Analysis of different weighting functions of observations for GPS and Galileo PPP

Damian Kiliszek*, Krzysztof Kroszczynski, Andrzej Araszkiewicz

Military University of Technology in Warsaw

*Author contact: damian.kiliszek@wat.edu.pl

- ❑ **Background**
- ❑ **Motivation**
- ❑ **Methodology**
- ❑ **Results**
- ❑ **Conclusion**

Motivation

- The mathematical model of GNSS positioning needs to define the deterministic and stochastic description.
- The deterministic model (functional) describes the mathematical relationship between GNSS observations and the estimated parameters – **known.**
- The stochastic model describes the statistical properties of observations – **not fully known**.

- Each GNSS system has different characteristics – **requires different approaches to stochastic modeling?**

Motivation

- Stochastic modeling can be presented as variance-covariance (VC) matrix.
- $VC = \sigma_0^2 \cdot Q$:

  σ_0 – values of precision of observations;

  Q – cofactor matrix which depend on the used weighting functions.
- Defined the full population of VC is very difficult. *Depends on: used models, used GNSS systems (also blocks of satellites) and their observations (frequencies and signals), used equipment (receiver and antenna types), noise, multipath, and other mis-modeled errors.*
- In most cases the weighting of observations depends on the elevation angel of satellite - using only variance population.

Motivation

The aims:

- Analyze the effect of using different elevation angle dependent weighting functions on the accuracy, convergence time and ZPD by the conventional PPP model for different GNSS constellations.
- Proposal of the best weighing functions for GPS-only, Galileo-only and GPS+Galileo for the PPP method.

Methodology

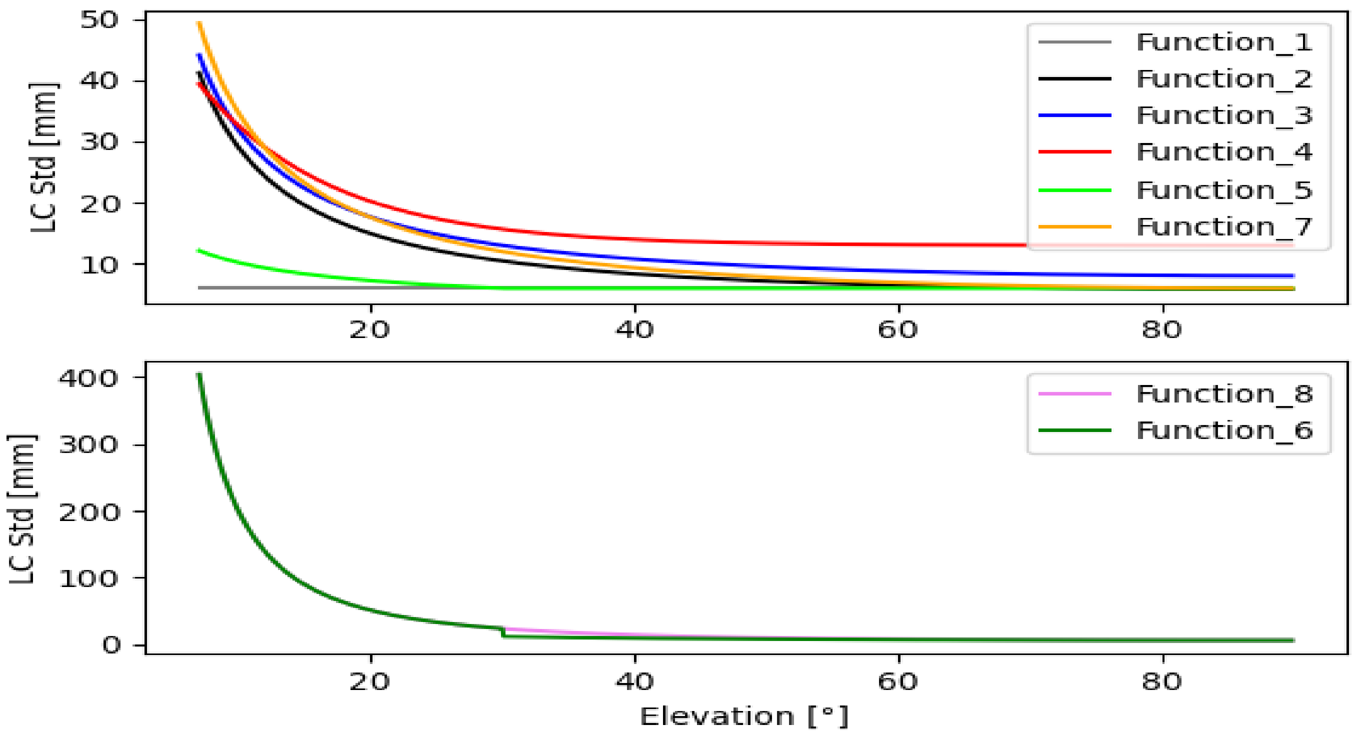
Items	Models/Methods
PPP model	static mode, conventional PPP model using dual-frequency code and phase ionosphere-free combination
Signals	GPS: L1, L2; Galileo: E1, E5a
Constellations	G, E, GE; where: G-GPS, E-Galileo
Stochastic modeling	different weighting functions (next slide)
Cut-off elevation angle	7°
Interval estimation	30-s
Software	PPPH*; implemented different weighting functions
Periods	one week: from 38 DoY to 44 DoY of 2021
Precise products	CODE MGEX
Solutions	**G, E, GE** – the same precision of observations **GE1** – worse precision for Galileo observations

*Bahadur, B.; Nohutcu, M. PPPH: A MATLAB-Based Software for Multi-GNSS Precise Point Positioning Analysis. GPS Solutions 2018 22:4 2018, 22, 1–10, doi:10.1007/S10291-018-0777-Z.

Methodology

Functions	Solutions	Precision of Pseudorange PR_{IF}	Precision of Carrier-phase Φ_{IF}
Function_1: $\sigma^2 = \sigma_0^2 = constans$	G, E, GE GE1 (for Galileo observations)	$\sigma_0 = 0.6m$ $\sigma_0 = 0.9m$	$\sigma_0 = 0.006m$ $\sigma_0 = 0.009m$
Function_2: $\sigma^2 = a^2 + \frac{b^2}{\sin^2(E)}$	G, E, GE	$a = 0.3m;\ b = 0.5m$	$a = 0.003m;\ b = 0.005m$
Function_3: $\sigma^2 = \left(a + \frac{b}{\sin(E)}\right)^2$	GE1 (for Galileo observations)	$a = 0.4m;\ b = 0.6m$	$a = 0.004m;\ b = 0.006m$
Function_4: $\sigma^2 = \left(c + de^{\frac{-E}{E_0}}\right)^2$	G, E, GE GE1 (for Galileo observations)	$c = 1.3m;\ d = 5.3m$ $c = 2.3m;\ d = 6.3m$ $E_0 = 10°$	$c = 0.013m;\ d = 0.053m$ $c = 0.023m;\ d = 0.063m$ $E_0 = 10°$
Function_5: $\sigma^2 = \frac{\sigma_0^2}{2\sin(E)}, E < 30°$ $\sigma^2 = \sigma_0^2, E \geq 30°$			
Function_6: $\sigma^2 = \left(\frac{\sigma_0}{\sin^2(E)}\right)^2, E < 30°$ $\sigma^2 = \left(\frac{\sigma_0}{\sin(E)}\right)^2, E \geq 30°$	G, E, GE	$\sigma_0 = 0.6m$	$\sigma_0 = 0.006m$
Function_7: $\sigma^2 = \left(\frac{\sigma_0}{\sin(E)}\right)^2$	GE1 (for Galileo observations)	$\sigma_0 = 0.9m$	$\sigma_0 = 0.009m$
Function_8: $\sigma^2 = \left(\frac{\sigma_0}{\sin^2(E)}\right)^2$			

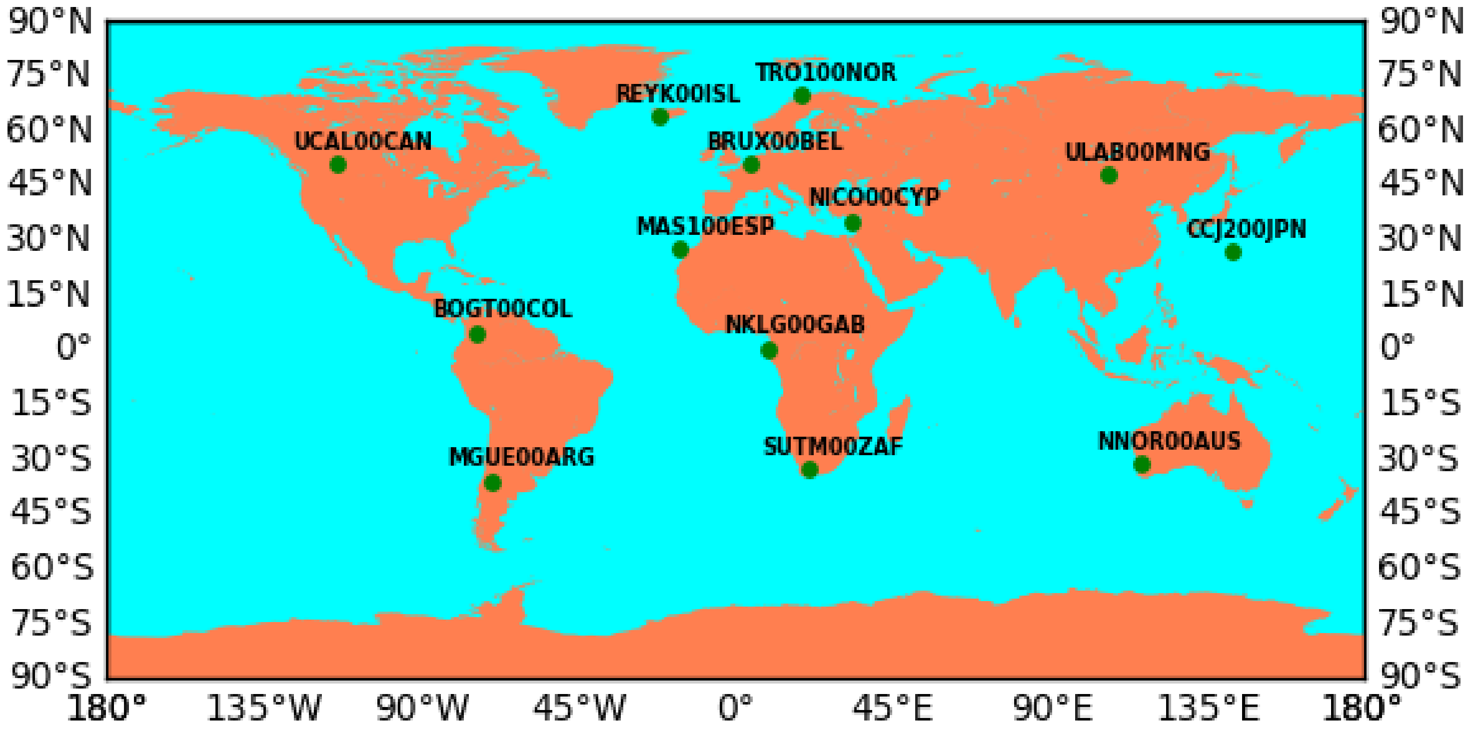
Methodology



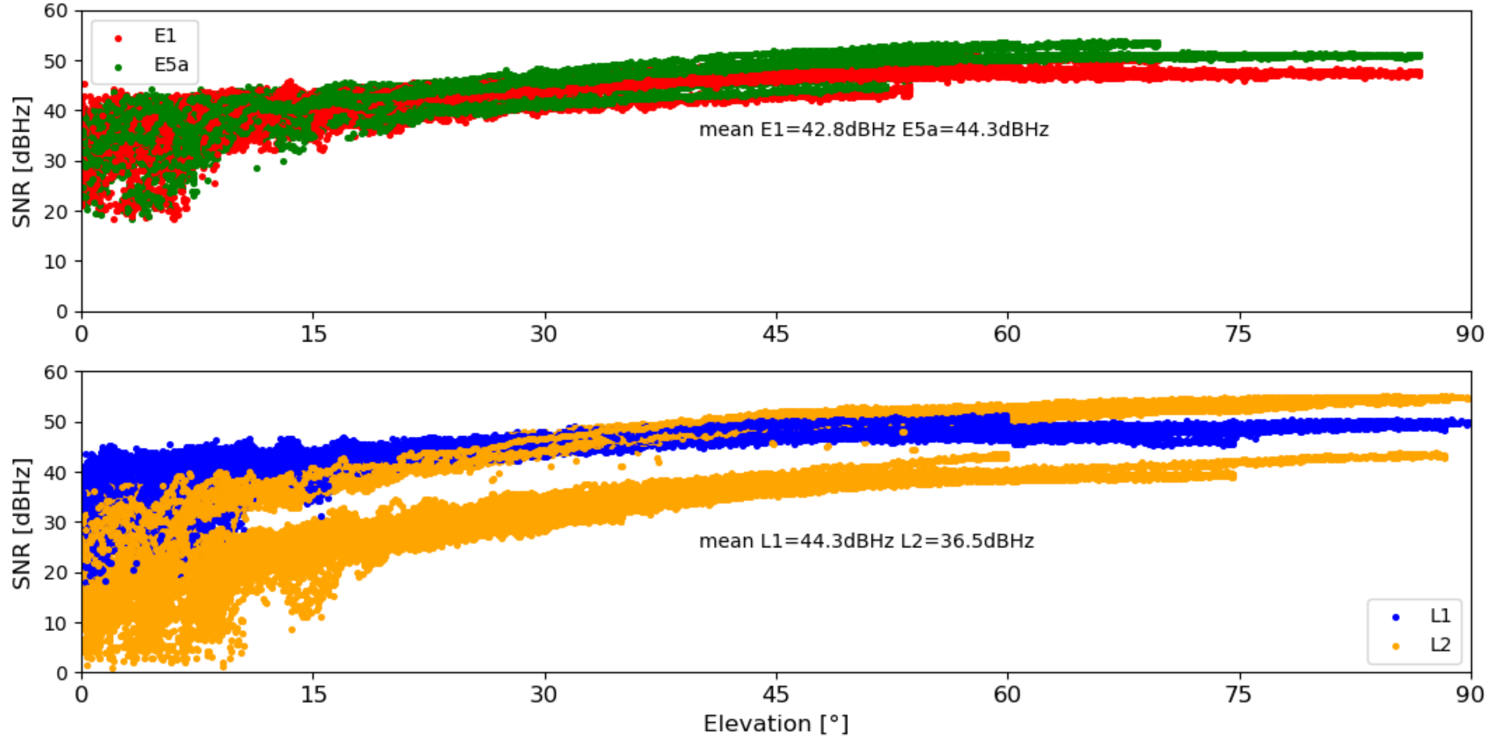
Standard deviations of carrier-phase of ionosphere-free linear combination with function of elevation angle for analyzed weighting functions.

Methodology

13 global distribution MGEX stations

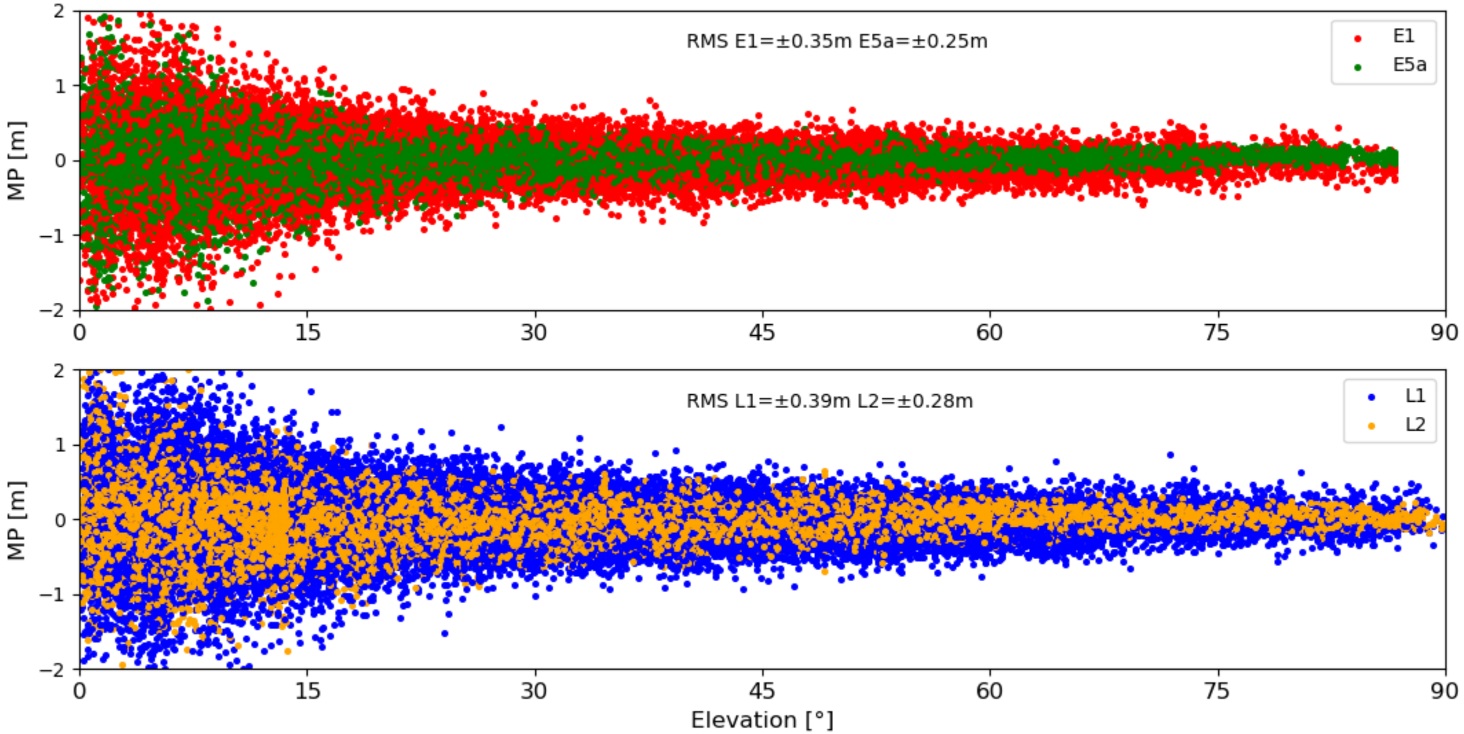


Results



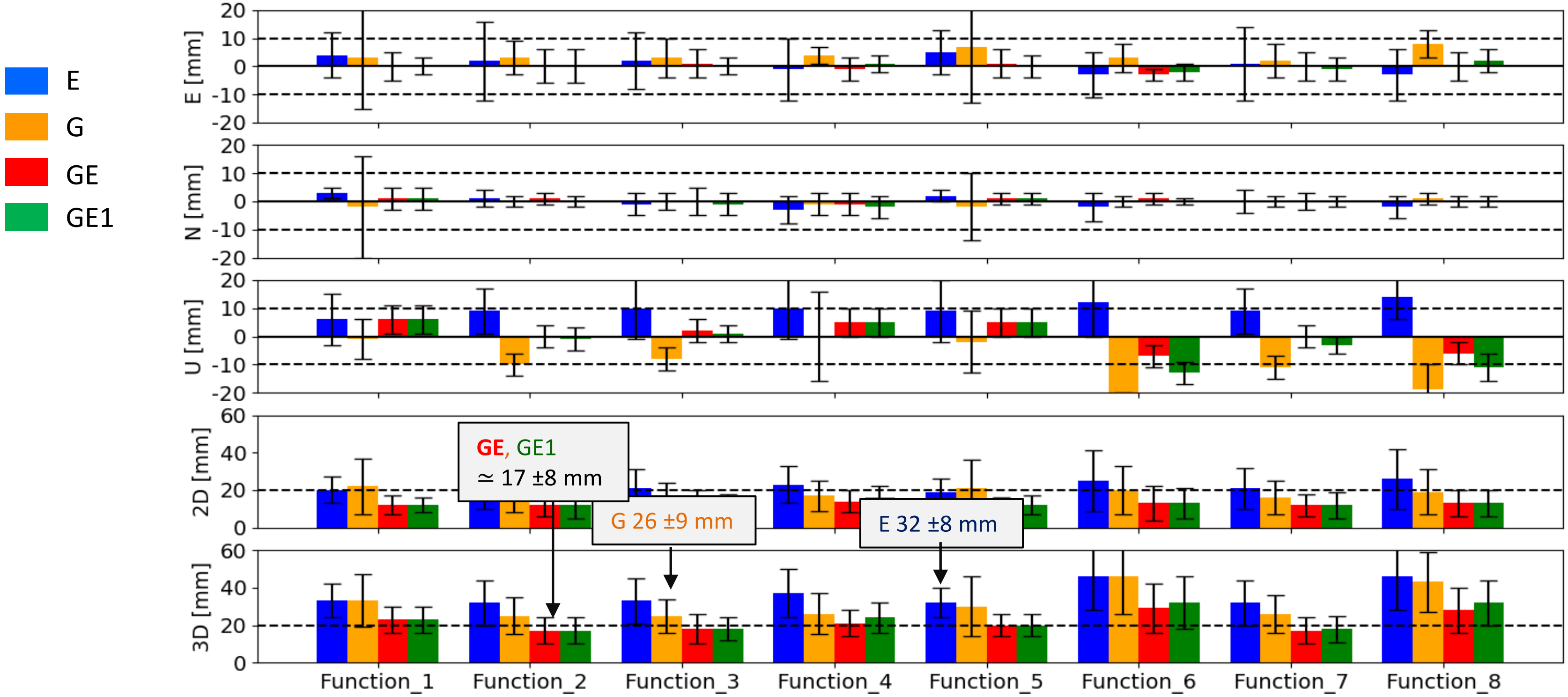
Signal to noise ratio (SNR) for the E1 and E5a observations for the Galileo and L1 and L2 obser-vations for the GPS for the MAS100ESP station for the 39 DoY with function of elevation angle.

Results



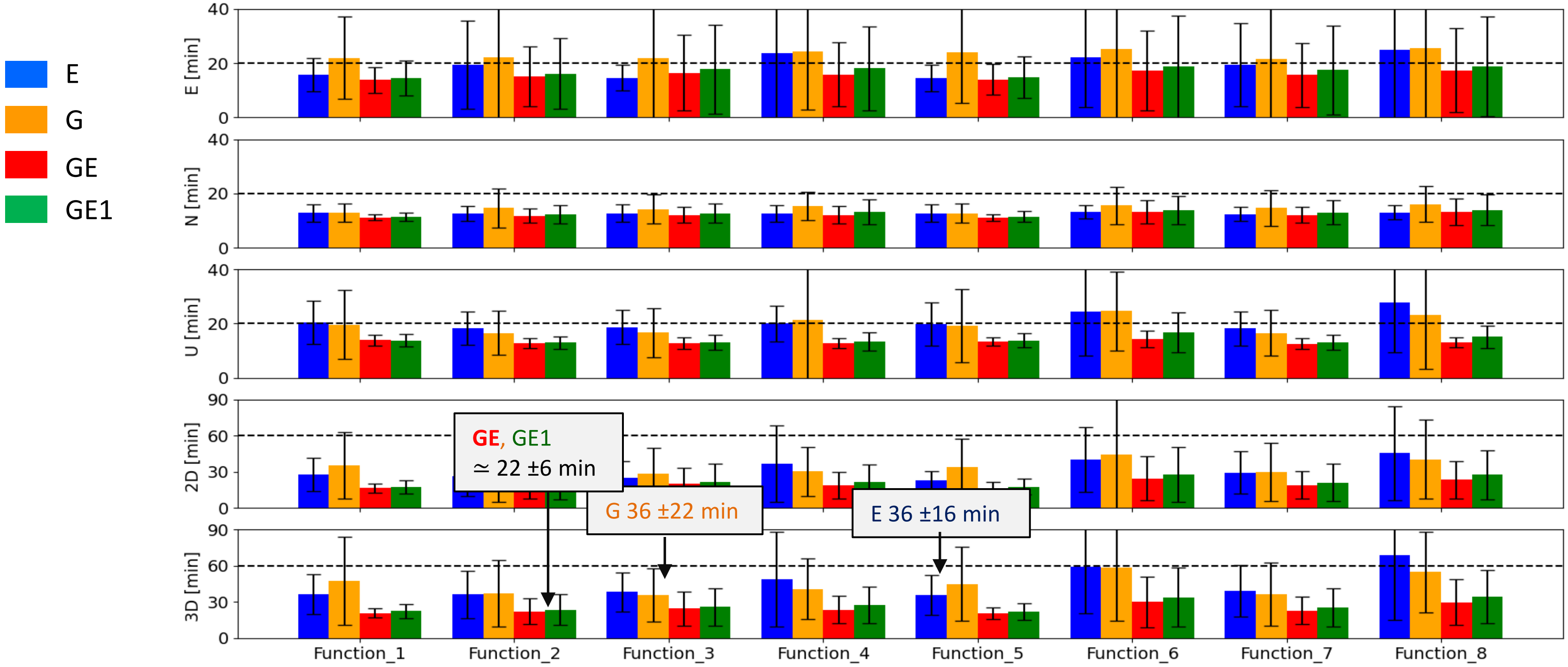
Multipath code combination (MP) for the E1 and E5a observations for the Galileo and L1 and L2 observations for the GPS for the MAS100ESP station for the 39 DoY with function of elevation angle.

Results



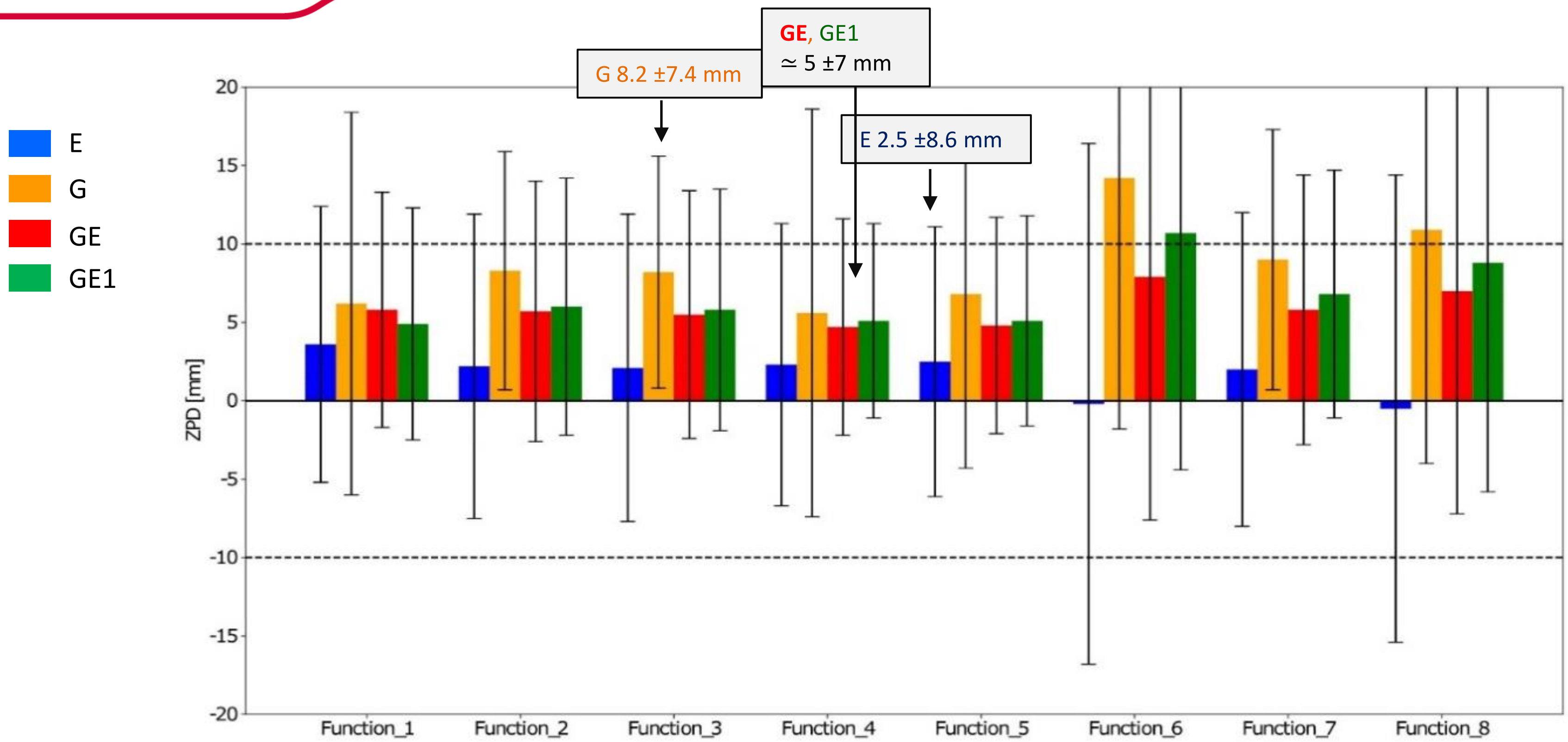
Mean accuracy with standard deviation from all stations and all periods for all analyzed weighting functions.

Results



Mean convergence time with standard deviation from all stations and all periods for all analyzed weighting functions.

Results



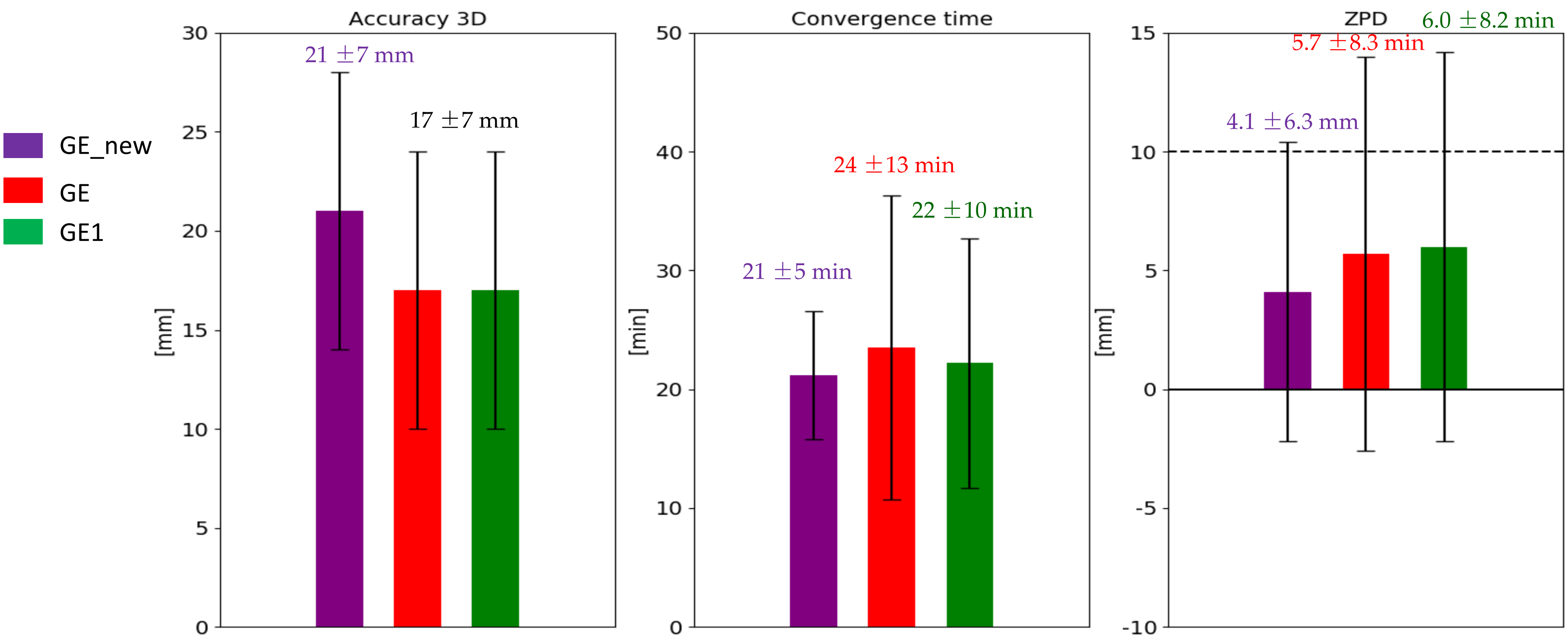
Mean accuracy of the ZPD with standard deviation from all stations and all periods for all analyzed weighting functions.

Results

New approach - GE_new solution

- For the GPS+Galileo solution was used two functions, separately for those systems: for GPS the Function_3 and for Galileo the Function_5.

- Results were compared with the best functions from GE and GE1 the Function_2.



Conclusion

- Different weighting functions have the biggest impact for the Up component. This concerns the accuracy, convergence time and ZPD.
- For different constellations, different weighting functions allowed to obtain the best results.
- For GPS-only the highest accuracy was obtained for the Function_3, while for Galileo-only the best results was obtained for the Function_5.
- Both functions depend on the elevation angle, but for the Function_5 for lower satellites have higher weights. For low Galileo satellites the observations were with higher signal strength and less multipath effect.
- For both GPS+Galileo solutions (GE and GE1) the best results were obtained for the same function - Function_2.
- The accuracy for the GE solution was better than for the GE1, where for the GE1 solution was a little worse precision of observations for Galileo.

Conclusion

- The worst results were obtained for the Function_6 and Function_8. The solutions were even worse than the solution without weights (Function_1). Both functions give very low weights to low observations, an order of magnitude lower than for the other models analyzed. This shows that improper weighting of observations can degrade the results.
- The best accuracy of the tropospheric solutions was obtained for the Galileo-only solution.
- Similary to accuracy the best results of tropospheric were obtained for the Function_5 for Galileo-only solution, while for the G-only solutions the best results were obtained for the Function_3.
- For the GPS+Galielo solutions the best results of tropospheric were obtained for the Function_4, again better results were for the GE solution than for the GE1 solution.

Conclusion

- For the GPS+Galileo proposed weighting method (GE_new solution), using two different weighting functions for both systems from the best weighting functions from GPS-only and Galileo-only gives better results. An improvement of about 5% was obtained for the convergence time and about 30% for the tropospheric delay, especially with smaller standard deviations.

- **Considering that each system has different characteristics, different weighting functions of observations should be used.**
- **As Galileo observations at lower elevation angles perform better than GPS, they should be given more weight than GPS observations.**

THANK YOU FOR YOUR ATTENTION!

More information available in the article:
Kiliszek, D.; Kroszczyński, K.; Araszkiewicz, A. Analysis of Different Weighting Functions of Observations for GPS and Galileo Precise Point Positioning Performance. Remote Sens. 2022, 14, 2223. https://doi.org/10.3390/rs14092223

or please contact: damian.kiliszek@wat.edu.pl