2C	-163.0 ^b
	L5	L5I,Q	-157.9 ^c
GLN	G1	C/A	-161.0
	G2	C/A	-161.0

GNSS	Band	Signal	Power (dBW)
GAL	E1	D(B)	-160.0
		P(C)	
	E5	E5a E5b	-158.0
	E6	D(B) P(C)	-158.0
BDS	B1-2	OS	-163.0
	B2b	OS	-163.0

based on Montenbruck et al., 2017

Notes: ^a -164.5 for block IIA/IIR, ^b -161.5 for block III, ^c -157.0 for block III.



Case studies

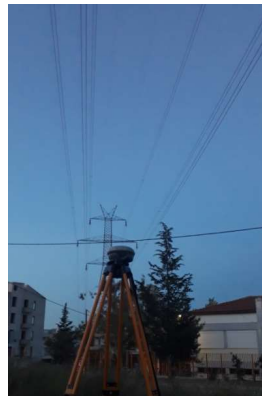
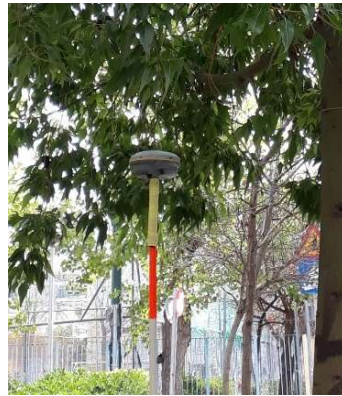


Analyzed data:

- **Measurements under tree canopies**
- **Measurements in the presence of E/M interferences**

Case studies

Representative examples

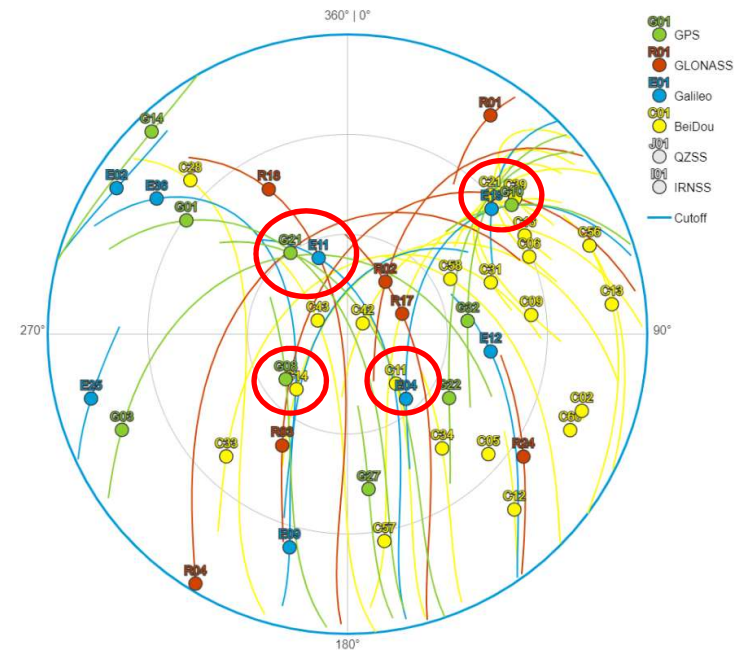


Data analysis

Notes on the analysis strategy

Comparison of SNR among GNSS:

- Compare with a receiver tracking on a nearby 'good' point
- Only satellites with similar Elev. & Az. were compared





Data analysis



Notes on the analysis strategy

Comparison of signals among GNSS:

- E5 vs. L2: Imposed by practical reasons
- E5 vs. L5: Theoretically more correct



Data analysis



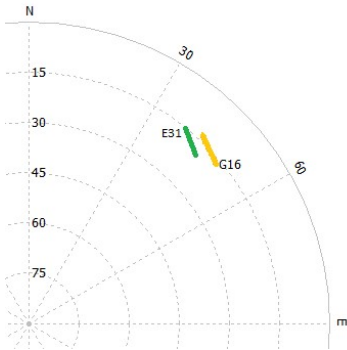
Notes on the analysis strategy

Comparison of coordinate errors among GNSS:

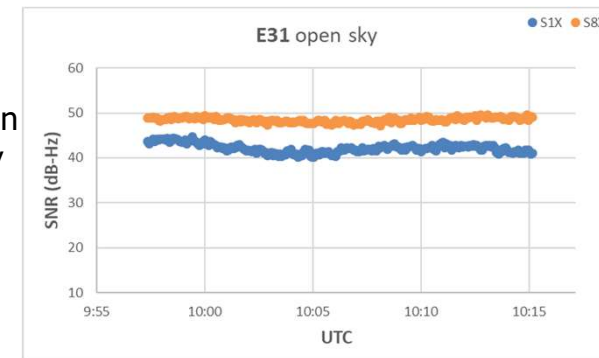
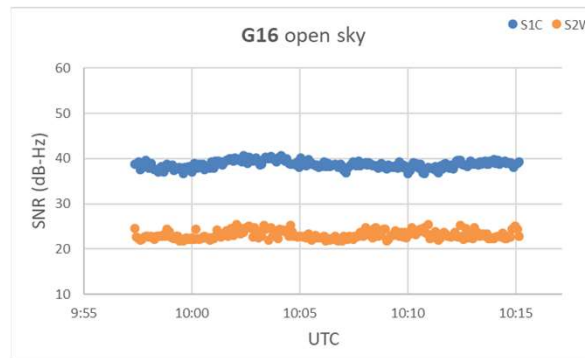
- Use all sv of each GNSS: OK from practical point of view
- Use same # of sv, similar DOP etc.: More fair comparison

Data analysis

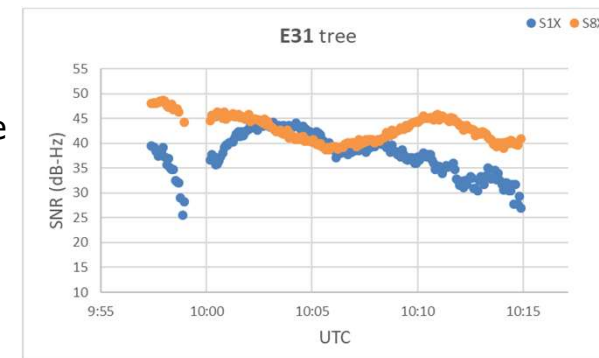
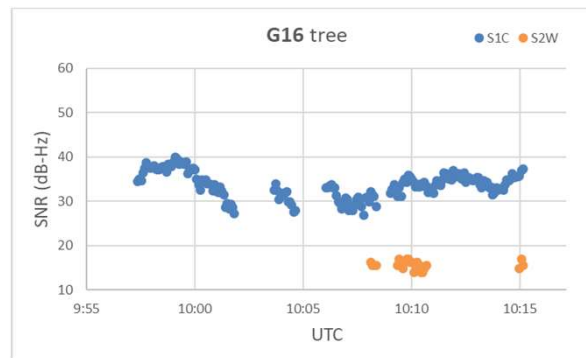
Tree canopies: SNR analysis



GPS vs. GAL	
L1	E1
L2	E5



Open sky



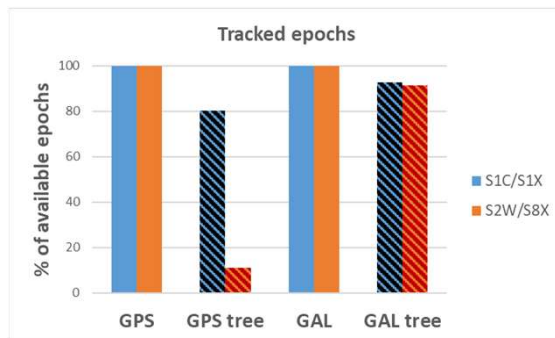
tree

Data analysis

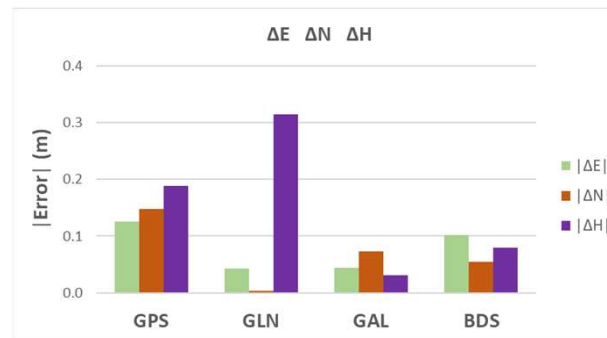


Tree canopies: Comparison GPS, GLN, GAL, BDS

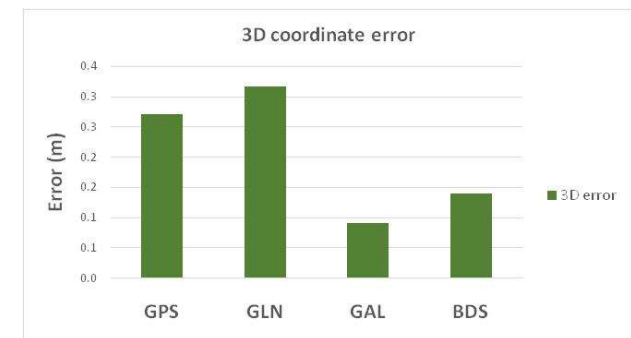
Tracked epochs (G16 - E31)



Positioning error (ΔE ΔN ΔH)

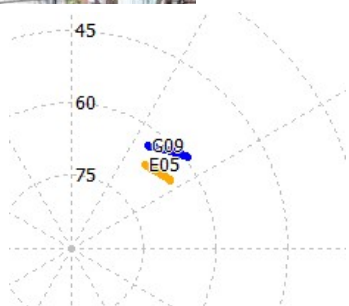


Positioning error (3D error)

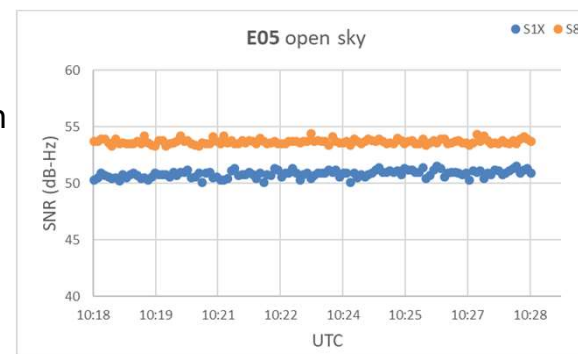
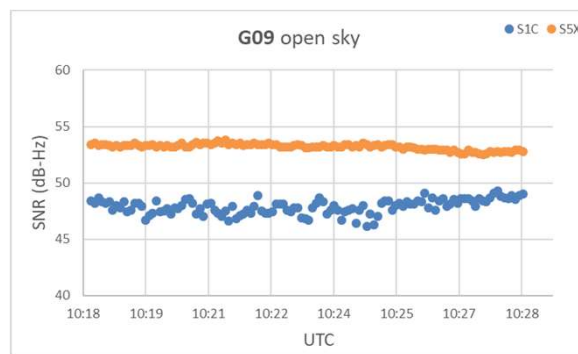


Data analysis

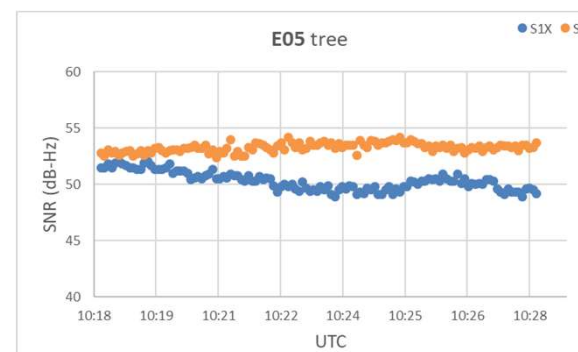
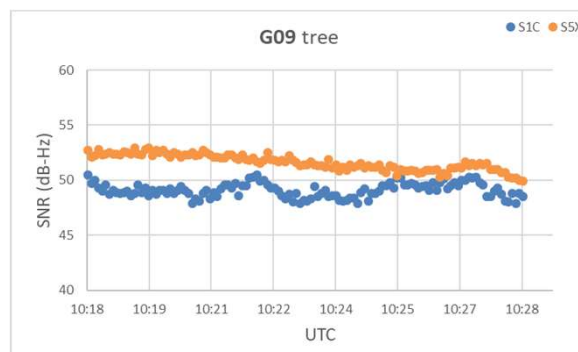
Tree canopies: SNR analysis



GPS vs. GAL	
L1	E1
L5	E5



Open sky



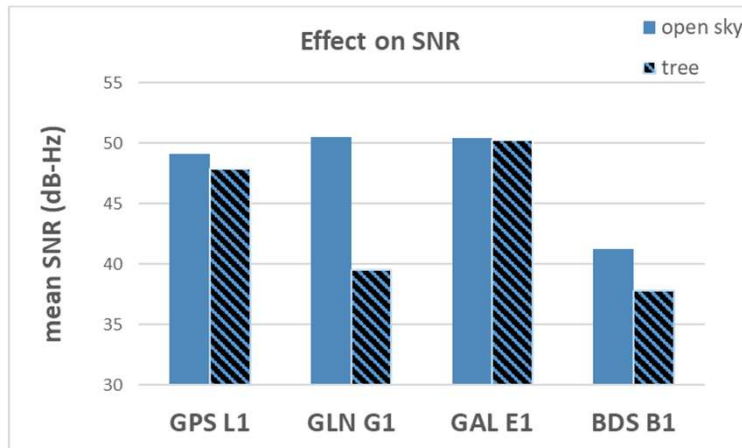
tree

Data analysis

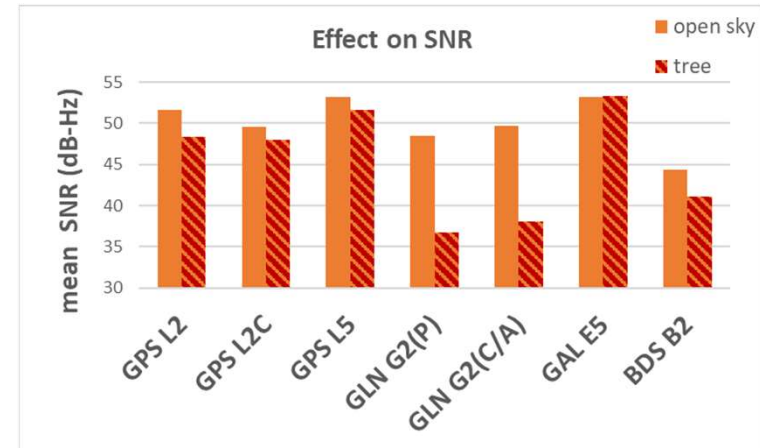


Tree canopies: Comparison GPS, GLN, GAL, BDS

SNR (L1, G1, E1, B1)



SNR (L2, G2, E5, B2)

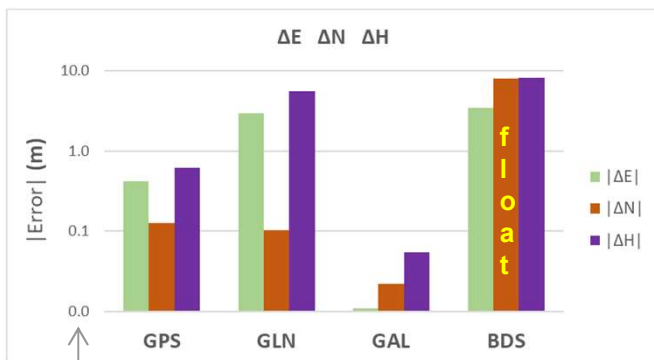


Data analysis



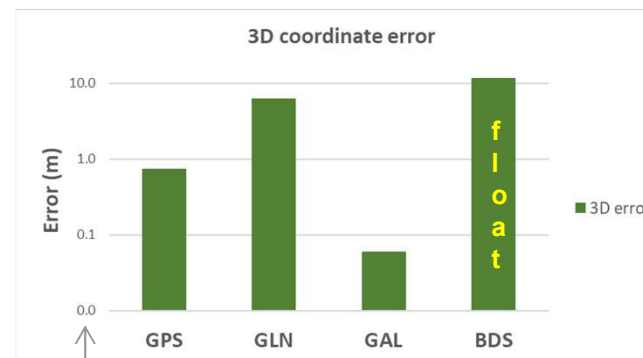
Tree canopies: Comparison GPS, GLN, GAL, BDS

Positioning error ($\Delta E \Delta N \Delta H$)



Logarithmic scale !

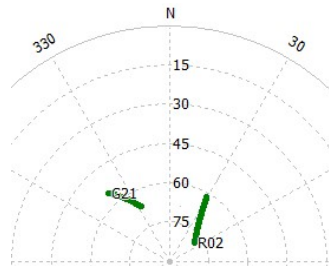
Positioning error (3D error)



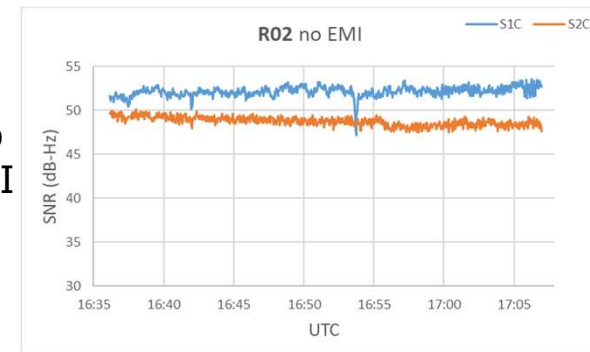
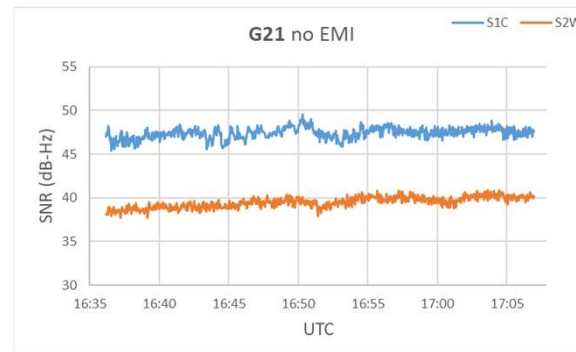
Logarithmic scale !

Data analysis

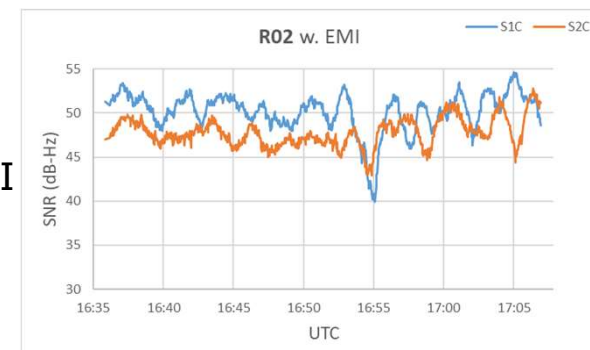
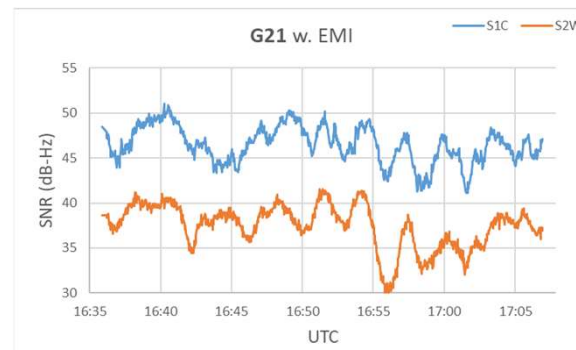
Electromagnetic interferences (EMI): SNR analysis



GPS		vs.	GLN	
L1			G1	
L2			G2	



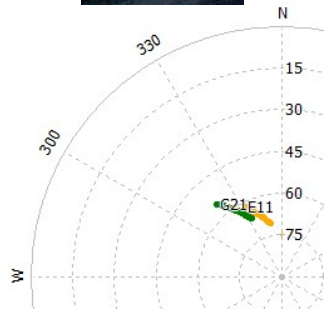
no
EMI



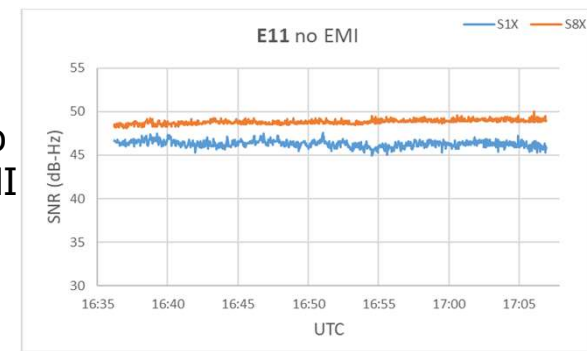
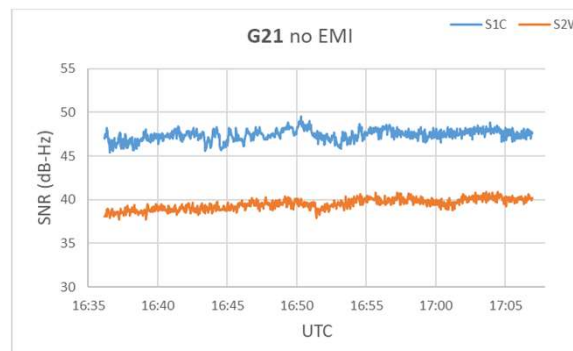
w.
EMI

Data analysis

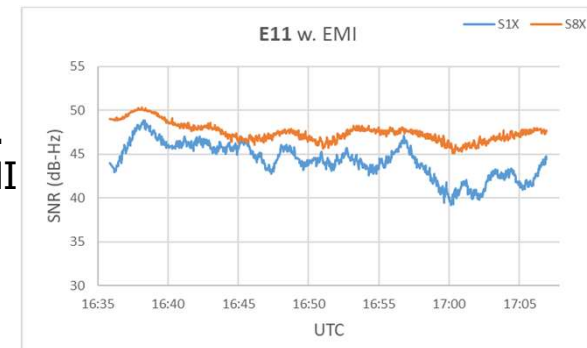
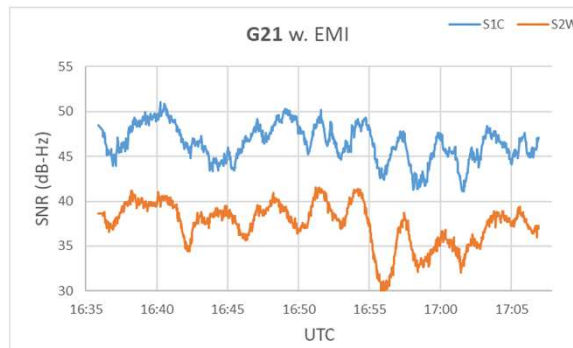
Electromagnetic interferences (EMI): SNR analysis



GPS vs. GAL	
L1	E1
L2	E5



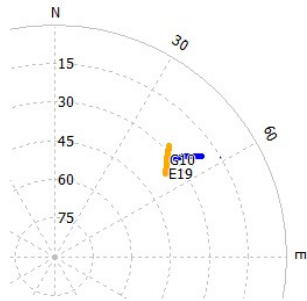
no
EMI



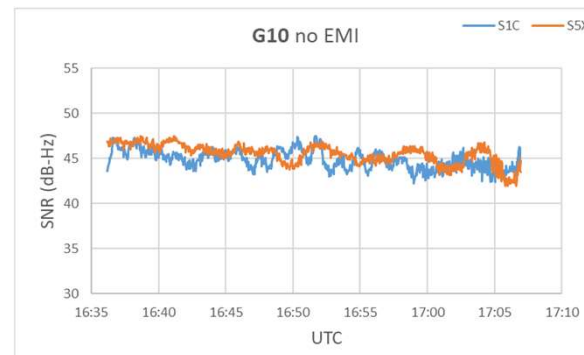
w.
EMI

Data analysis

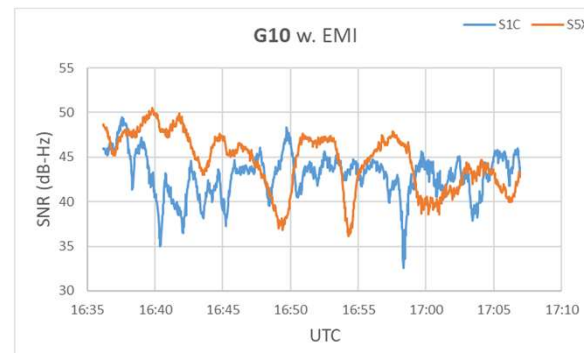
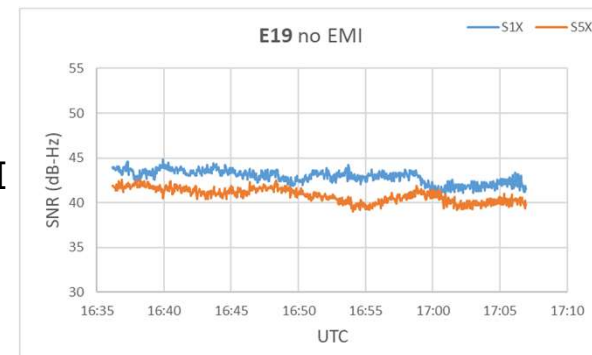
Electromagnetic interferences (EMI): SNR analysis



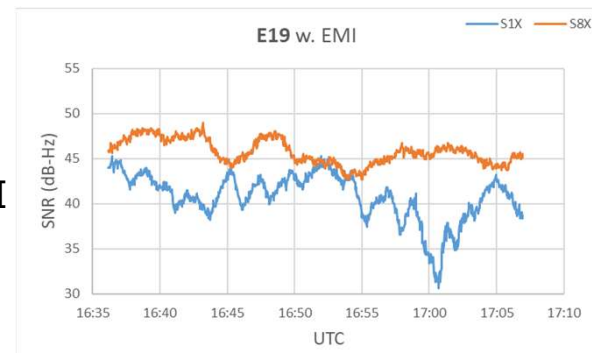
GPS vs. GAL	
L1	E1
L5	E5



no
EMI

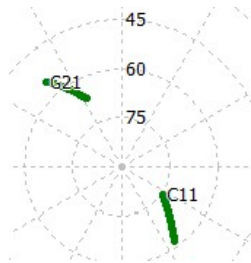


w.
EMI

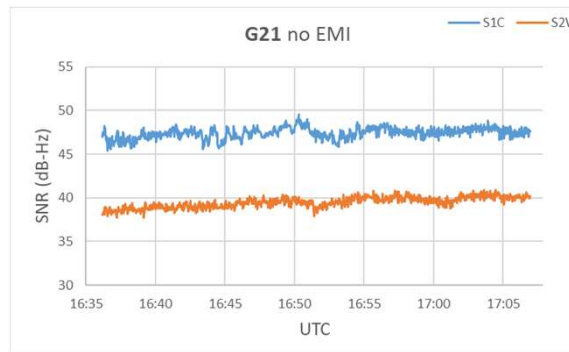


Data analysis

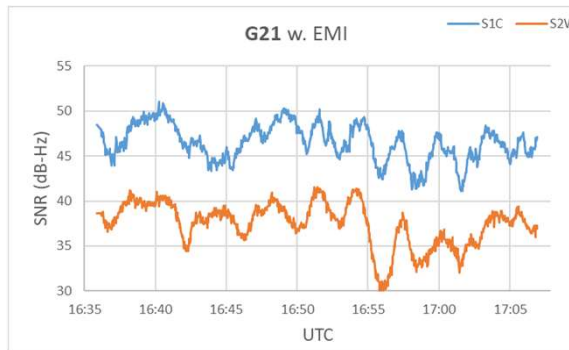
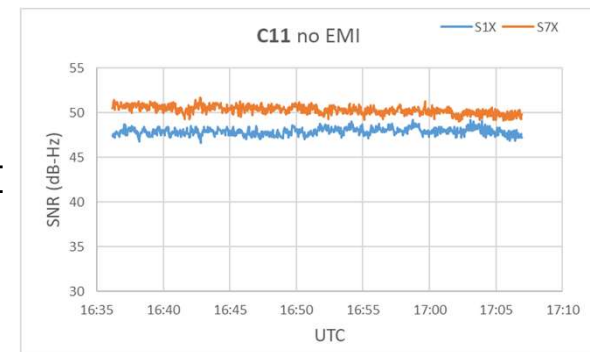
Electromagnetic interferences (EMI): SNR analysis



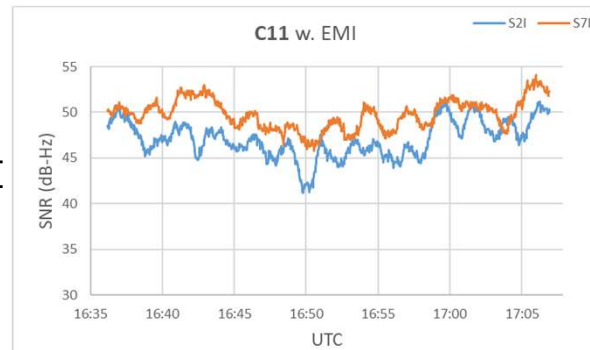
GPS vs. BDS	
L1	B1
L2	B2



no
EMI

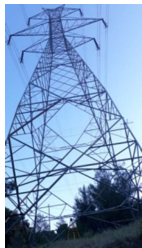


w.
EMI

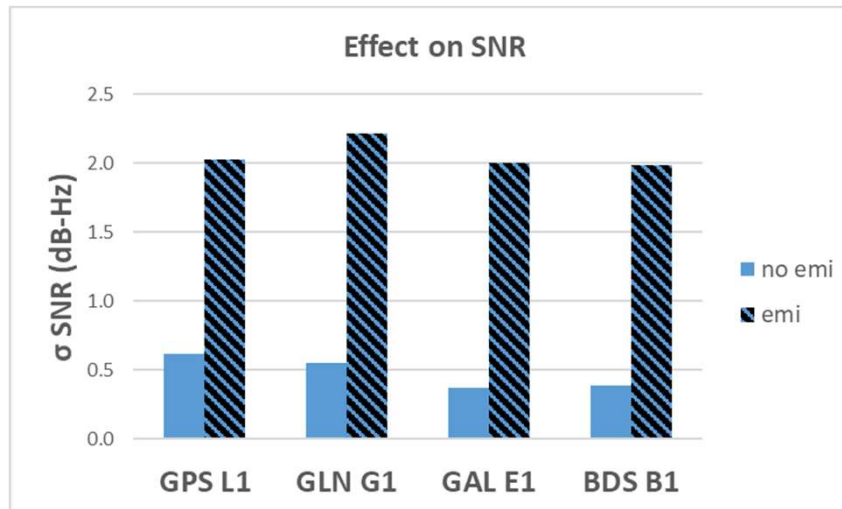


Data analysis

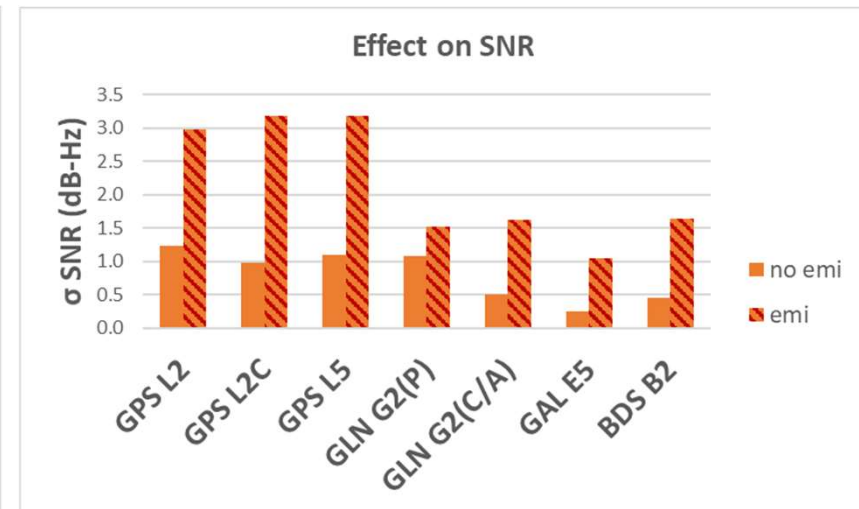
Electromagnetic interferences (EMI): Comparison GPS, GLN, GAL, BDS



SNR (L1, G1, E1, B1)



SNR (L2, G2, E5, B2)

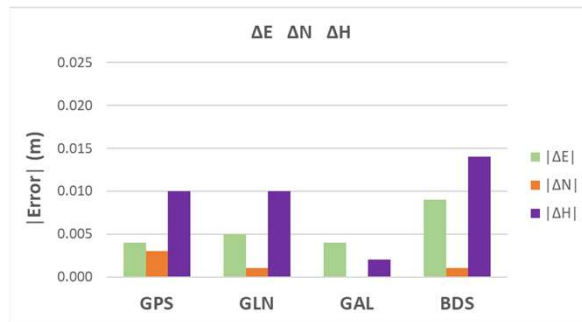


Data analysis

Electromagnetic interferences (EMI)

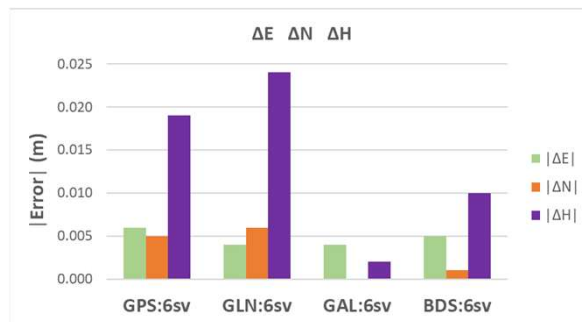
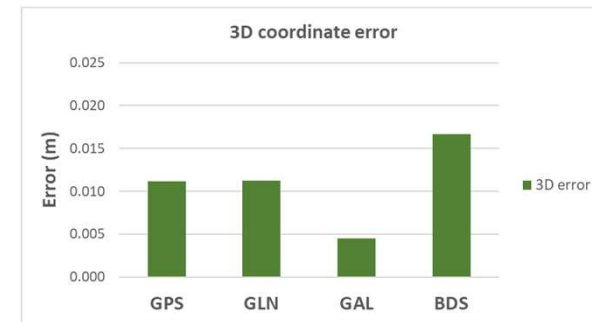


Positioning error (ΔE ΔN ΔH)

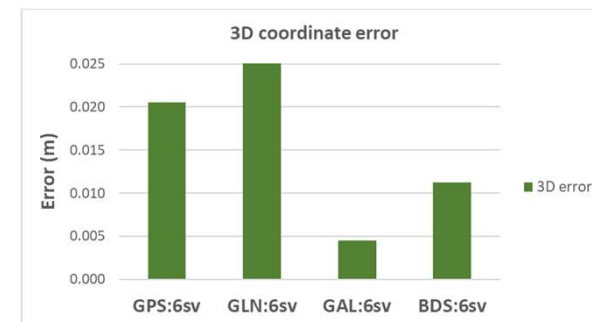


all sv
of each GNSS

Positioning error (3D error)



same # of sv,
similar DOP



Conclusions

➤ **Tracking under tree canopies**

- E1 performs slightly better than L1
- E5 performs much better than L2 (L8X vs. L2W)
- E5 performs slightly better than L5, G2, B2
- G1 and G2 are mostly affected

} **importance of L2C, L5, L1C**

➤ **Tracking in the presence of EMI**

- E1 performs more or less similar to L1, G1, B1
- E5 performs better than L2, L5, G2, B2

➤ **Positioning error**

- Galileo shows a superior performance



Future work



- Examine more cases
- Distinguish between different kinds of interferences (in-band, out-of-band etc.)
- Focus on modernized signals (L2C, L5, L1C, B1C, B2a etc.)
- Investigate dependency on receiver architecture



Thank you for your attention!

