Accuracy of PPP along with the development of GPS, GLONASS and Galileo

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Background

- Background
- Motivation
- Methodology
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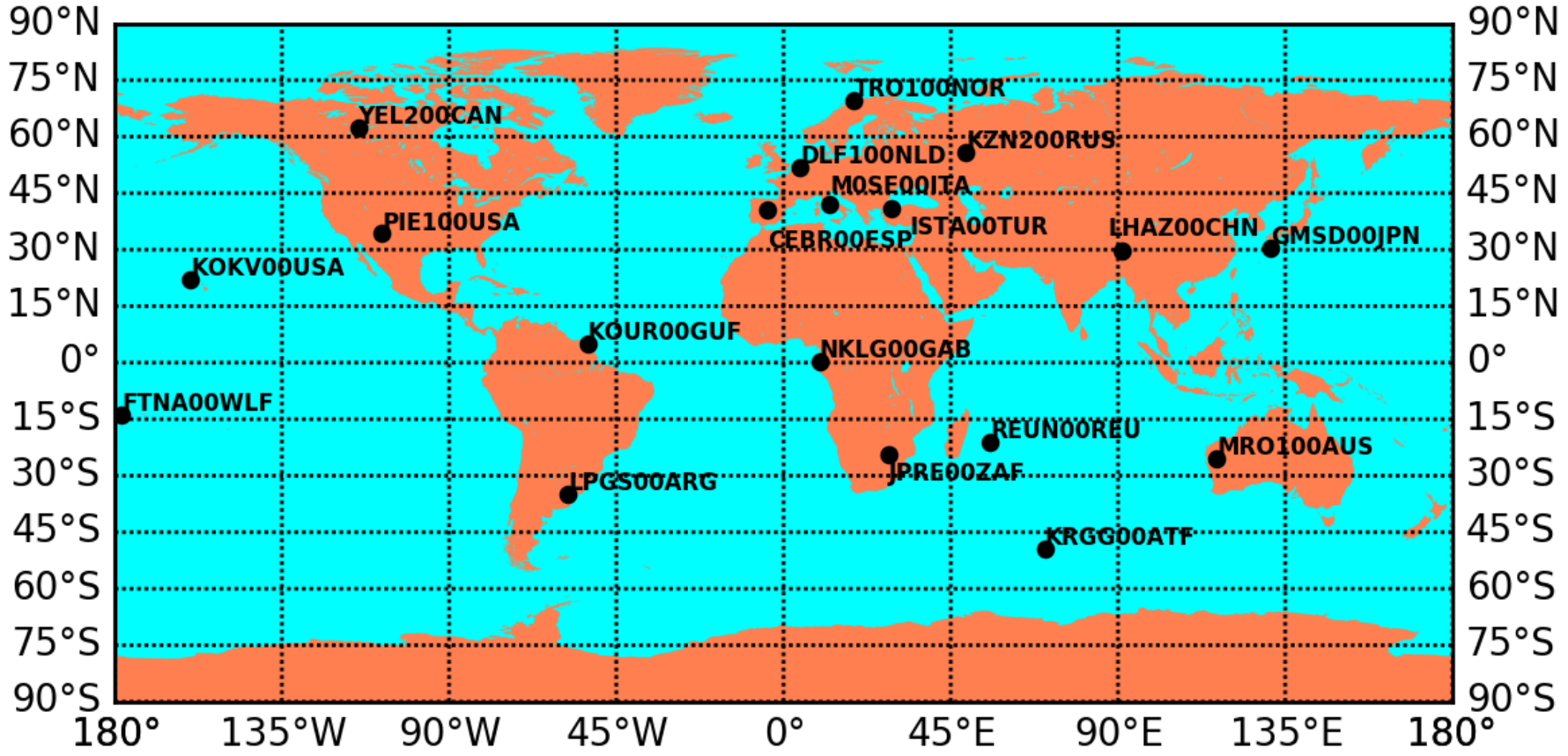
- Conclusion

Motivation

- Currently, significant development of existing GNSS systems (GPS, GLONASS) and construction of new ones (Galileo, BDS) can be seen.
- Also in recent years one can notice a significant development of the PPP method and its increasing applications.
- Most of the studies of the PPP and multi-GNSS already developed were carried out only for the selected period in addition using various models and software.
- In our research we want to check how the performance of the PPP changes with the development of GPS, GLONASS and Galileo systems in the last 3 years (2017-2019), using the same model and software.

Methodology

19 global distribution MGEX stations



Methodology

Items	Models/Methods
PPP model	static mode, basic PPP model using dual-frequency code and phase ionosphere-free combination
Signals	GPS: L1, L2; GLONASS: G1, G2; Galileo: E1, E5a
Solutions	G, R, E, GR, GE, RE and GRE where: G-GPS, R-GLONASS, E-Galileo
Cut-off elevation angle	0°, 5°, 10°, 15°, 20°, 25°, 30°, 35° and 40°
Interval estimation	30-s
Software	GAMP*
Periods	Three periods – three weeks: from DoY 239 to DoY 245 of 2017 (September) from DoY 231 to DoY 237 of 2018 (August) from DoY 142 to DoY 156 of 2019 (May)
Reference frame	IGS14
Orbit	CODE MGEX with 5-min intervals
Clock	CODE MGEX with 30-s intervals
PCO and PCV for receiver antenna	igs14.atx for GPS and for GLONASS, for Galileo used model from GPS

*Zhou, F., Dong, D., Li, W. et al. GAMP: An open-source software of multi-GNSS precise point positioning using undifferenced and uncombined observations. GPS Solut 22, 33 (2018). https://doi.org/10.1007/s10291-018-0699-9

Methodology

Number of available GNSS satellites in products and space

System	period I (September 1, 2017)		period II (August 21, 2018)		period III (June 1, 2019)	
	Space segment	Product	Space segment	Product	Space segment	Product
GPS	32	32	32	32	31(+1)	32
GLONASS	22(+2)	23	23(+2)	22	24(+2)	23
Galileo	14(+2+2)	17	18(+2+2)	20	22(+2+2)	24

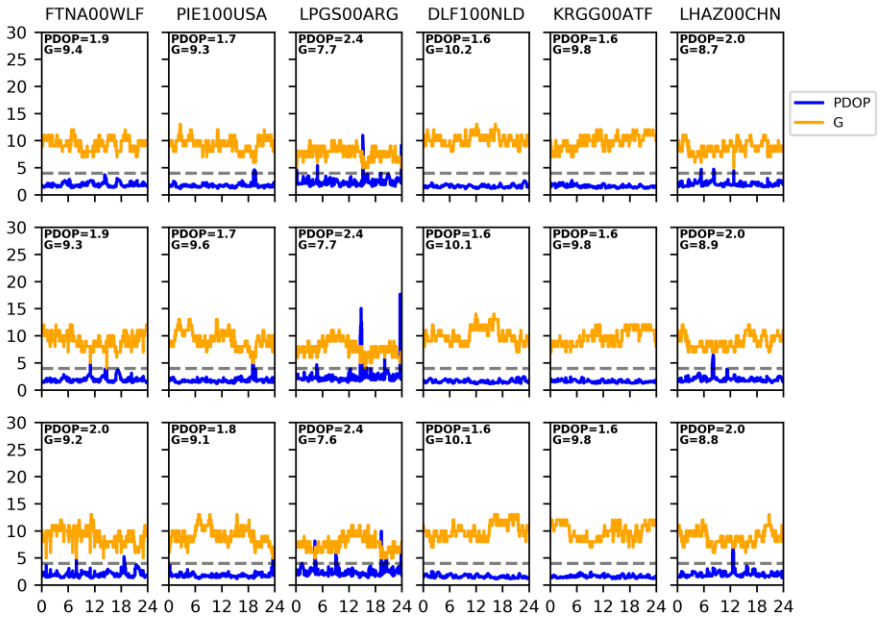
Results

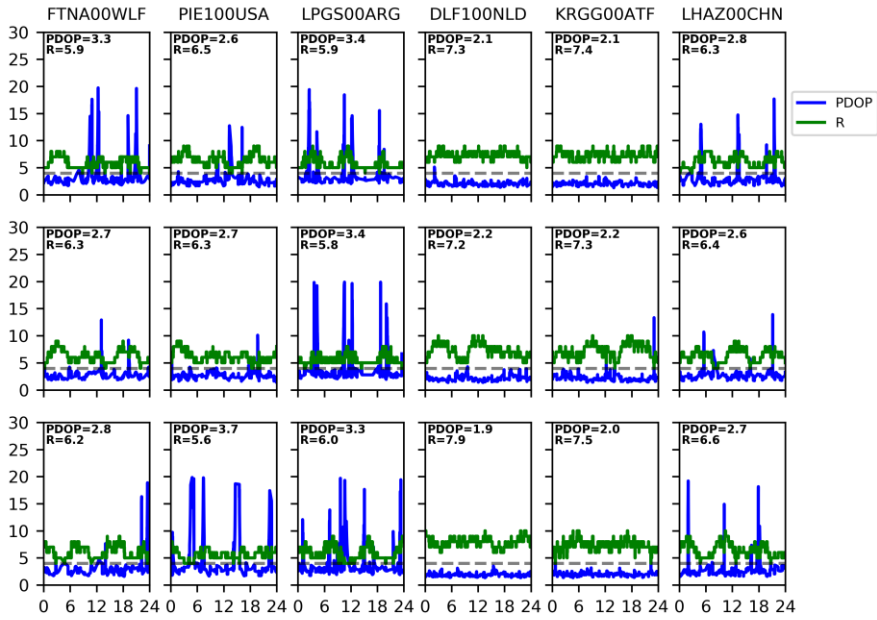
Results divided on two ways:

1. 5^{o} cut-off elevation angle; individual station.
2. All cut-off elevation angle; mean from all stations.

Results

1. Number of used GNSS satellites with PDOP (stations: FTNA00WLF, PIE100USA, LPGS00ARG, DLF100NLD, KRGG00ATF, LHAZ00CHN).



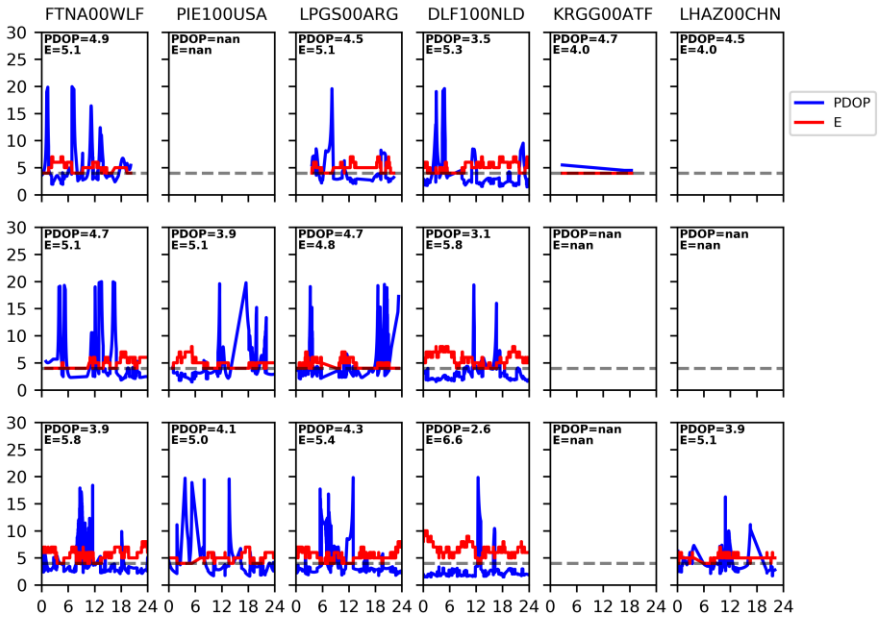


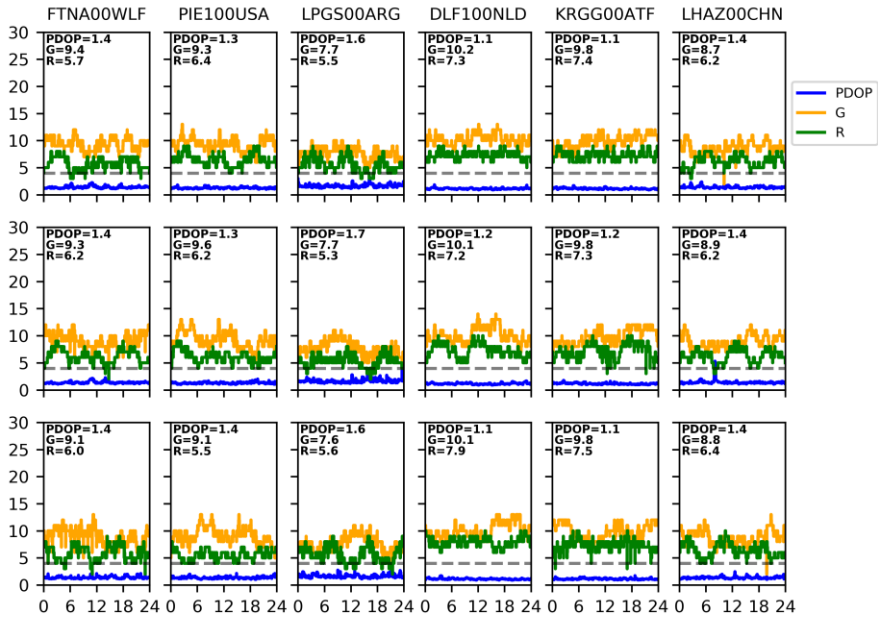
Top, middle and bottom means first (September 1, 2017), second (August 21, 2018) and third (June 1, 2019) period respectively

G R

Results

1. Number of used GNSS satellites with PDOP (stations: FTNA00WLF, PIE100USA, LPGS00ARG, DLF100NLD, KRGG00ATF, LHAZ00CHN).



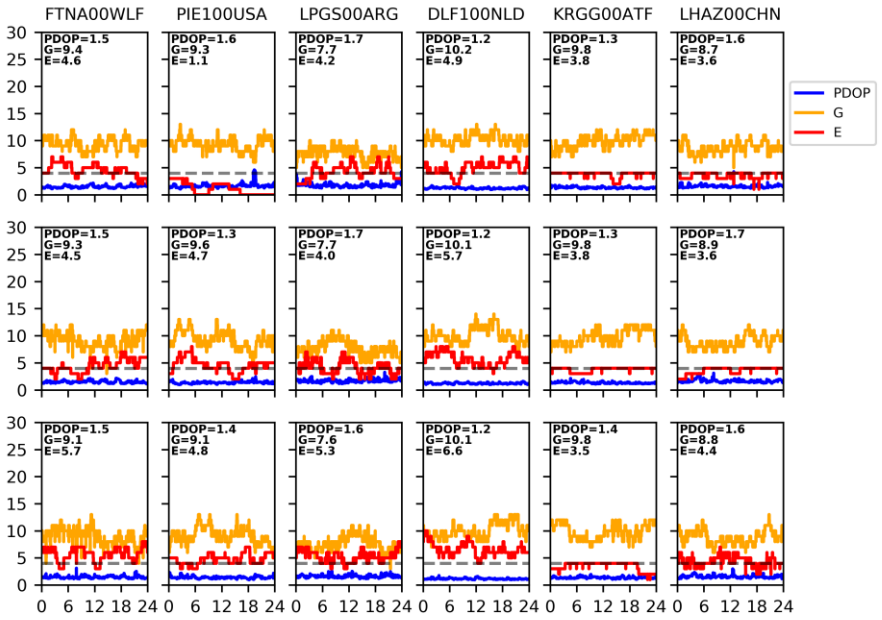


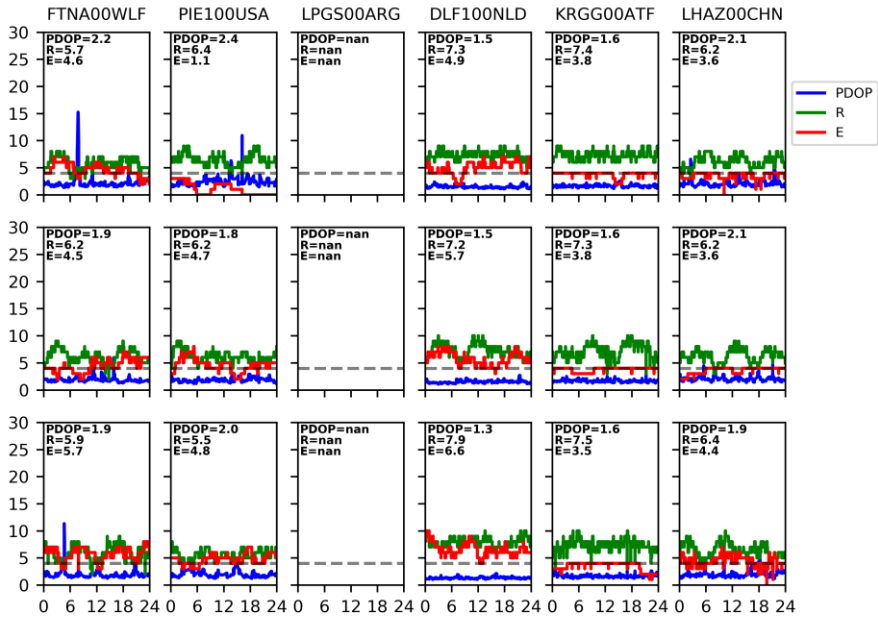
Top, middle and bottom means the first (September 1, 2017), the second (August 21, 2018) and the third (June 1, 2019) period respectively

E GR

Results

1. Number of used GNSS satellites with PDOP (stations: FTNA00WLF, PIE100USA, LPGS00ARG, DLF100NLD, KRGG00ATF, LHAZ00CHN).





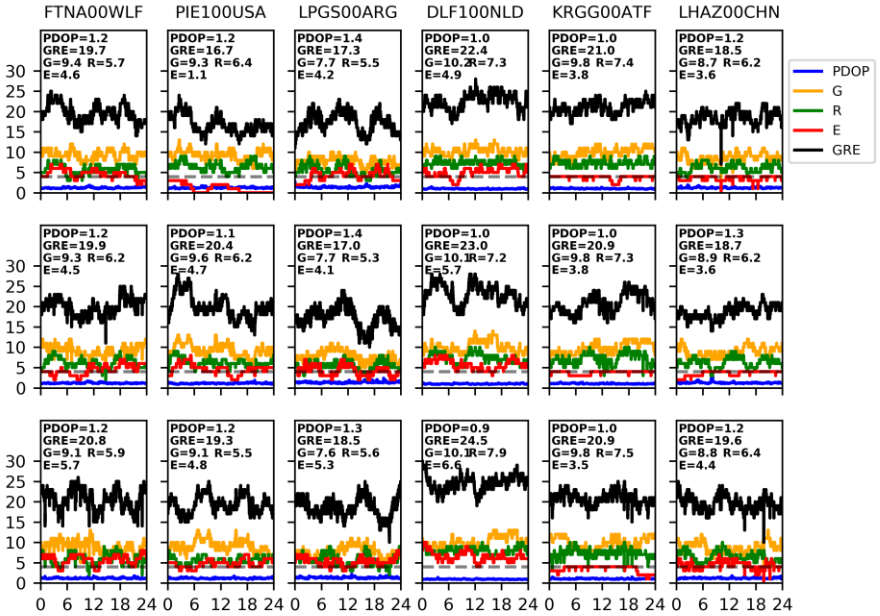
Top, middle and bottom means the first (September 1, 2017), the second (August 21, 2018) and the third (June 1, 2019) period respectively

GE

RE

Results

1. Number of used GNSS satellites with PDOP (stations: FTNA00WLF, PIE100USA, LPGS00ARG, DLF100NLD, KRGG00ATF, LHAZ00CHN).

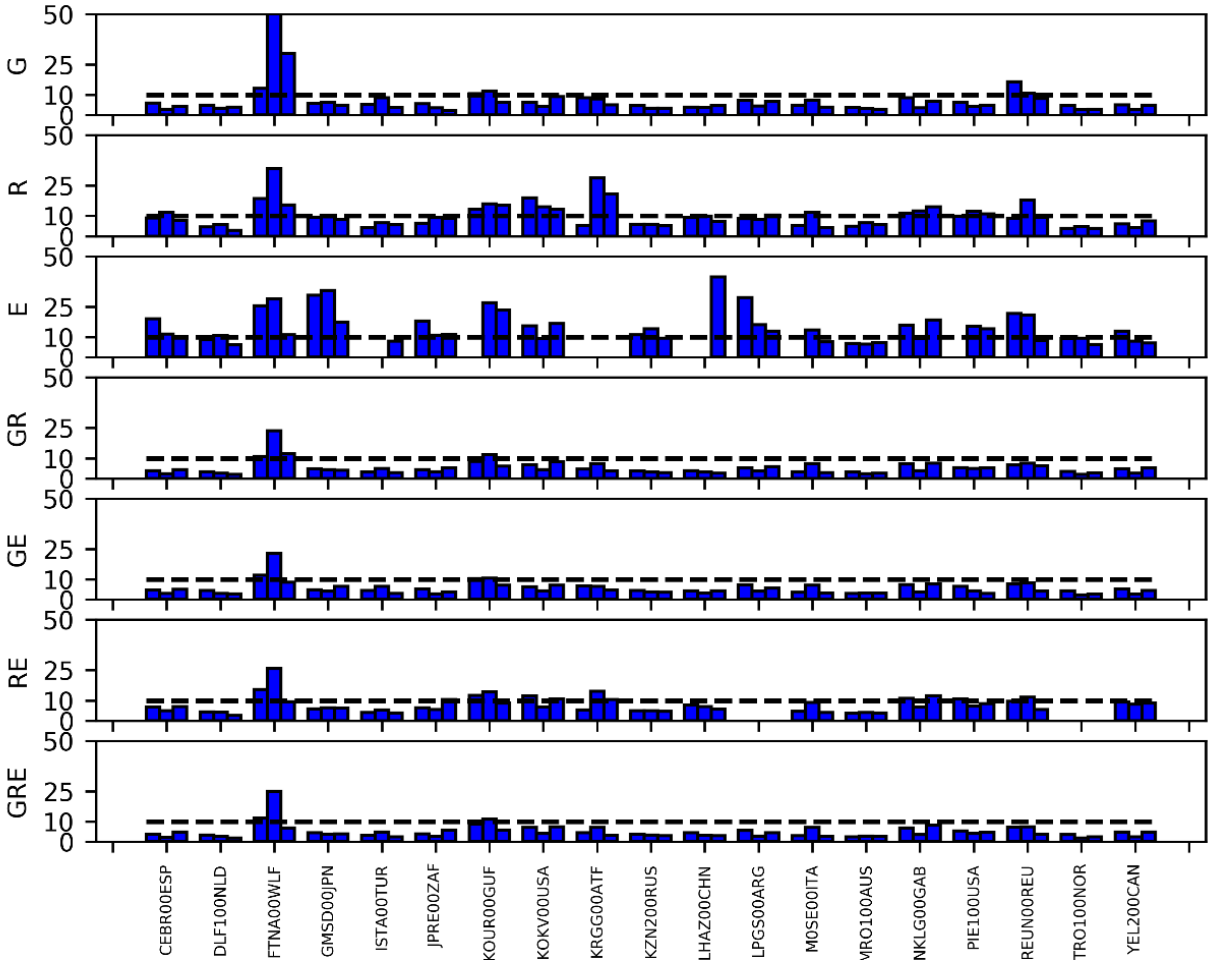


Top, middle and bottom means the first (September 1, 2017), the second (August 21, 2018) and the third (June 1, 2019) period respectively

GRE

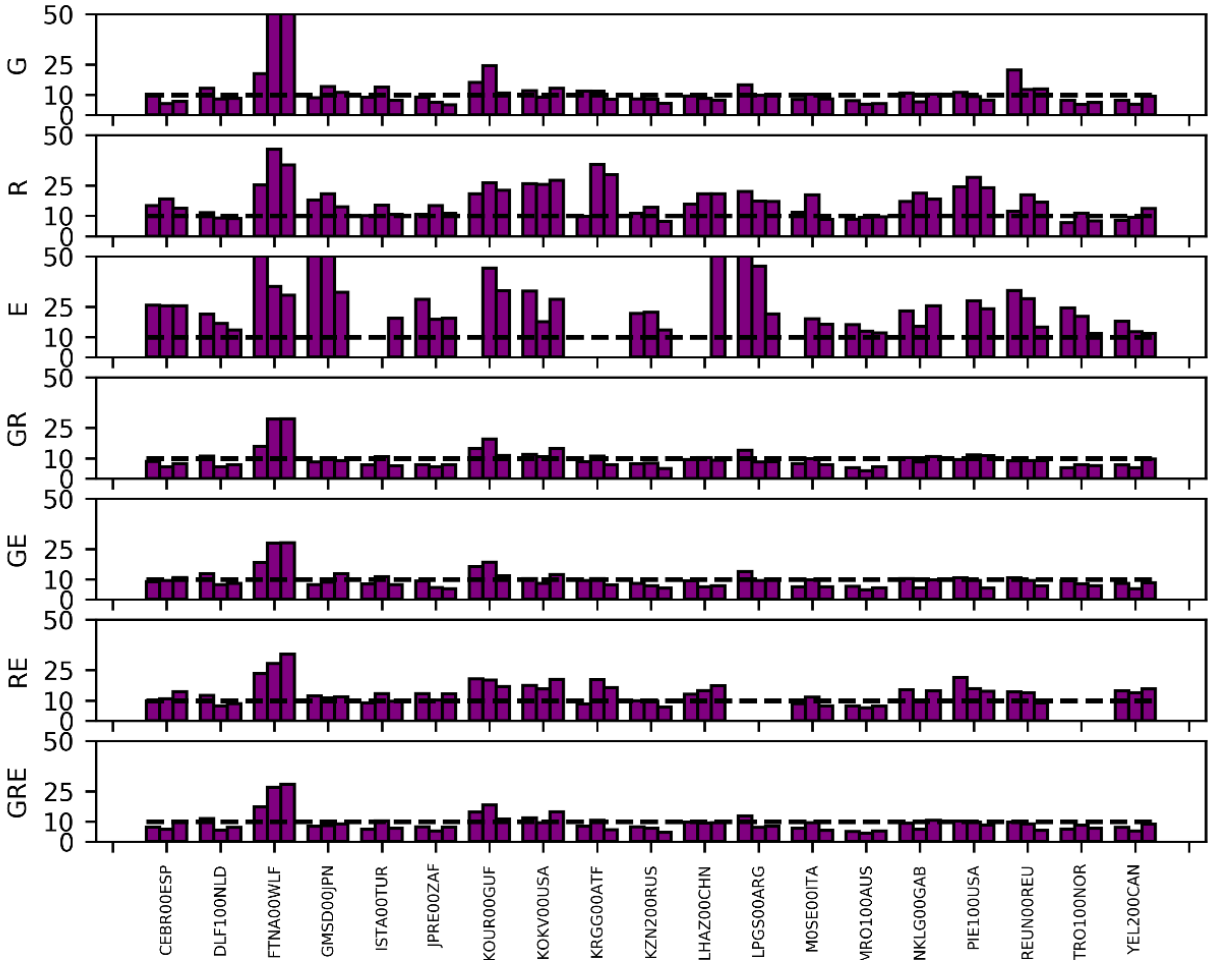
Results

1. 2D error for all stations and for all solutions. Left, center and right bar means the first, the second and the third period respectively.



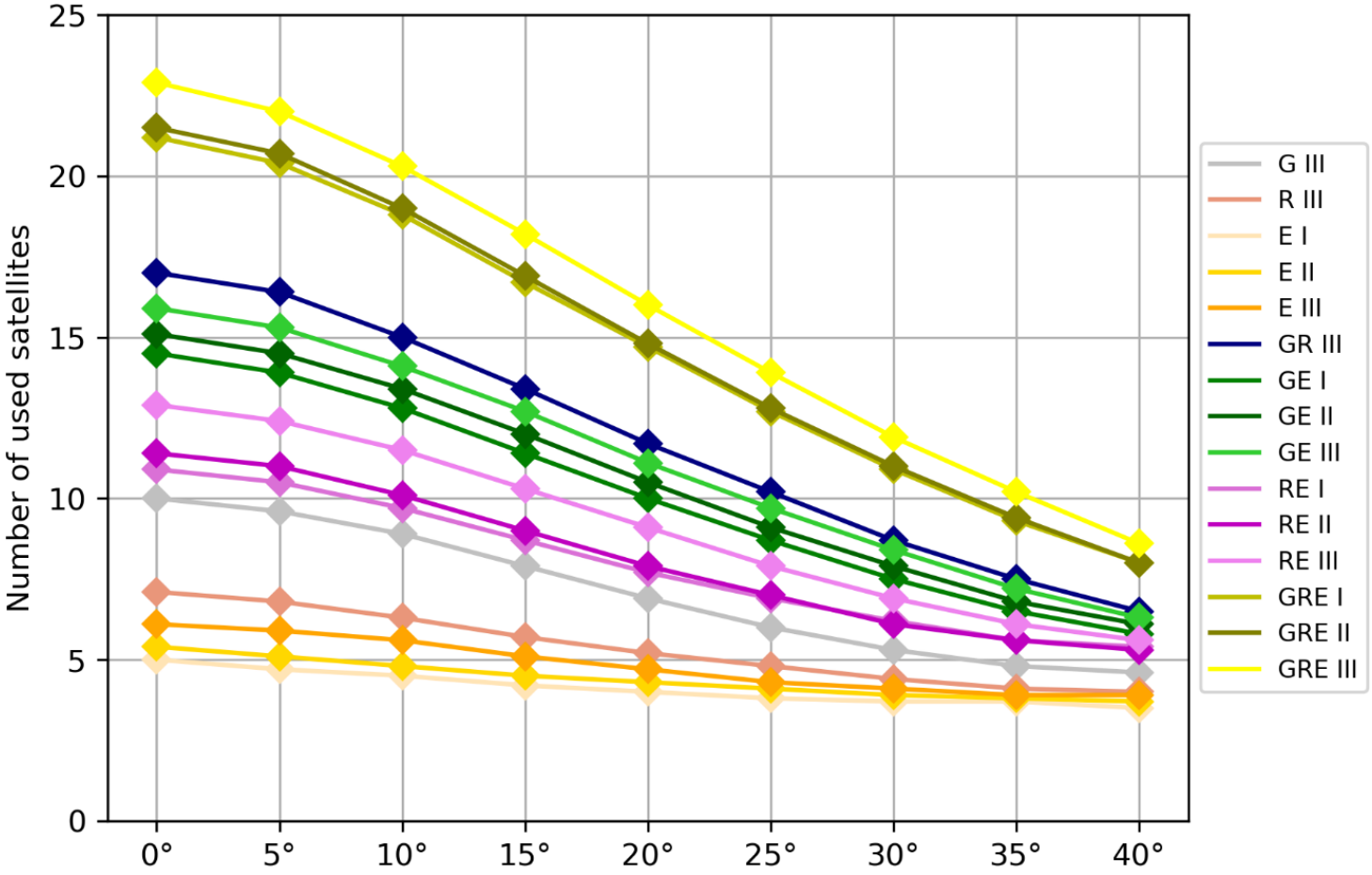
Results

1. 3D error for all stations and for all solutions. Left, center and right bar means the first, the second and the third period respectively.



Results

2. Average number of satellites usable for determination of positions for all analyzed solutions, all periods and all cut-off elevation angles. In order to better visibility for G, R and GR solutions we plotted only third period (I and II period are similar).



Results

2. Mean percentage of available position solutions [%] for all solutions, all elevation angles and all periods. I, II and III means the first, the second and the third period.

Percentage of available position solutions [%] - mean from all stations										
		0	5	10	15	20	25	30	35	40
G	I	99	99	99	99	99	98	93	79	51
	II	97	97	97	97	97	96	90	76	49
	III	99	99	99	99	99	98	92	77	49
R	I	94	93	93	86	74	53	28	11	4
	II	90	90	86	78	62	45	25	11	4
	III	96	95	95	90	79	57	33	14	5
E	I	52	52	48	41	31	18	7	2	1
	II	69	68	63	55	43	29	16	8	4
	III	83	84	83	77	68	53	34	17	8
GR	I	99	98	99	98	99	98	98	95	81
	II	97	97	97	97	97	97	96	93	78
	III	99	99	99	99	99	99	99	96	83
GE	I	99	99	99	99	98	98	96	90	69
	II	97	97	97	97	97	97	96	90	73
	III	99	99	99	99	99	99	99	97	83
RE	I	82	81	81	80	80	74	66	49	29
	II	82	82	82	82	81	81	73	53	33
	III	84	83	84	83	84	83	80	65	44
GRE	I	99	99	99	99	99	98	98	95	85
	II	97	97	97	97	97	97	96	95	85
	III	99	99	99	99	99	99	99	99	92

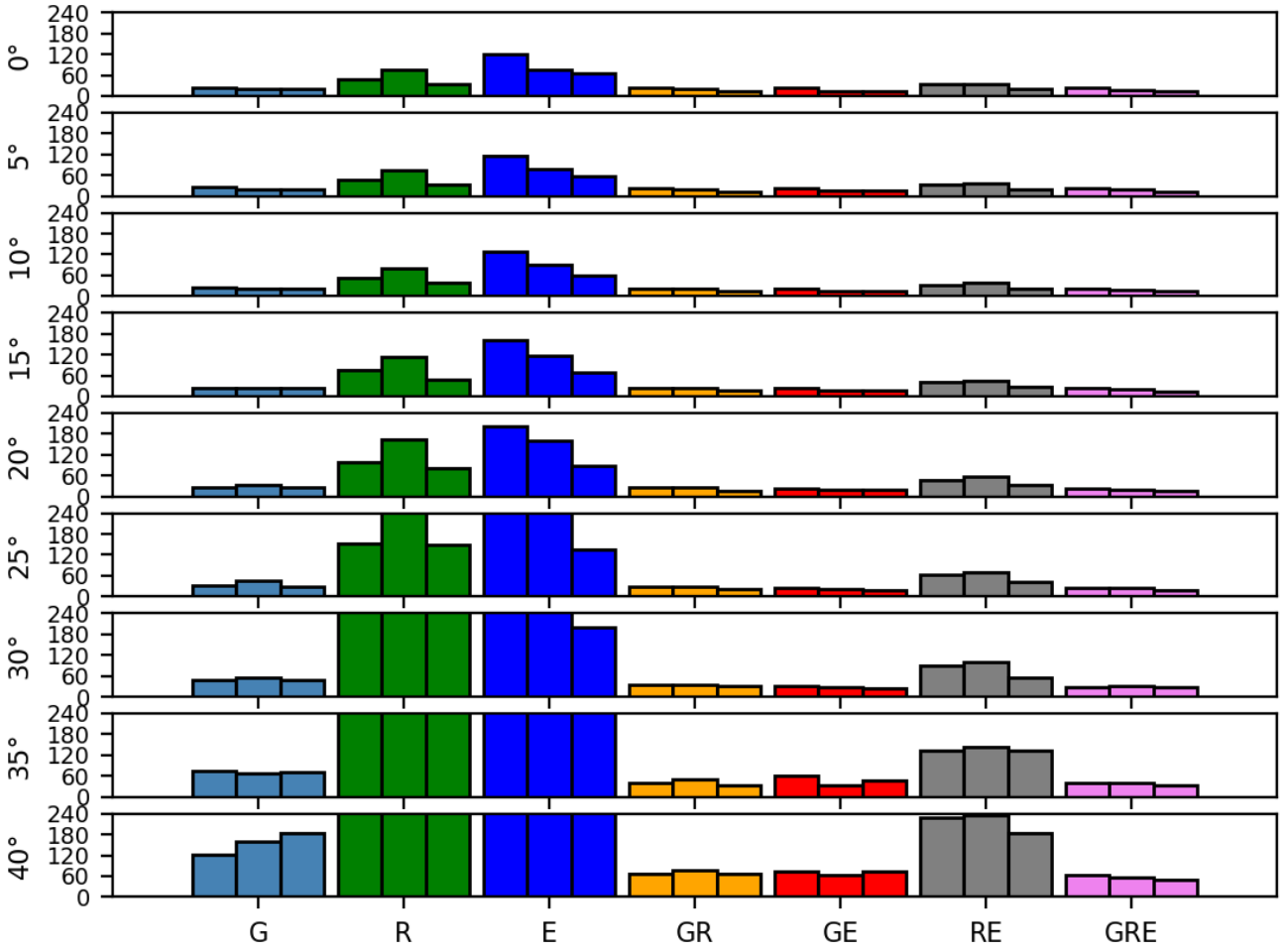
Results

2. Mean 3D accuracy for all solutions, all elevation angles and all periods. I, II and III means the first, the second and the third analyzed periods. Values in mm.

3D										
		0°	5°	10°	15°	20°	25°	30°	35°	40°
G	I	13.4	11.4	11.7	14.0	16.3	20.5	28.2	47.2	79.2
	II	14.1	11.9	12.7	15.8	19.5	24.5	34.6	55.6	85.1
	III	12.9	10.6	11.7	14.3	18.5	23.9	34.1	49.9	81.9
R	I	16.1	15.1	15.5	20.5	29.4	47.6	89.2	164.3	236.1
	II	23.5	21.2	22.8	29.7	43.7	65.5	113.4	167.8	227.0
	III	17.6	16.9	18.0	23.2	32.6	47.5	80.8	130.4	215.3
E	I	37.2	33.2	36.4	44.5	56.7	80.6	146.6	226.6	209.8
	II	30.1	26.4	27.6	33.1	43.8	61.1	102.1	181.2	185.8
	III	25.4	23.8	25.3	28.6	35.9	48.7	80.9	142.3	153.3
GR	I	11.0	9.3	9.1	10.5	12.7	16.5	22.0	32.6	55.8
	II	11.5	10.0	9.8	11.8	14.8	18.9	24.4	36.5	56.2
	III	11.4	9.5	9.4	11.4	15.3	20.0	24.5	36.3	61.1
GE	I	12.2	10.2	10.4	11.7	13.7	20.0	33.5	52.6	70.5
	II	11.3	9.6	9.7	11.3	14.9	21.0	35.5	54.7	62.9
	III	11.0	9.3	9.5	11.1	15.0	20.9	35.0	54.9	65.2
RE	I	14.8	13.6	13.4	15.2	19.3	29.3	48.0	81.0	108.2
	II	14.8	13.9	14.8	16.9	20.9	33.1	55.5	86.4	112.7
	III	14.6	14.0	14.9	17.0	21.8	30.7	49.4	73.6	90.5
GRE	I	11.1	9.3	9.1	10.1	12.4	18.3	28.2	43.7	57.6
	II	10.7	9.3	9.0	10.4	13.1	18.1	28.0	44.5	54.0
	III	10.7	9.2	8.9	10.3	13.8	19.1	27.4	40.8	56.0

Results

2. Mean convergence time for the threshold value of 10 cm, all solutions and all cut-off elevation angles. Value in min. Left bar: the first period, middle bar: the second period, right bar: the third period.



Conclusion

- Progressive improvement of accuracy and a shortening of convergence time in recent years;
- The best accuracy with shortest convergence time was achieved in 2019 for GRE; average 22 satellites were observed with accuracy of 1 cm and convergence time of 13 min;
- In 2019, the Galileo system already allows for positioning with high accuracy anywhere on Earth with average 6 satellites were observed; the positioning accuracy of about 2 cm and the convergence time less than 1h which is better by about 50% than in 2017;
- G and R positioning still provide high accuracy achieved the best accuracy for GPS-based solutions;
- Multi-GNSS PPP caused greater stability by removing individual discrepancies which appeared in single GNSS positioning;
- Multi-GNSS PPP enabled positioning with high accuracy in difficult conditions (needed high cut-off elevation angles);

Conclusion

- For RE achieved worse accuracy than for G but with smaller standard deviation (constant error that may arise from the problem of iner-frequency bias (IFB) and inter-system bias (ISB) modeling and the use for Galileo observations of PCO/PCV receiver models from GPS);
- For the cut-off elevation angle of 40^{o}, the use of GRE enabled to achieve about 90% availability of solutions with position estimation accuracy of cm;
- E solution had improved more with years but it was still worse than G and R solutions;
- In the following years the E positioning will be improved and in the near future may be on the same accuracy as G and R; Galileo will also be Full Opeartioanl Capability (FOC) in the near future containing the full constellation of operational satellites in space; Galileo still does not have corrections for the receiver antenna models, and the accuracy of the orbits/clocks of the satellites and other models are constantly being improved.

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More information will be available soon in the article or please contact: damian.kiliszek@wat.edu.pl