ANNUAL OF NAVIGATION 2/2000

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GEOMETRY OF GPS AND GLONASS FOR DIFFERENT NUMBER OF OPERATIONAL SATELLITES

ABSTRACT Nowadays there are two world wide satellite navigation systems - American GPS and Russian GLONASS. Distribution (in per cent) and comparison (in per cent) of GDOP (**G**eometric **D**ilution **O**f **P**recision) coefficient values for different number of operational satellites for the observer at different latitude for different masking elevation angle for both systems are demonstrated in this paper.

INTRODUCTION

The ship's position can be obtained by many different methods. At present (July 2000) the most frequently used methods are the methods based on the propriety of radio waves, in particular terrestrial radionavigation system (Loran C) or satellite navigation systems (GPS, Differential GPS, GLONASS). But only two systems: American GPS and Russian GLONASS are global systems.

Fix position can be calculated from these satellites only, which elevation angle at the moment of measurement is higher than masking angle (H_{min}). The receiver needs to see at least four satellites to calculate latitude, longitude, altitude and time. The geometry of the visible satellites is an important factor in achieving high quality results especially for point positioning and kinematic surveying. This geometry changes with time due to the relative motion of the satellites. a measure for this geometry is the Dilution of Precision (DOP) factor. The distributions (in per cent) of GDOP (Geometric Dilution of Precision) coefficient values for the observer at different latitude for different angle H_{min} for GPS system were described in [Spilker 1996] and by the author in [Januszewski 1998,1999]. It was considered that all 24 GPS satellites and all 24 GLONASS satellites are fully operational.

As the position accuracy depends on the geometry of the satellites visible by the user we can ask the questions:

- Can the ship equipped with GPS or GLONASS receiver obtain her position at each moment and at each point on the Earth when one or more satellites SNO (SNO – satellite non operational) of these systems are out of service?
- How GDOP coefficient increases for SNO = 1, 2 and 3 for different angle H_{min} and for different latitude of observer?
- For which system the damage of n satellites causes the greater consequences?

1. TEST METHOD

The final space segment configuration of GPS and GLONASS systems allows to evaluate the distribution of numbers (ls) of satellites visible at H_{min} (masking elevation angle) or higher above horizon for the observer at different latitude and the different distribution of (GDOP) coefficient. GPS space configuration consists of 24 operational satellites. At present (July 2000) the real number of GLONASS operational satellites is less than 24 but for the geometrical confrontation of these two systems, it was considered in this paper 24 GLONASS satellites being fully operational too.

The latitude of observer 0^O–90^O was divided into 9 zones, each 10^O wide. The number of satellites used for pseudorange measurements can be less than the number of satellites visible at a given moment and given point on the Earth for many reasons:

- satellite is out of service,
- satellite signal is too weak,
- received data are incomplete.

It means that the real number of operational satellites (SO) can be for the user less than 24. That's why it was considered in this paper that SNO (24 – SO) is equal to 0, 1, 2 or 3.

Constellation characteristics - right ascension of ascending nodes and arguments of latitude for all 24 GPS satellites and for all 24 GLONASS satellites at the referred time were known (1÷4 - number of satellites of orbit I, 5÷8 - orbit II, 9÷12 - orbit III, etc.) (1÷8 - number of satellites of orbit I, 9÷16 - orbit II, 17÷24 - orbit III). The difference of the arguments of latitude between GPS satellite number 3 and satellite number 4 is equal 33^O. Masking elevation angle H_{min} was assumed 0^O, 5^O, 10^O and 15^O. Satellite selection criteria (combination of 4 satellites) were founded on the minimization of GDOP. All calculations, based upon a reference ellipsoid WGS-84, were made with the use of author's simulating program.

For each system, for each zone of latitude and for each masking elevation angle random-number generator with uniform distribution generated (Hmin) 1000 geographic-time coordinates of the observer:

- latitude interval 0 - 600 minutes (10^O),
- longitude interval 0 - 21600 minutes (360^O),
- time interval 0 -1440 minutes (24 hours) for GPS System and time interval 0 - 11487 minutes (7 days, 23 hours, 27 minutes) for GLONASS System were assumed.

For each geographic-time coordinates the number of visible satellites (ls) and GDOP coefficient value were calculated. GDOP value (w) was divided into 6 intervals: 1 for $w \leq 2$, 2 for $2 < w \leq 3$, 3 for $3 < w \leq 4$, 4 for $4 < w \leq 6$, 5 for $6 < w \leq 20$ and 6 for $w > 20$.

For the simulation tests it was considered that for SO = 23 the satellite number 1 of orbit I, for SO = 2 the satellite numbers 1 and 2 of this orbit and for SO = 21 the satellite numbers 1, 2 and 3 of the same orbit are non operational.

2. THE RESULTS

If the number of operational satellites (SO) is less than 24, GDOP coefficient increases with angle H_{min} in each zone of the latitude for both systems. Comparison of the distribution (in per cent) of GDOP for $H_{min} = 5^O$ and $H_{min} = 15^O$ for SO equal 23 and 24 is presented in the table 1, for SO equal 21 and 24 in the table 2.

If the number of satellites visible by observer is less than 4, it's 3D position cannot be obtained (the position is not available – No fix > 0). For SO = 23 and $H_{min} = 5^O$ (masking angle used in the most receivers) No fix is equal 0 in each zone for both systems, if $H_{min} = 15^O$ No fix is greater than zero at latitude 10–70^O for GPS System and at latitude 0–50^O for GLONASS System. The increase of GDOP coefficient values is greater for GPS System except zone 80–90^O. For SO = 21 and $H_{min} = 5^O$ No fix is greater than 0 for GLONASS System only, if $H_{min} = 15^O$ at latitude 0–60^O No fix is considerably less for GPS System, while increase of GDOP coefficient values is considerably less for GLONASS System.

No fix (in per cent) and the distribution (in per cent) of GDOP coefficient values for different combination of non operational satellites for $H_{min} = 5^O$ and 15^O for the observer at latitude 50–60^O (latitude of Poland) for GPS System is demonstrated in the table 3 and for GLONASS System in the table 4. The results depend not only on the number of non operational satellites (SNO), but also on their position on the orbit.

For GPS System the simulation tests were realised different combination of non operational satellites:

- for 2 different SNO (satellite number 1 and 3),
- for 5 combinations of 2 SNO (I – satellite number 1 and 2, II – 3 and 4, III – 1 and 3, IV – 1 and 5, V – 1 and 13)
- for 4 combinations of 3 SNO (I – satellite number 1, 2 and 3, II – 2, 3 and 4, III – 1, 2 and 5, IV 1, 5 and 9).

The increasing of GDOP coefficient values is smallest if satellite SNO or one of the satellites SNO is satellite number 3 – one of these two satellites on the orbit, for which the difference of the arguments of latitude is about 30^O.

For GLONASS System the calculations were realised for following combinations:

- for one non operational satellite (satellite number 1),
- for 3 combinations of two SNO (I – satellite number 1 and 2, II – 1 and 5, III – 1 and 9)
- and for 3 combinations of three SNO (I–1, 2 and 3, II–1, 3 and 6, III–1, 2, and 9).

For SNO = 2 the increasing of GDOP coefficient values, for $H_{min} = 5^O$ as well as for $H_{min} = 15^O$, is the smallest for combination of two satellites – number 1 and number 5, i.e. the satellites of one orbit, for which difference of the arguments of latitude is 180^O.

No fix (in per cent) and the distribution (in per cent) of GDOP coefficient values for different number of operational satellites (SO = 24, 23, 22 and 21) for H_{min} = 0, 5, 10 and 15^O for both systems for the observer at latitude 50–60^O is demonstrated in the Table 5.

Table 1. No fix (in per cent) and comparison of the distribution (in per cent) of GDOP coefficient values for 23 and 24 operational satellites for GPS System and GLONASS System for different masking elevation angle (H_{min}) at different observer's latitude (φ), "+" increasing, "–" decreasing, "0" – without change

Φ [°]	H_{min} [°]	Sys-tem	No Fix 24/23 [%]	GDOP(23) – GDOP(24) = w [%]				
				w≤3	3<w≤4	4<w≤6	6<w≤20	w>20
0 –10	5	GPS	0 / 0	- 6,4	+ 4,8	+ 1,4	+ 0,2	-
		GLO	0 / 0	- 4,9	+ 3,6	+ 1,2	+ 0,1	-
	15	GPS	0 / 0	- 6,5	+ 0,5	+ 2,4	+ 3,0	+ 0,6
		GLO	0 / 1,0	- 3,5	- 5,7	+ 4,2	+ 2,7	+ 1,3
10-20	5	GPS	0 / 0	- 6,4	+ 5,6	+ 0,7	+ 0,1	-
		GLO	0 / 0	- 5,1	+ 0,2	+ 4,6	+ 0,2	+ 0,1
	15	GPS	0 / 0,4	- 2,9	- 4,4	+ 2,3	+ 4,0	+ 0,6
		GLO	0 / 1,4	- 1,7	- 5, 4	+ 3,7	+ 1,9	+ 0,1
20–30	5	GPS	0 / 0	- 5,9	+ 5,1	+ 0,6	+ 0,2	-
		GLO	0 / 0	- 5,0	+ 0,1	+ 4,8	+ 0,1	-
	15	GPS	0 / 0,2	- 2,8	- 2,5	+ 1,6	+ 2,8	+ 0,7
		GLO	0 / 0,5	- 1,4	- 4,6	+ 2,4	+ 1,9	+ 1,2
30–40	5	GPS	0 / 0	- 5,1	+ 3,7	+ 0,9	+ 0,5	-
		GLO	0 / 0	- 2,8	- 1,4	+ 4,1	-	+ 0,1
	15	GPS	0,1 / 0,3	- 2,1	- 5,0	+ 2,7	+ 3,2	+ 1,0
		GLO	0 / 0,3	- 0,3	- 5,2	+ 1,4	+ 1,8	+ 2,0
40–50	5	GPS	0 / 0	- 6,0	+ 2,6	+ 1,9	+ 0,5	-
		GLO	0 / 0	- 5,8	+ 3,8	+ 2,0	-	-
	15	GPS	0 / 0,6	- 1,9	- 6,9	+ 4,5	+ 2,9	+ 0,8
		GLO	0 / 0,9	- 0,5	- 3,1	+ 1,4	+ 1,8	- 0,5
50–60	5	GPS	0 / 0	- 6,0	+ 2,9	+ 2,7	+ 0,4	-
		GLO	0 / 0	- 6,0	+ 3,2	+ 2,8	-	-
	15	GPS	0,1 / 0,6	- 1,4	- 7,6	+ 4,3	+ 3,6	+ 0,6
		GLO	0 / 0	- 1,6	- 4,5	+ 4,2	+ 1,9	0
60–70	5	GPS	0 / 0	- 5,5	+ 1,2	+ 0,9	+ 3,4	-
		GLO	0 / 0	- 2,1	- 1,4	+ 3,5	-	-
	15	GPS	0 / 0,9	- 0,2	- 5,2	+ 0,8	+ 3,3	+ 0,4
		GLO	0 / 0	0	- 5,6	+ 3,5	+ 2,1	-
70–80	5	GPS	0 / 0	-	- 4,7	+ 2,2	+ 2,5	-
		GLO	0 / 0	-	- 3,2	+ 2,1	+ 1,1	-
	15	GPS	0 / 0	-	- 0,9	- 4,3	+ 4,6	+ 0,6
		GLO	0 / 0	-	- 0,7	- 3,5	+ 4,2	-
80–90	5	GPS	0 / 0	-	-	- 1,4	+ 1,0	+ 0,4
		GLO	0 / 0	-	-	- 1,2	+ 1,0	+ 0,2
	15	GPS	0 / 0	-	-	- 0,1	- 0,3	+ 0,4
		GLO	0 / 0	-	-	- 0,3	- 0,5	+ 0,8

Table 2. No fix (in per cent) and comparison of the distribution (in per cent) of GDOP coefficient values for 21 and 24 operational satellites for GPS System and GLONASS System for different masking elevation angle (H_{min}) at different observer's latitude (φ), "+" increasing, "–" decreasing, "0" – without change

Φ [°]	**H_{min} [°]**	**Sys-tem**	**No Fix 24/21 [%]**	**GDOP (21) – GDOP (24) = w [%]**				
				$w\le 3$	**$3< w\le 4$**	**$4< w\le 6$**	**$6< w\le 20$**	**$w>20$**
0 –10	5	GPS	0 / 0	- 16,2	+ 13,6	+ 2,3	+ 0,3	-
		GLO	0 / 0,7	- 18,1	+ 8,3	+ 6,8	+ 1,8	+ 0,5
	15	GPS	0 / 0,1	- 16,4	+ 0,9	+ 7,3	+ 6,8	+ 1,3
		GLO	0 / 8,9	- 8,8	- 14,9	+ 6,1	+ 6,6	+ 2,1
10-20	5	GPS	0 / 0	- 16,2	+ 13,9	+ 2,2	+ 0,1	-
		GLO	0 / 2,0	- 16,2	+ 2,3	+ 9,6	+1,7	+ 0,6
	15	GPS	0 / 0,6	- 8,4	- 10,2	+ 7,0	+ 8,7	+ 2,3
		GLO	0 / 9,1	- 4,4	- 14,2	+ 5,5	+ 3,1	+ 0,9
20–30	5	GPS	0 / 0	- 14,7	+ 10,1	+ 4,1	+ 0,5	-
		GLO	0 / 1,8	- 13,9	- 1,5	+ 11,7	+ 0,8	+ 1,1
	15	GPS	0 / 1,3	- 6,4	- 11,1	+ 7,4	+ 7,4	+ 1,4
		GLO	0 / 8,2	- 3,7	- 11,2	+ 2,7	+ 1,1	+ 2,9
30–40	5	GPS	0 / 0	- 14,7	+ 7,6	+ 5,7	+ 1,4	-
		GLO	0 / 1,7	- 8,3	- 4,5	+ 9,9	+ 0,4	+ 0,8
	15	GPS	0,1 / 1,8	- 5,3	- 12,6	+ 6,8	+ 7,6	+ 1,8
		GLO	0 / 7,0	- 0,7	- 12,9	+ 1,8	+ 2,0	+ 2,8
40–50	5	GPS	0 / 0	- 14,3	+ 6,5	+ 6,4	+ 1,4	-
		GLO	0 / 0,8	- 15,2	+ 7,8	+ 6,2	+ 0,4	+ 0,2
	15	GPS	0 / 2,1	- 4,9	- 17,0	+ 11,5	+ 6,5	+ 1,8
		GLO	0 / 4,5	- 3,3	- 14,4	+ 14,2	+ 6,3	+ 2,7
50–60	5	GPS	0 / 0	- 15,8	+ 7,2	+ 7,2	+ 1,4	-
		GLO	0 / 0	- 15,2	+ 5,0	+ 10,1	-	-
	15	GPS	0,1 / 2,7	- 3,0	- 17,9	+9,8	+7,2	+1,3
		GLO	0 / 2,8	- 3,1	- 14,7	+9,3	+4,4	+1,3
60–70	5	GPS	0 / 0	- 10,6	- 2,6	+ 10,9	+ 2,3	-
		GLO	0 / 0	- 6,3	- 5,0	+ 11,3	-	-
	15	GPS	0 / 2,7	- 0,4	- 13,3	+ 2,3	+ 8,1	+ 0,6
		GLO	0 / 0,4	0	- 17,1	+ 10,7	+ 5,0	+ 1,0
70–80	5	GPS	0 / 0	-	- 11,1	+ 1,8	+ 9,3	-
		GLO	0 / 0	-	- 8,2	+ 5,1	+ 3,1	-
	15	GPS	0 / 0,2	-	- 1,9	- 13,1	+ 13,8	+ 1,0
		GLO	0 / 0	-	- 1,4	- 7,5	+ 7,6	+ 1,3
80–90	5	GPS	0 / 0	-	-	- 3,5	+ 2,2	+ 1,3
		GLO	0 / 0	-	-	- 3,1	+ 2,2	+ 0,9
	15	GPS	0 / 0	-	-	- 0,9	- 0,9	+ 1,8
		GLO	0 / 0	-	-	- 0,6	- 3,0	+ 3,6

Table 3. No Fix (in per cent) and distribution (in per cent) of GDOP coefficient values for the different number of non operational satellites (SNO) for different masking elevation angle (H_{min}) for GPS System for the observer at latitude 50–60^O

H_{min} [^{O}]	SNO	No Fix [%]	GDOP coefficient – w [%]					
			w≤3	3<w≤4	4<w≤5	5<w≤6	6<w≤20	w>20
5	-	0	64,4	34,6	0,9	0,1	-	-
	1	0	58,4	37,5	2,8	0,8	0,5	-
	3	0	60,6	35,1	3,4	0,5	0,4	-
	1 and 2	0	52,6	41,5	4,0	1,3	0,6	-
	3 and 4	0	55,3	36,8	4,4	2,1	1,2	0,2
	1 and 3	0	54,4	38,2	5,3	1,2	0,9	-
	1 and 5	0	52,6	39,3	6,0	1,1	1,0	-
	1 and 13	0	50,0	43,2	3,6	1,4	1,7	0,1
	1, 2 and 3	0	48,6	41,8	6,8	1,4	1,4	-
	2, 3 and 4	0	49,4	40,5	5,9	2,3	1,7	0,2
	1, 2 and 5	0	47,4	41,4	8,0	2,0	1,2	-
	1, 5 and 9	0	48,4	39,7	7,8	1,8	2,1	0,2
15	-	0,1	6,5	58,4	20,5	7,7	5,7	1,1
	1	0,6	5,1	50,8	22,5	10,0	9,3	1,7
	3	0,6	6,0	53,8	23,0	7,7	7,4	1,5
	1 and 2	1,7	4,0	44,7	24,4	11,8	11,4	2,0
	3 and 4	3,8	5,0	48,7	21,7	9,0	10,1	1,7
	1 and 3	1,1	4,6	46,2	25,0	10,0	11,0	2,1
	1 and 5	2,3	4,8	44,0	25,2	11,1	10,3	2,3
	1 and 13	3,0	2,8	46,1	22,2	11,1	12,2	2,6
	1, 2 and 3	2,7	3,5	40,5	26,7	11,3	12,9	2,4
	2, 3 and 4	5,4	3,9	43,0	23,4	10,3	12,0	2,0
	1, 2 and 5	2,9	3,2	40,3	23,8	12,5	14,2	3,1
	1, 5 and 9	5,4	4,4	41,0	24,8	10,2	10,8	3,4

No Fix (in per cent) and comparison of the distribution (in per cent) of GDOP coefficient values for different number of operational satellites (SO = 23, 22 and 21) and for different H_{min} for both systems for the observer at latitude 50–60^O is shown in the table 6. For H_{min} = 0^O and H_{min} = 15^O the increase of GDOP is greater for GPS than for GLONASS System for each number of SO.

Table 4. No Fix (in per cent) and distribution (in per cent) of GDOP coefficient values for the different number of non operational satellites (SNO) for different masking elevation angle (H_{min}) for GLONASS System for the observer at latitude 50–60^{O}

H_{min} [^{O}]	SNO	No Fix [%]	GDOP coefficient – w [%]					
			w≤3	3<w≤4	4<w≤5	5<w≤6	6<w≤20	w>20
5	-	0	61,1	38,5	0,4	-	-	-
	1	0	55,1	41,7	3,2	-	-	-
	1 and 2	0	51,3	42,7	6,0	-	-	-
	1 and 5	0	48,6	46,5	4,6	0,2	0,1	-
	1 and 9	0	49,3	45,9	4,6	0,1	0,1	-
	1, 2 and 3	0	46,0	43,5	9,8	0,7	-	-
	1, 3 and 6	0	43,0	48,6	8,2	0,2	-	-
	1, 2 and 9	0	44,7	45,6	9,1	0,4	0,2	-
15	-	0	7,0	56,7	30,3	5,1	0,2	0,7
	1	0	5,4	52,2	32,1	7,5	2,1	0,7
	1 and 2	0,4	4,9	46,3	34,9	8,1	4,0	1,4
	1 and 5	0,1	4,2	48,8	32,1	9,0	4,8	1,0
	1 and 9	0,1	4,6	47,3	34,6	5,8	6,2	1,4
	1, 2 and 3	2,8	3,9	42,0	36,6	8,1	4,6	2,0
	1, 3 and 6	0,5	3,1	41,7	36,2	10,7	6,9	0,9
	1, 2 and 9	2,6	4,2	41,7	35,4	6,4	7,3	2,4

Table 5. No fix (in per cent) and distribution (in per cent) of GDOP coefficient values for the different number of operational satellites (SO) for different masking elevation angle (H_{min}) for GPS System and GLONASS System for the observer at latitude 50–60^{O}

SO	H_{min} [^{O}]	Sys-tem	No Fix [%]	GDOP coefficient – w [%]					
				w≤2	2<w≤3	3<w≤4	4<w≤6	6<w≤20	w>20
24	0	GPS	-	0,6	85,2	14,0	0,2	-	-
		GLO	-	0,3	88,5	11,2	-	-	-
	5	GPS	-	-	64,4	34,6	1,0	-	-
		GLO	-	-	61,1	38,5	0,4	-	-
	10	GPS	-	-	28,9	62,8	7,7	0,4	02
		GLO	-	-	27,9	66,1	6,0	-	-
	15	GPS	0,1	-	6,5	58,4	28,2	5,7	1,1
		GLO	-	-	7,0	56,7	35,4	0,2	0,7
23	0	GPS	-	-	81,1	17,7	1,2	-	-
		GLO	-	0,1	84,9	14,3	0,7	-	-
	5	GPS	-	-	58,4	37,5	3,6	0,5	-
		GLO	-	-	53,1	41,7	3,2	-	-
	10	GPS	-	-	24,0	61,8	11,9	2,0	0,3
		GLO	-	-	22,8	65,2	11,8	0,2	-
	15	GPS	0,6	-	5,1	50,8	32,5	9,3	1,7
		GLO	-	-	5,4	52,2	39,6	2,1	0,7
22	0	GPS	-	0,2	75,2	22,9	1,7	-	-
		GLO	-	0,1	81,3	17,4	1,2	-	-
	5	GPS	-	-	52,6	41,5	5,3	0,6	-
		GLO	-	-	51,3	42,7	6,0	-	-
	10	GPS	-	-	21,0	59,5	16,2	3,0	0,3
		GLO	-	-	20,7	60,3	18,7	0,3	-
	15	GPS	1,7	-	4,0	44,7	36,2	11,4	2,0
		GLO	0,4	-	4,9	46,3	43,0	4,0	1,4
21	0	GPS	-	-	71,7	24,5	3,5	0,3	-
		GLO	-	-	77,0	20,3	2,7	-	-
	5	GPS	-	-	48,6	41,8	8,2	1,4	-
		GLO	-	-	46,0	43,5	10,5	-	-
	10	GPS	0,1	-	19,3	55,9	20,1	4,1	0,5
		GLO	-	-	17,3	56,7	24,5	1,5	-
	15	GPS	2,7	-	3,5	40,5	38,0	12,9	2,4
		GLO	2,4	-	3,9	42,0	44,9	4,6	2,2

Table 6. No fix (in per cent) and comparison (in per cent) of GDOP coefficient values for the different masking elevation angle (H_{min}) for the different number of operational satellites (SO) for GPS System and GLONASS System for the observer at latitude 50–60^{O},"+" increasing, "–" decreasing, "0" – without change

H_{min} [^{O}]	SO	System	No Fix 24/SO [%]	GDOP(SO) – GDOP(24) = w [%]				
				w≤3	3<w≤4	4<w≤6	6<w≤20	w>20
0	23	GPS	0 / 0	- 4,7	+ 3,7	+ 0,7	-	-
		GLO	0 / 0	- 3,8	+ 3,1	+ 1,0	-	-
	22	GPS	0 / 0	- 10,4	+ 8,9	+ 1,5	-	-
		GLO	0 / 0	- 7,4	+ 6,2	+ 1,2	-	-
	21	GPS	0 / 0	- 14,1	+ 10,5	+ 3,3	+ 0,3	-
		GLO	0 / 0	- 11,8	+ 9,1	+ 2,7	-	-
5	23	GPS	0 / 0	- 6,0	+ 2,9	+ 2,7	+ 0,4	-
		GLO	0 / 0	- 6,0	+ 3,2	+ 2,8	-	-
	22	GPS	0 / 0	- 11,8	+ 6,9	+ 4,3	+ 0,6	-
		GLO	0 / 0	- 9,8	+ 4,2	+ 5,6	-	-
	21	GPS	0 / 0	- 15,8	+ 7,2	+ 7,2	+ 1,4	-
		GLO	0 / 0	- 15,2	+ 5,0	+ 10,1	-	-
10	23	GPS	0 / 0	- 4,9	- 1,0	+ 4,2	+ 1,6	+ 0,1
		GLO	0 / 0	- 5,1	- 0,9	+ 5,8	+ 0,2	-
	22	GPS	0 / 0	- 7,9	- 3,3	+ 8,5	+ 2,6	+ 0,1
		GLO	0 / 0	- 7,2	- 5,8	+ 12,7	+ 0,3	-
	21	GPS	0 / 0,1	- 9,6	- 6,9	+ 12,4	+ 3,7	+ 0,3
		GLO	0 / 0	- 10,6	- 9,4	+ 18,5	+ 1,5	-
15	23	GPS	0,1 / 0,6	- 1,4	- 7,6	+ 4,3	+ 3,6	+ 0,6
		GLO	0 / 0	- 1,6	- 4,5	+ 4,2	+ 1,9	0
	22	GPS	0,1 / 1,7	- 2,5	- 13,7	+ 8,0	+ 5,7	+ 0,9
		GLO	0 / 0,4	- 2,1	- 10,4	+ 7,6	+ 3,8	+ 0,7
	21	GPS	0,1 / 2,7	- 3,0	- 17,9	+ 9,8	+ 7,2	+ 1,3
		GLO	0 / 2,8	- 3,1	- 14,7	+ 9,3	+ 4,4	+ 1,3

CONCLUSIONS

The position of observer can be calculated in each zone of latitude and for both systems when only one of the GPS or GLONASS satellite is non operational and $H_{min} = 5^O$.

If $H_{min} = 15^O$ this position cannot be calculated at the middle latitude (10–50^O) for both systems.

If three of the GPS satellites are non operational and $H_{min} = 5^O$ the position of observer can be calculated in each zone.

If the number of satellites fully operational is less than 24, the increase of GDOP coefficient value depends on the number of non operational satellites and their position on the orbit, the masking angle H_{min} and the latitude of observer.

For the observer at latitude of Poland (50–60^O), if $H_{min} \leq 10^O$ and two satellites are non operational, its position can be fixed for both systems.

REFERENCES

1. Januszewski J. *"Geometry of GPS and Glonass Systems"*, II European Symposium GNSS'98, tome II, Toulouse, 1998
2. Januszewski J. "Visibility and Geometry of GPS and Glonass", No 1, Annual of Navigation Polish Academy of Sciences, Polish Navigation Forum, Gdynia, 1999.
3. Spilker Jr. J.J. *"Satellite Constellation and Geometric Dilution of Precision"*, Global Positionning System: Theory and Applications vol. I, American Institute of Aeronautics and Astronauticus, Inc. Washington, 1996

Received July 2000
Reviewed December 2000