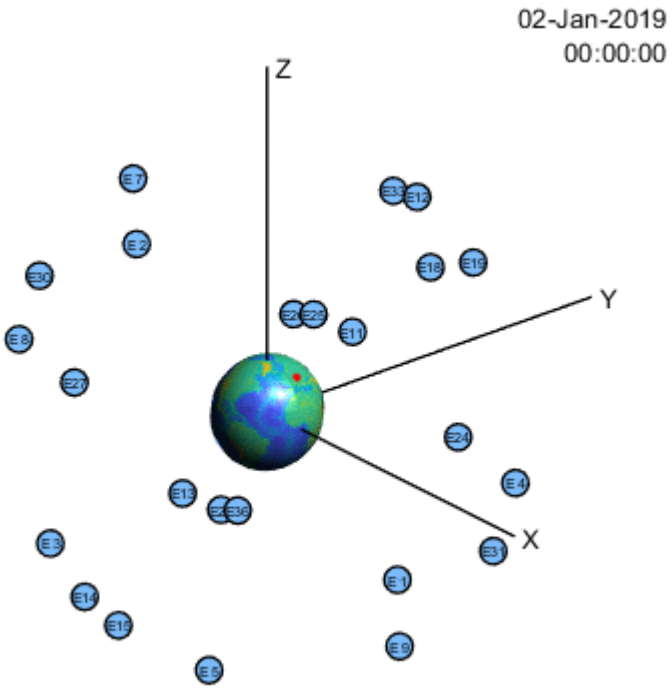
WROCŁAW UNIVERSITY OF ENVIRONMENTAL AND LIFE SCIENCES

Galileo-only positioning for the present Galileo constellation



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The EUREF Analysis Centres Workshop October 16-17, 2019, Warsaw, Poland

Motivation: Galileo status

22 + 2 + 2 Galileo satellites:

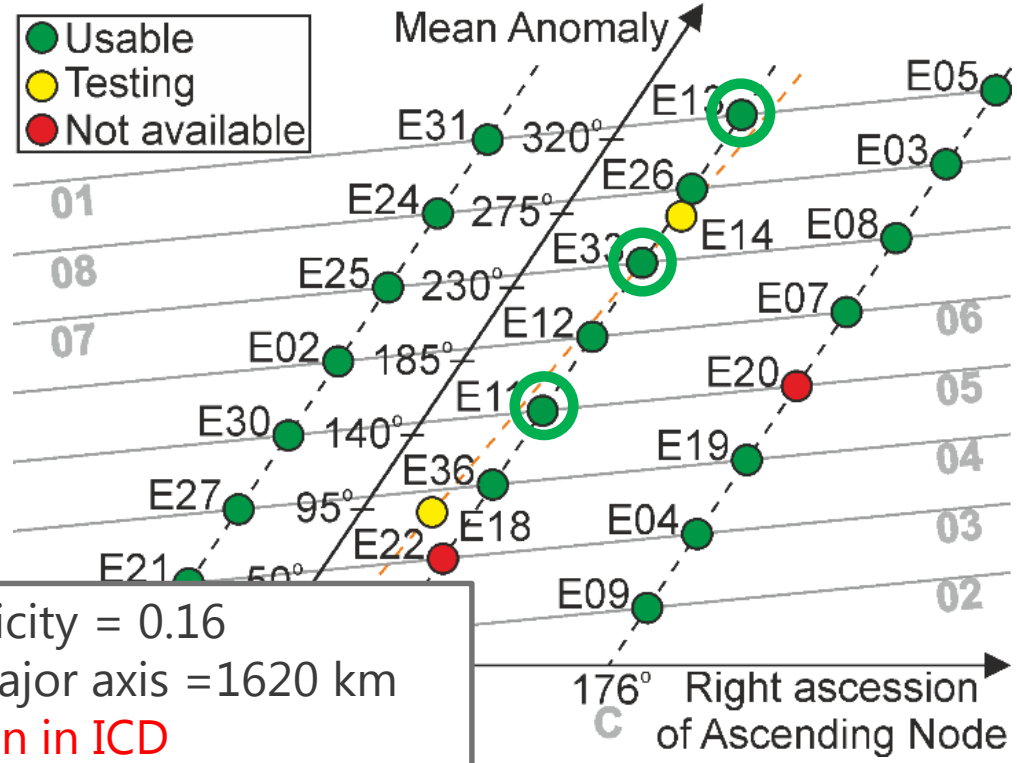
- February 11, 2019: **E11**, **E13**, **E15** and **E33** announced healthy
- **E20** and **E22** are unserviceable (single-frequency; management)
- **E14** and **E18** (first FOC) in elliptical orbits (missed their target)

- abnormal eccentricity = 0.16
- dev. of the semimajor axis =1620 km

Out of range foreseen in ICD

Products:

- 24 broadcast ephemeris
- 24 IGS MGEX orb+clk
- 22 (-4) IGS RTS orb+clk



Galileo constellation status as of January 1, 2019. Satellites are marked with PRN numbers, grey letters and numbers allow for identifying a satellite slot

Motivation: Galileo-only positioning

Literature:

☑ GPS only @ BRDC / FIN / RT products

☑ GNSS (=GPS+GLO/GAL/BDS) @ BRDC / FIN / RT products

☑ GLO/BDS only, incomplete GAL

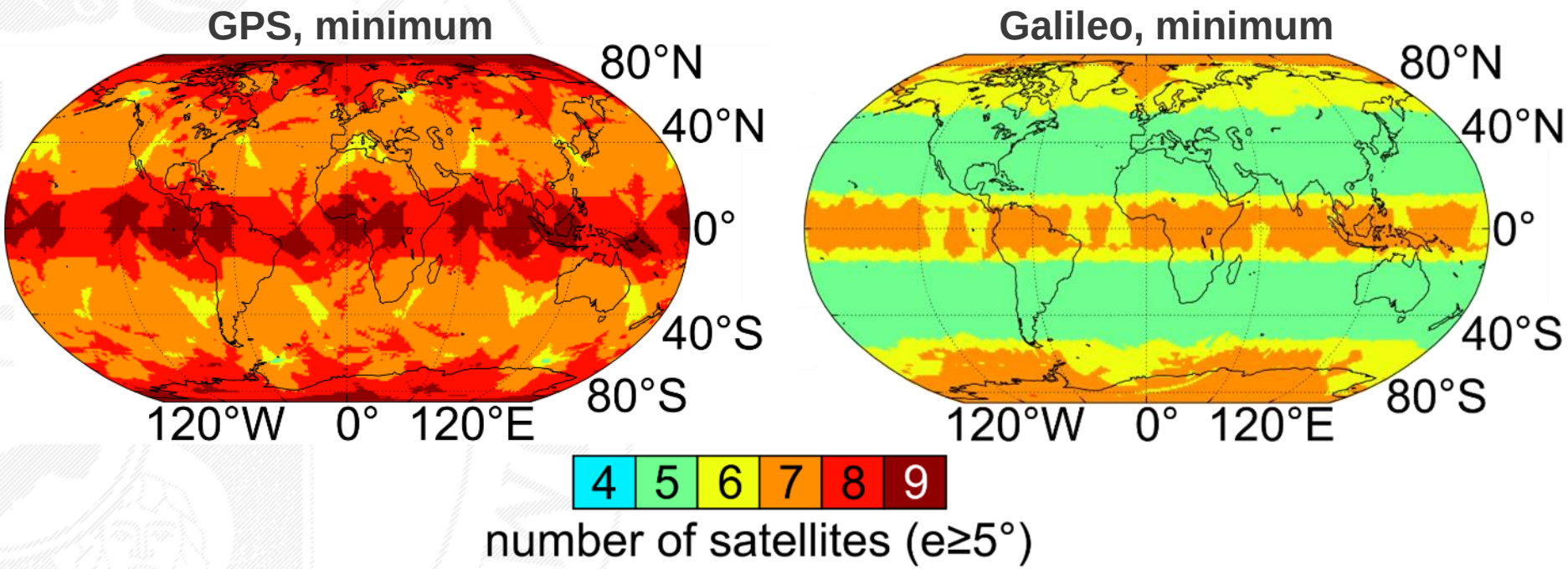
☒ Galileo only @ BRDC / FIN / RT products

Galileo > other GNSS:

- multiple signals and frequencies
- 0.25 m tracking range error of E1 (<0.10 m for E5 AltBOC)
- SISRE=0.15 m (2-3x better than GPS) [1]

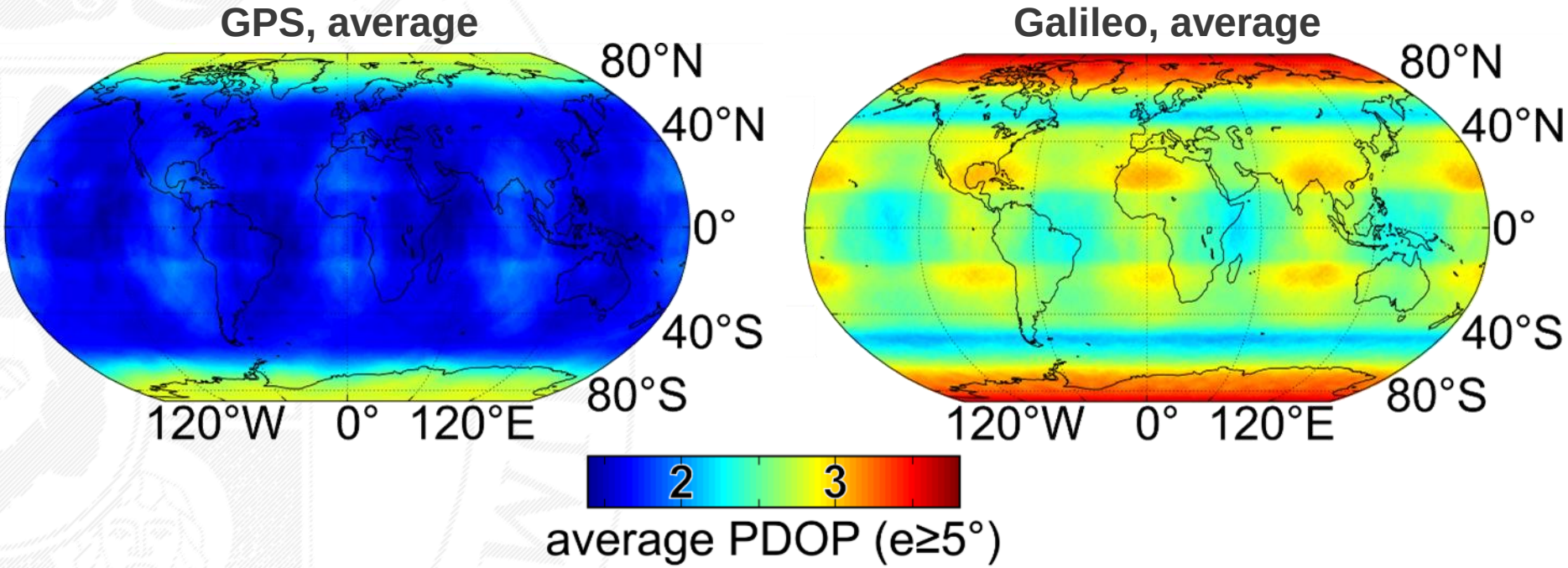
[1] Steigenberger and Montenbruck, 2017, Multi-GNSS SISRE Monitoring – Methodology and Results, German Space Operations Center (GSOC)

Global availability (elev.≥5°, Jan 1-7, 2019)



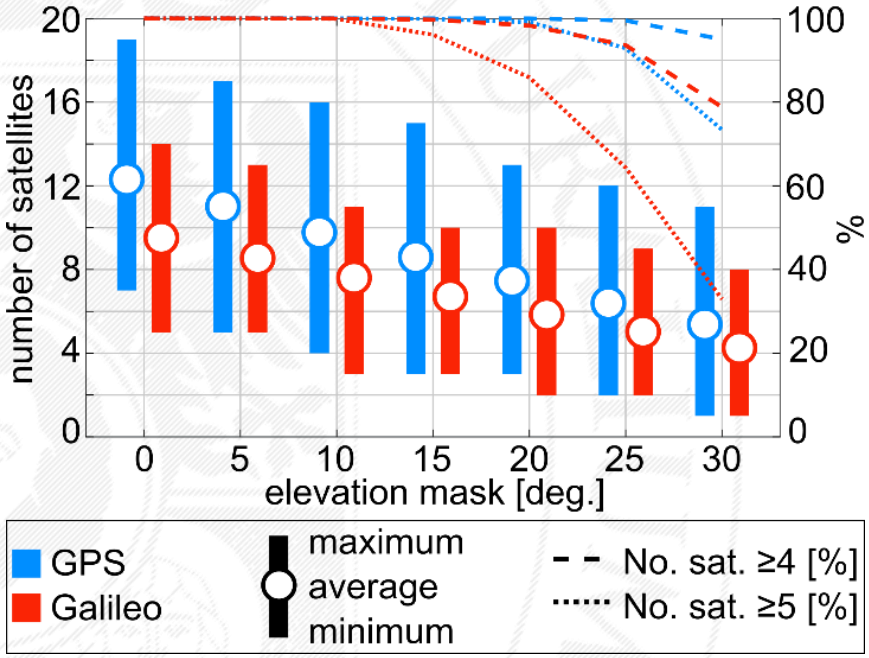
- **≥5 Galileo satellites available 100% (global PPP / RTK / …)**
- **ca. 2 more GPS satellites than Galileo satellites**

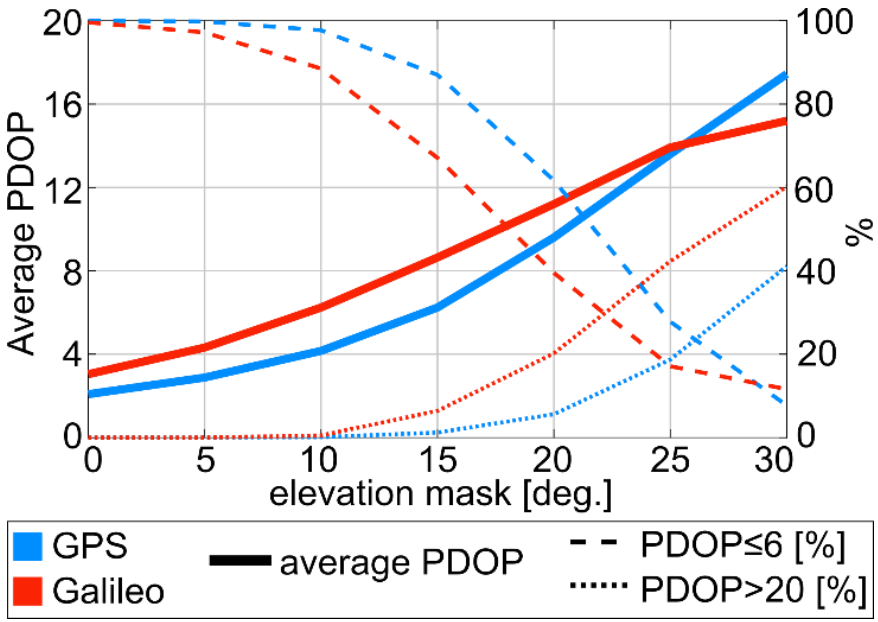
Global PDOP (elev.≥5°, Jan 1-7, 2019)



- GPS PDOP <2.0 (except poles, with PDOP up to 2.8)
- Galileo PDOP from 2.1 to 3.0 (poles up to 3.8)

Availability and PDOP (Galileo vs. GPS)





- **GPS>Galileo (#SV & PDOP); GPS better for urban canyons**
- **maximum 14 Galileo satellites (Antarctica)**

Galileo-only positioning – methodology (1)

Undifferenced uncombined functional model [2] in GNSS-WARP:

$$\boldsymbol{C_i^s - \rho_0^s + c\delta t^s + b_{C,i}^s = e_r^s \cdot \delta X_r + c\delta t_r + m^s T_Z + \mu_i I^s}$$

$$\boldsymbol{L_i^s - \rho_0^s + c\delta t^s + b_{L,i}^s = e_r^s \cdot \delta X_r + c\delta t_r + m^s T_Z - \mu_i I^s + \lambda_i N_i^s}$$

$$\boldsymbol{e_r^s} = \begin{bmatrix} \frac{X_r - X^s}{\rho_0^s} & \frac{Y_r - Y^s}{\rho_0^s} & \frac{Z_r - Z^s}{\rho_0^s} \end{bmatrix} \qquad \delta X_r = [\delta X_r \quad \delta Y_r \quad \delta Z_r]^T$$

$$\mu_i = f_1^2 / f_i^2 \qquad \rho_0^s = \sqrt{\left(X^s - X_{r,0}\right)^2 + \left(Y^s - Y_{r,0}\right)^2 + \left(Z^s - Z_{r,0}\right)^2}$$

In this study:

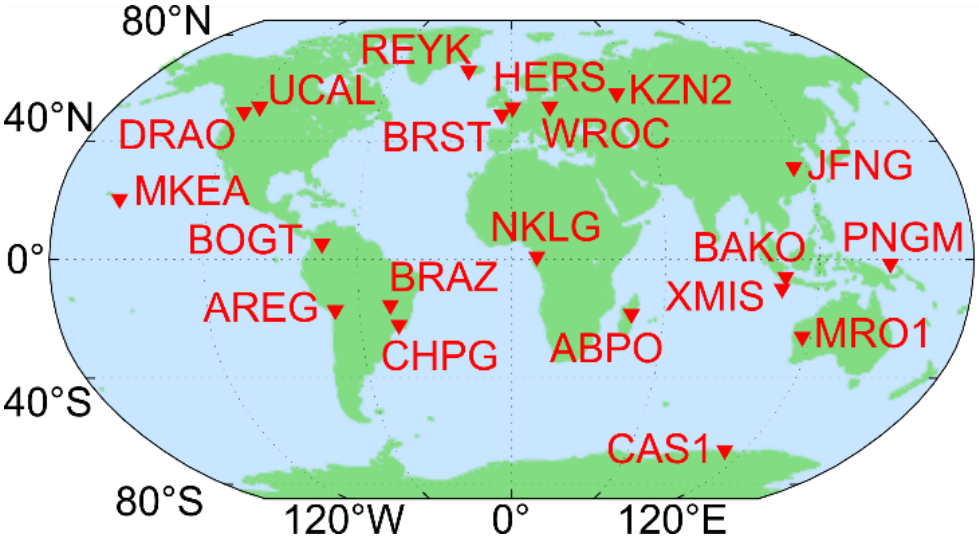
- dual frequency data (*i*=1,2)
- PPP uses C & L observations
- SPP uses C observations only
- no constraints on *I*
- float ambiguities

[1] Schönemann E (2014) Analysis of GNSS raw observations in PPP solutions. Dissertation, Technische Universität Darmstadt

Galileo-only positioning – methodology (2)

Data:

- January 1 to 7, 2019
- 20 IGS stations
- RINEX v3.03
- E1/E5a + I/NAV
- FIN: MGEX CODE
- RTS: CLK93

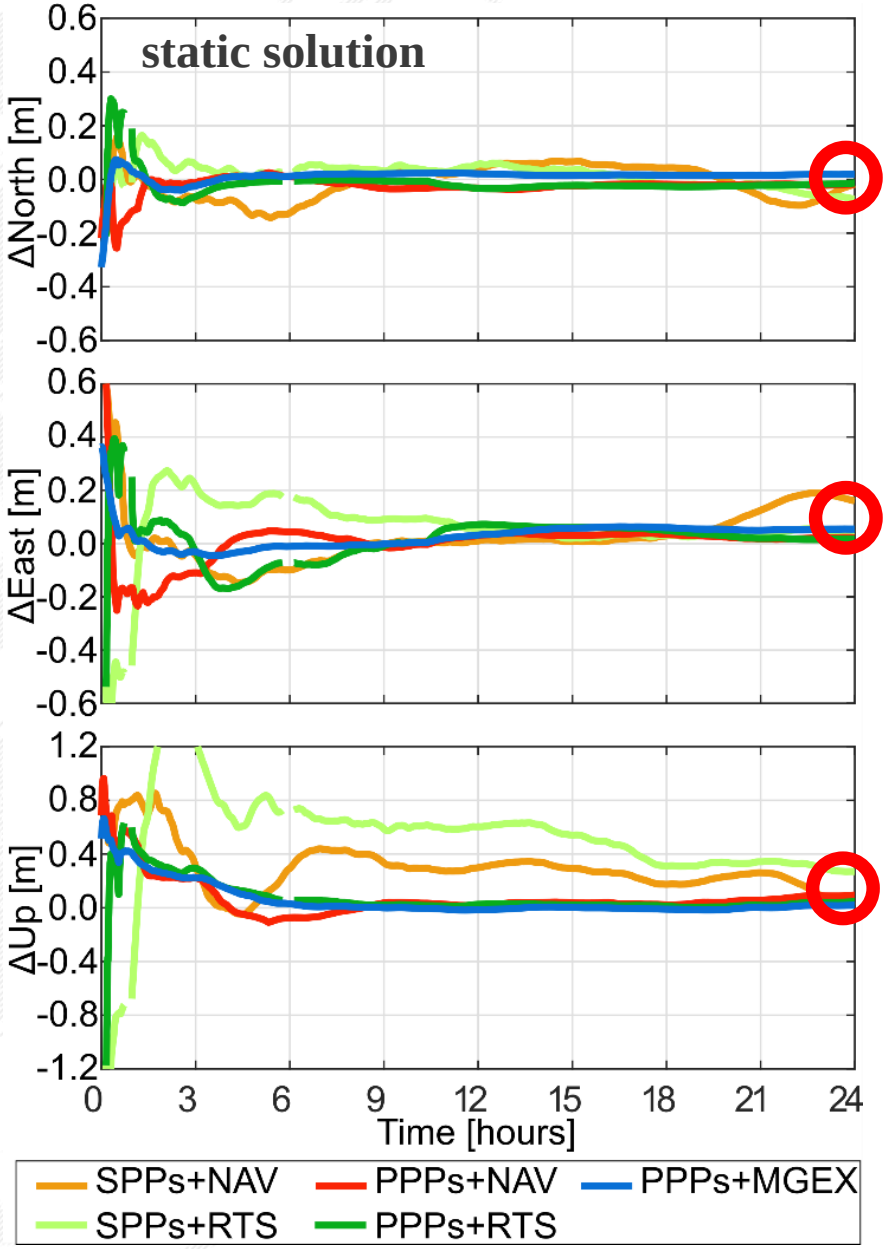


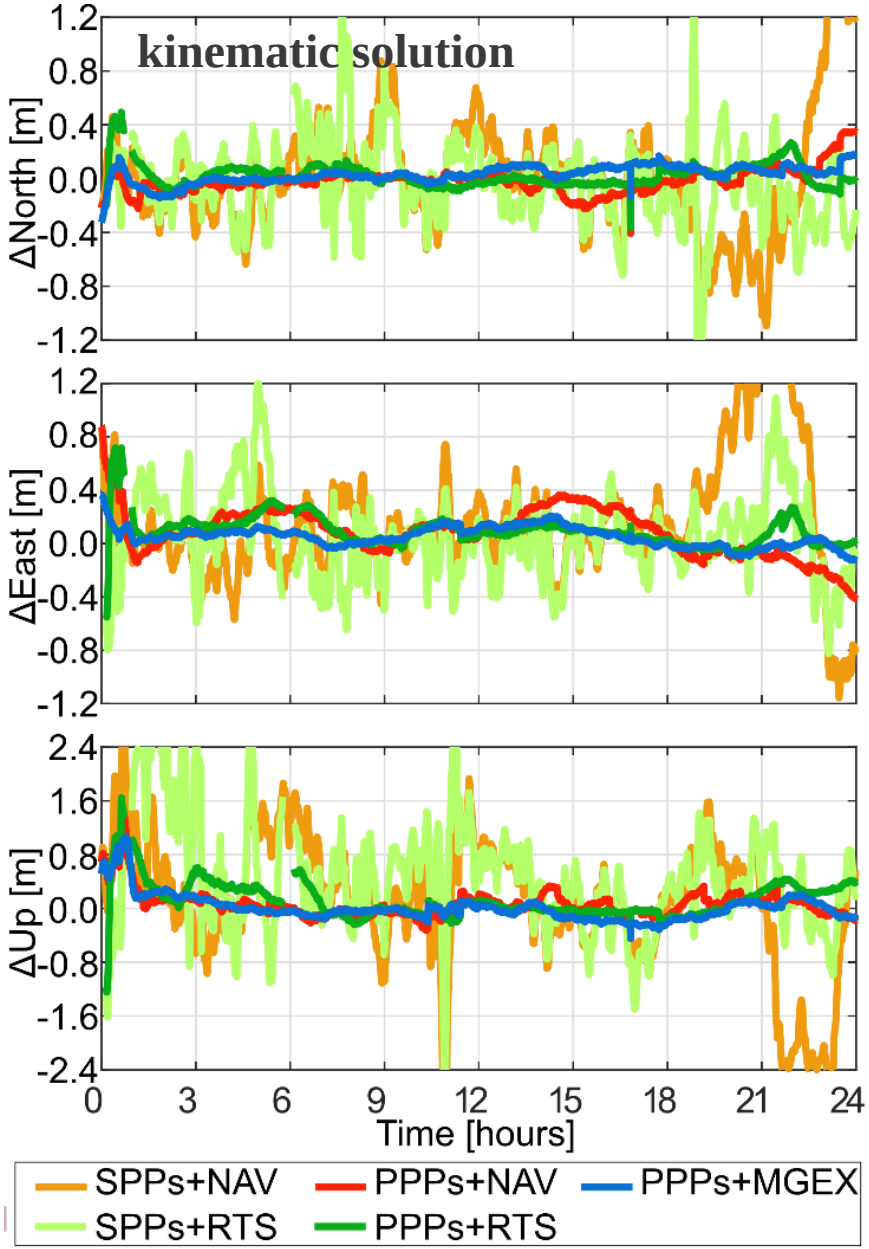
Location of test stations

Processing variants:

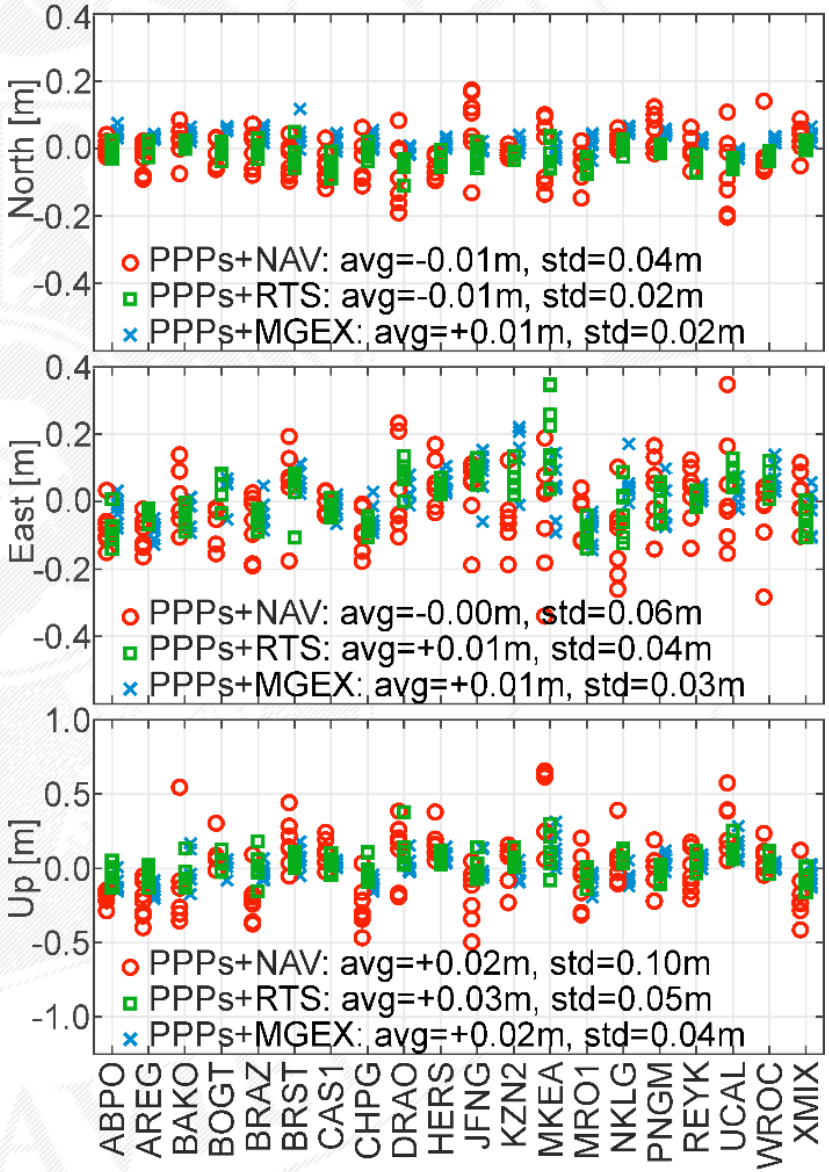
	SPPs +NAV	SPPs +RTS	PPPs +NAV	PPPs +RTS	PPPs+ MGEX	SPPk +NAV	SPPk +RTS	PPPk +NAV	PPPk +RTS	PPPk+ MGEX
Coordinates mode	Static					Kinematic				
Observables	C		C+L			C		C+L		
Orbits and clocks	BRCD	RTS	BRCD	RTS	MGEX CODE	BRCD	RTS	BRCD	RTS	MGEX CODE
Satellite biases	0		0			0		0		
Troposphere delay	fixed		T_Z estimated			fixed		T_Z estimated		

Examplary results for WROC station, January 1, 2019





Static positioning results (1)



PPP (E1C/E5C + E1W/E5W) accuracy:

a) +NAV

- **RMS Hz = 0.07 m**
- **RMS V = 0.10 m**

b) +RTS

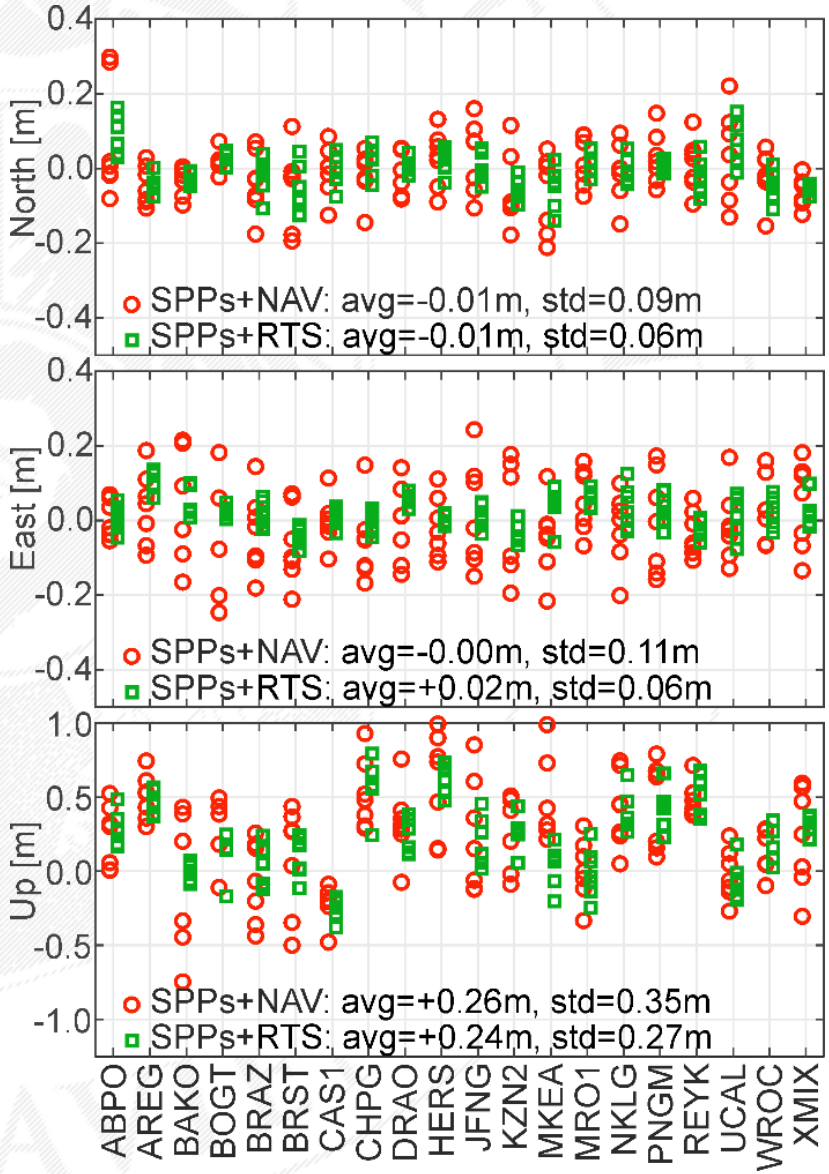
- **RMS Hz = 0.05 m**
- **RMS V = 0.06 m**

c) +MGEX

- **RMS Hz = 0.04 m**
- **RMS V = 0.05 m**

Differences between coordinates obtained from Galileo-only pseudorange and carrier-phase daily static solutions and IGS weekly combined solution

Static positioning results (2)



SPP (E1C/E5C) accuracy (RMS):

a) +NAV

- **RMS Hz = 0.14 m**
- **RMS V = 0.43 m**
  - **+0.25 m avg. bias (~~tropo~~)**

b) +RTS: improves:

- **Hz by 37%**
- **V by 16%**

Differences between coordinates obtained from Galileo-only daily static solutions and IGS weekly combined solution

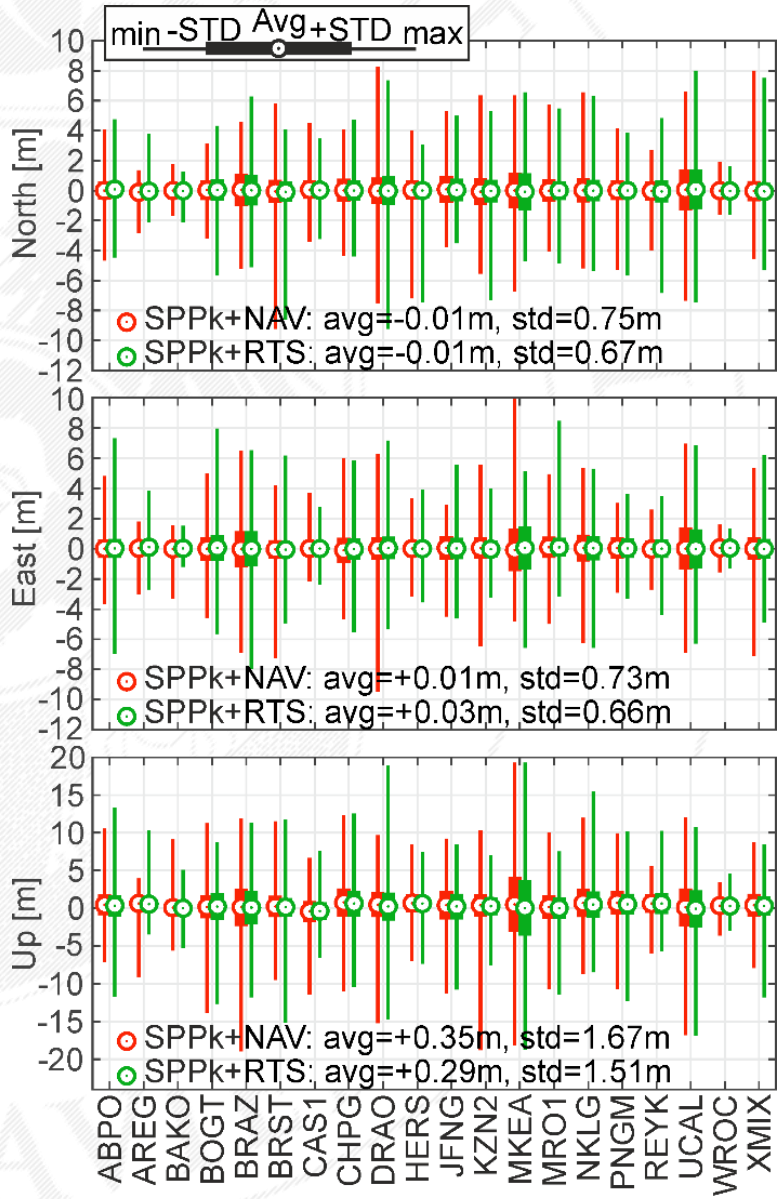
Galileo vs GPS (static mode)

RMSE between estimated coordinates and IGS weekly combined solution for GPS-only and Galileo-only dual-frequency static positioning

Processing variant	Horizontal [m]		Vertical [m]	
	GPS	Galileo	GPS	Galileo
SPPs+NAV	0.279	0.141	0.701	0.433
SPPs+RTS	0.115	0.089	0.418	0.365
PPPs+NAV	0.197	0.067	0.188	0.098
PPPs+RTS	0.031	0.049	0.044	0.060
PPPs+MGEX	0.012	0.039	0.013	0.045

- precise Galileo static positioning still not as good as with GPS (less accurate orbit and clock products, less satellites)
- outsdanding accuracy of Galileo static SPP/PPP+NAV
- code based static positioning benefits from RTS (even more for GPS)

Kinematic positioning results (1)



SPP (E1C/E5C) accuracy:

a) +NAV

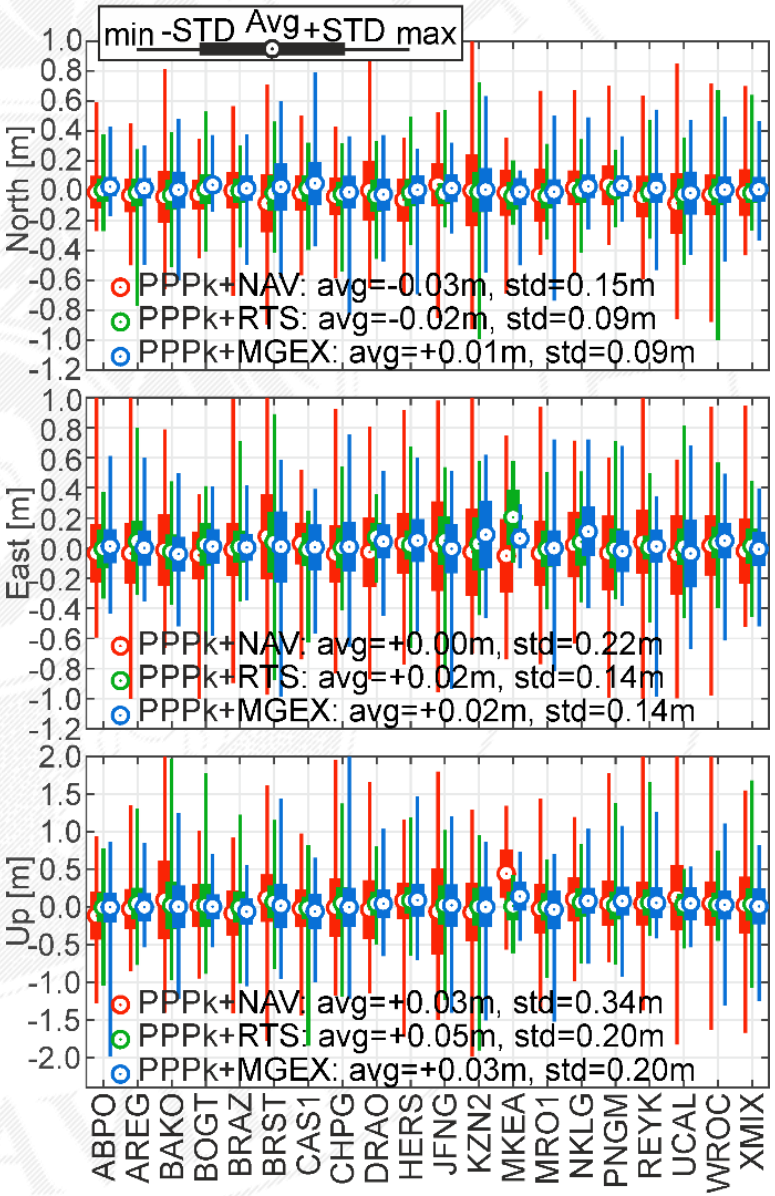
- **RMS Hz = 1.0 m**
- **RMS V = 1.7 m**
  - **+0.3 m avg. bias (~~tropo~~)**

b) +RTS: improves:

- **Hz by 10%**
- **V by 10%**

Differences between coordinates obtained from Galileo-only pseudorange kinematic solutions and IGS weekly combined solution

Kinematic positioning results (2)



PPP (E1C/E5C + E1W/E5W) accuracy:

a) +NAV

- RMS Hz = 0.27 m
- RMS V = 0.34 m

b) +RTS

- RMS Hz = 0.16 m
- RMS V = 0.21 m

c) +MGEX

- RMS Hz = 0.16 m
- RMS V = 0.20 m

Differences between coordinates obtained from Galileo-only pseudorange and carrier-phase kinematic solutions and IGS weekly combined solution

Galileo vs GPS (kinematic mode)

RMSE between estimated coordinates and IGS weekly combined solution for GPS-only and Galileo-only dual-frequency kinematic positioning

Processing variant	Horizontal [m]		Vertical [m]	
	GPS	Galileo	GPS	Galileo
SPPs+NAV	1.269	1.045	2.211	1.702
SPPs+RTS	0.921	0.938	1.557	1.536
PPPs+NAV	0.313	0.267	0.352	0.337
PPPs+RTS	0.080	0.164	0.103	0.210
PPPs+MGEX	0.160	0.165	0.178	0.205

- code based kinematic positioning benefits from RTS (but not that much as static)
- kinematic Galileo SPP/PPP+NAV better than GPS (ca. 10%)
- Galileo kinematic RT-PPP 2x worse than GPS

Conclusions

- **Development of space segment and IGS:**

  Galileo-only absolute positioning is available!

- **Broadcast ephemeris allow for accurate SPP/PPP.**

- **SPP (GPS and Galileo) benefits from RTS.**

- **Further improvement of the quality of final and real-time products for Galileo is required;**

  Galileo should outperform GPS!

Thank you for your attention!

Hadas T., Kazmierski K. & Sośnica K.
Performance of Galileo-only dual-frequency absolute positioning using the fully serviceable Galileo constellation
GPS Solut (2019) 23: 108.
https://doi.org/10.1007/s10291-019-0900-9

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Foundation for Polish Science