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Global Positioning System (GPS) location accuracy improvement due to Selective Availability removal

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Abstract – Global Positioning System (GPS) is an important new technology for spatio-temporal behaviour studies of animals. Differential correction improves location accuracy. Previously, it mostly removed partially the influence of Selective Availability (SA). SA was deactivated in May 2000. The aim of this study was to quantify the influence of SA cancellation on location accuracy of various GPS receivers. We tested the accuracy of locations obtained from non-differential and differential GPS animal collars before and after SA removal. We found a significant improvement in accuracy for both types of GPS collars. However, differential GPS still provides more accurate locations. ***To cite this article: C. Adrados et al., C. R. Biologies 325 (2002) 165–170.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

differential correction / Global Positioning System (GPS) / location accuracy / Selective Availability / Wildlife telemetry

Résumé – Amélioration de l'exactitude des localisations GPS liée au retrait de la SA. Le *Global Positioning System* (GPS) est une nouvelle technique d'étude du comportement spatio-temporel des animaux. Une correction différentielle permet d'améliorer l'exactitude des localisations. Avant la suppression en mai 2000 de la *Selective Availability* (SA), c'est surtout l'influence de celle-ci qu'elle supprimait partiellement. Le but de notre étude était de tester l'exactitude des localisations obtenues avec des colliers GPS différentiels et non-différentiels, avec et sans SA. Nous avons constaté une augmentation significative de l'exactitude des localisations depuis la suppression de la SA. Toutefois, le mode différentiel reste plus performant que le mode non-différentiel. ***Pour citer cet article : C. Adrados et al., C. R. Biologies 325 (2002) 165–170.*** © 2002 Académie des sciences / Éditions scientifiques et médicales Elsevier SAS

correction différentielle / *Global Positioning System* (GPS) / exactitude / *Selective Availability* / faune sauvage / télémétrie

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. Version abrégée

Dès les premières utilisations du *Global Positioning System* (GPS) pour la localisation d'animaux, la connaissance de l'exactitude des localisations a été un point essentiel. La *Selective Availability* (SA), mise en place par le département de la défense des États-Unis et qui dégradait volontairement les performances du système, était la principale source d'erreur jusqu'à sa suppression au mois de mai 2000. Une correction différentielle des données recueillies, par rapport à celles fournies par une station GPS de référence fixe dont les coordonnées sont connues avec exactitude, permettait d'en limiter grandement les effets. Cette correction implique cependant plus de temps et une plus grande complexité de mise en œuvre. L'acquisition d'une station GPS de référence entraîne également une augmentation non négligeable du coût du système. Le but de cette étude est de quantifier l'effet de l'élimination de la SA sur l'exactitude des localisations obtenues par GPS différentiel et non-différentiel, afin d'apporter des éléments de réponse aux utilisateurs potentiels de ces techniques, concernant le choix du mode de calcul des localisations le plus adapté à leurs objectifs. Pour cela, trois types de matériels ont été testés : une station de référence 12 canaux fonctionnant en mode non-différentiel et des colliers GPS 8 canaux différentiels et non-différentiels. La station de référence était utilisée dans des conditions optimales (faible masque topographique) contrairement aux colliers dont les antennes GPS étaient privées de plan de sol (normalement constitué par le cou de l'animal), ce qui diminue leurs performances. De même, la station de référence utilisée pour la correction des données issues des colliers GPS différentiels était éloignée d'environ 420 km, ce qui est proche de la limite maximale d'utilisation de 500 km spécifiée par le fabricant, réduisant ainsi l'exactitude des localisations obtenues après correction différentielle. Les résultats sont donnés en fonction de deux paramètres indicateurs de l'exactitude des localisations : le statut des localisations en 2 ou 3 dimensions (selon le nombre de satellites utilisés pour le calcul d'une localisation), et la *dilution of precision* (*DOP*) qui est un indice de la qualité de la configuration des satellites pris en compte pour le calcul d'une localisation. Pour les trois types de matériels testés, nous avons constaté une augmentation logique de l'exactitude de localisation, accompagnée d'une diminution des erreurs maximales observées. Pour la station de référence, l'erreur moyenne passe de 23,9 m à 1,4 m après suppression de la SA. Elle décroît de 78,0 m à 11,9 m pour les colliers non-différentiels, et de 11,3 m à 5,2 m pour les colliers différentiels. En mode non-différentiel, la diminution de l'erreur est significative pour toutes les classes de localisations. En mode différentiel, seules les classes de localisations les plus précises (2D et *DOP* < 5 ; 3D et *DOP* < 10) ont bénéficié d'un gain significatif d'exactitude. Les localisations obtenues en mode différentiel restent toujours plus précises, car la correction différentielle permet aussi de corriger partiellement d'autres sources d'erreurs telles que celles provenant de l'horloge et de l'éphéméride des satellites, et des vitesses de propagation des signaux lors de la traversée de l'atmosphère. Toutefois, la précision obtenue par GPS non-différentiel (donc avec moins de contraintes techniques et financières) peut maintenant s'avérer suffisante pour certaines applications (étude du domaine vital, migrations…). L'utilisation du GPS différentiel permet dorénavant d'aborder des études à une échelle encore plus fine (relation animal-plante, trajectométrie…) ouvrant ainsi de nouvelles perspectives de recherche.

1. Introduction

Since the first application of Global Positioning System (GPS) technology to locate wild animals [1] there have been recurrent questions about location accuracy. One of the main sources of error was a random degradation intentionally imposed by the United States Department of Defence called Selective Availability (SA). To manage SA influence, and to achieve better accuracy, it was possible to use GPS animal collars in differential mode [1–7]. This method consists of storing measured distances to individual satellites (called pseudoranges) in the GPS collar, and correcting it in post-treatment with data obtained simultaneously by a pinpointed GPS reference base station. Locations are then accurately determined. Both differential and non-differential GPS collars are used in wildlife applications, the latter being cheaper and easier to use, but less accurate. SA was removed at the beginning of May 2000, and theoretically [2,6] it is possible to calculate the effect of this removal. However, we decided to test this impact on location accuracy of our GPS base station (as an example) and of non-differential and differential GPS collars in stationary positions. The goal of this paper is to help future wildlife GPS users to choose the most appropriate GPS mode to suit their scientific objectives.

2. Materials and methods

We studied the influence of SA elimination on location accuracy of three very different GPS receivers in stationary positions: a reference base station, non differential and differential GPS collars. Our goal was not to compare the GPS performance among devices but location accuracy before and after SA removal within each one. In fact it is almost impossible to directly compare the results obtained from the various GPS receivers because: *(i)* the reference base station was used under optimal conditions with an effective ground plane (a better ground plane improves antenna performances, particularly by increasing antenna gain); *(ii)* GPS collars are not designed to work without a ground plane (which is usually the body of the fitted animal); *(iii)* channel number is higher for the reference base station than for the collars (more satellites can be tracked simultaneously); *(iv)* the fix interval was different among devices, and it has an influence both on location success rate [5] and accuracy [6]; and *(v)* the GPS receivers were located in different places (with different topographic obstructions) and did not work simultaneously.

2.1. Reference base station

Fixes were obtained from a 12-channel GPS Pathfinder base station (Trimble Navigation Inc., USA, PFCBS software version 2.67) working in non-differential mode, one month before and one month after SA removal, with a fix interval of 5 s. The reference base station was located in south-west France (43°31'N, 01°30'E). Topographic obstruction was below the elevation mask threshold of 10° set in the base station software.

2.2. Non-differential GPS collars

Locations were collected from non-differential 8-channel GPS Simplex collars (TVP Positioning AB., Sweden), more than 4 months before and after SA removal, with a fix interval of 6 min. Collars were processed using Simpset software version 2.0 and data were downloaded via a wire link to a personal computer. The GPS collars were tested in south-east France (45°57'N, 05°90'E). Topographic obstructions were low to the North (7°), East (5°) and West (10°) but higher to the South (35°).

2.3. Differential GPS collars

Pseudoranges were recorded from differential 8-channel GPS_1000 collars (Lotek Engineering Inc., Canada, software version 2.17) more than 4 months before and after SA removal, with a fix interval of 5 min. We chose to test the GPS collars 420 km away from the reference base station; i.e., close to the 500-km limit given by Trimble instructions [2]. The area was located in a mountainous environment in south-east France (45°16'N, 05°58'E), with significant topographic obstructions to the North and West (N 43°, E 12°, S 10°, W 31°), thus potentially increasing multipath effects, as for non-differential collars, compared to reference base station. Data were downloaded via a radio modem command unit to a personal computer using Gpshost 1000 software version 3.08 [8]. The pseudoranges were differentially corrected using N4win software version 1.1895.

We converted all GPS locations from latitude–longitude to the French Lambert III coordinate system using GPS Pathfinder Office software version 2.7 (Trimble Navigation Ltd., Sunnyvale, USA). Locations were pooled into different classes according to fix status: 2- or 3-dimensional location (2D or 3D) and Dilution of Precision (*DOP*), both of them having an influence on location accuracy. 2D locations are less accurate than 3D locations, and *DOP* is a measure of the quality of satellite geometry: satellites that are close together will provide a lower accuracy and a higher *DOP*. We determined location error as the distance in metres between each observed location and an estimated true location. The true location was estimated as the geometric centre of the most accurate locations (3D locations with $DOP < 5$) obtained at each site. As location errors cannot be < 0, the variance is related to the mean. Error data was then transformed by natural logarithm before statistical analysis, as suggested by [3,4]. We tested the hypothesis that SA removal had an effect on location error within these different classes of GPS location, for both differential and non-differential GPS collars, using analysis of variance (ANOVA). Significance level of all tests was $p = 0.05$. We report exact p-values when $p > 0.001$. Statistical tests were conducted using SPSS for Windows (SPSS Science, Chicago, IL, USA).

3. Results

3.1. Reference base station

We analysed two sets of 4320 locations recorded by our reference base station before and after SA removal. All of these were 3D locations with *DOP* values lower than 5. Mean location error decreased significantly from 23.9 m with SA ($SE = 0.2$, $max = 94.8$) to 1.4 m without SA ($SE = 0.01$, $max = 3.1$) ($F_{1,8640} = 4.1\ 10^{4}$, $p < 10^{-3}$). Table 1 shows the influence of SA removal on location error distribution.

Table 1. Cumulative percentages of location errors around calculated reference point (from reference base station). Results are shown with and without Selective Availability (SA; no SA). All the locations were 3D with *DOP* < 5. Mean, *SE* and maximum (*max*) locations errors (in metres) are also indicated

Location error (m)	Cumulative % of locations	
	SA	no SA
n	4320	4320
0–5	4.1	100
5–10	15.6	
10–15	30.0	
15–20	46.3	
20–30	74.8	
30–40	87.7	
40–50	93.5	
50–100	100	
mean	23.9	1.4
SE	0.2	0.01
max	94.8	3.1

3.2. Non-differential GPS collars

We recorded respectively 354 and 339 locations before and after SA removal with non-differential GPS collars. Mean location error decreased significantly from 78.0 m with SA (*SE* = 4.9, *max* = 776.9) to 11.9 m without SA (*SE* = 0.7, *max* = 160.1) ($F_{1,692} = 784.4$, $p < 10^{-3}$). We collected very few locations with *DOP* ≥ 10 for 2D locations (*n* = 9 with SA and *n* = 4 without SA) and none for 3D locations, so we pooled data in 4 sets: *DOP* < 5 and *DOP* ≥ 5 for both 2D and 3D locations. For each data set, mean location error was significantly lower after SA removal (2D locations with *DOP* < 5: $F_{1,203} = 273.4$, $p < 10^{-3}$; 2D locations with *DOP* ≥ 5: $F_{1,69} = 135.4$, $p < 10^{-3}$; 3D locations with *DOP* < 5: $F_{1,326} = 470.6$, $p < 10^{-3}$ and 3D locations with *DOP* ≥ 5: $F_{1,91} = 159.34$, $p < 10^{-3}$). Table 2 shows the distribution of location error for each *DOP* and fix status class, with and without SA.

3.3. Differential GPS collars

We analysed 475 and 654 locations recorded with differential GPS collars before and after SA removal. Mean location error decreased significantly from 11.3 m (*SE* = 3.1, *max* = 1441.4) to 5.2 m (*SE* = 0.3, *max* = 171.8) ($F_{1,1128} = 24.7$, $p < 10^{-3}$). Few 2D locations were collected with *DOP* ≥ 10 (*n* = 19 with SA and *n* = 4 without SA) so we made only two *DOP* classes in this case: *DOP* < 5 and *DOP* ≥ 5. We pooled 3D locations in 4 classes: *DOP* < 5; 5 ≤ *DOP* < 10; 10 ≤ *DOP* < 15 and *DOP* ≥ 15 (Table 3 shows the influence of SA on location error distribution among each class). Mean location error decreased significantly without SA for 2D locations with *DOP* < 5 ($F_{1,74} = 6.0$, $p = 0.032$) while 2D locations with *DOP* ≥ 5 did not show a significant difference before and after SA removal. Mean location error was significantly lower after SA removal for 3D locations with *DOP* < 5 ($F_{1,475} = 5.04$, $p = 0.025$) and with 5 ≤ *DOP* < 10 ($F_{1,363} = 11.63$, $p < 10^{-3}$). For 3D locations with higher

Table 2. Cumulative percentages of location errors around calculated reference point (from non-differential GPS collars). Results are shown for 2D and 3D locations (2D; 3D) with 2 *DOP* classes (*DOP* < 5; *DOP* ≥ 5), with and without Selective Availability (SA; no SA). Mean, *SE* and maximum (*max*) location errors (in metres) are also indicated

Location error (m)	Cumulative % of locations							
	2D				3D			
	DOP < 5		*DOP* ≥ 5		*DOP* < 5		*DOP* ≥ 5	
	SA	no SA	SA	no SA	SA	no SA	SA	no SA
n	96	108	41	29	176	151	41	51
0–5	1.0	25.9		3.4	1.1	38.4		25.5
5–10	4.2	49.1		“	4.5	62.3		58.8
10–15	7.3	76.9		17.2	10.2	87.4	7.3	82.4
15–20	8.3	80.6		27.6	15.3	90.1	12.2	88.2
20–30	21.9	94.4		55.2	35.8	100	22.0	98.0
30–40	33.3	97.2	4.9	86.2	49.4		36.6	“
40–50	45.8	“	“	93.1	60.8		43.9	100
50–100	76.0	99.1	29.3	100	93.2		75.6	
100–200	94.8	100	53.7		99.4		100	
200+	100		100		100			
mean	81.9	13.1	206.4	27.9	48.3	8.8	68.0	10.1
SE	10.7	1.7	22.0	2.5	2.6	0.5	7.1	1.0
max	776.9	160.1	693.5	62.8	230.9	27.1	191.9	43.2

Table 3. Cumulative percentages of location errors around calculated reference point (differential GPS collars). Results are shown for 2D locations with 2 *DOP* classes (*DOP* < 5; *DOP* ≥ 5) and for 3D locations with 4 *DOP* classes (*DOP* < 5; 5 ≤ *DOP* < 10; 10 ≤ *DOP* < 15; *DOP* ≥ 15), with and without Selective Availability (SA; no SA). Mean, *SE* and maximum (*max*) locations errors (in metres) are also indicated

Location error (m)	Cumulative % of locations											
	2D				3D							
	DOP < 5		*DOP* ≥ 5		*DOP* < 5		5 ≤ *DOP* < 10		10 ≤ *DOP* < 15		*DOP* ≥ 15	
	SA	no SA	SA	no SA	SA	no SA	SA	no SA	SA	no SA	SA	no SA
n	66	9	30	6	196	280	116	248	25	67	42	44
0–5	33.3	88.9	6.7	50.0	66.3	70.4	51.7	66.5	36.0	52.2	28.6	31.8
5–10	66.7	100	26.7	“	94.4	98.2	86.2	94.0	80.0	82.1	59.5	77.3
10–15	87.9		36.7	“	99.0	100	94.8	99.6	96.0	92.5	69.0	86.4
15–20	90.9		50.0	“	100		98.3	100	“	98.5	78.6	88.6
20–30	98.5		70.0	66.7			100		“	100	85.7	93.2
30–40	100		76.7	“					“		88.1	“
40–50			86.7	83.3					“		90.5	97.7
50–100			90.0	100					100		97.6	“
100–200			93.3								100	100
200+			100									
mean	8.5	3.4	77.8	27.2	4.6	4.1	5.8	4.6	7.9	6.2	16.5	12.7
SE	0.85	0.9	47.6	9.6	0.2	0.1	0.4	0.2	1.9	0.6	3.4	3.9
max	30.2	9.8	1441.4	61.9	17.6	12.5	26.3	17.9	52.1	20.3	107.4	171.8

DOP values, there was no significant difference with or without SA, but maximum location error was lower after SA removal, except for *DOP* ≥ 15, where the maximum error value was linked to the highest *DOP* recorded among all data sets (*DOP* = 268.1). Without this location, maximum error dropped to 43.9 m (instead of 171.8 m) which was lower than the maximum error before SA removal.

4. Conclusion

Fix accuracy obtained for non-differential GPS locations improved significantly after SA elimination. Differences in location errors recorded by the reference base station and non-differential GPS collars cannot be compared, because:

– the antenna ground plane was more effective for the reference base station than for the collars;

– the number of channels receiving GPS-satellite signals was higher and the fix interval was shorter for the base station;

– the topographic mask was lower for the base station;

– the tests did not take place simultaneously.

The performance of non-differential GPS collars would probably have been better with an antenna ground plane (i.e., the neck of fitted animals) and without topographic obstruction.

The effect of SA removal is logically far more important for non-differential than differential GPS collars because the influence of SA was already limited by differential correction. However, for both GPS modes, SA elimination results in an important decrease in the maximum location error. Differential GPS collars are still more accurate because differential correction can remove other sources of error, such as: satellite clock and ephemeris errors; ionospheric and tropospheric delays [2,6]. The performance of differential GPS collars could have been improved without topographic obstruction, and using a better antenna ground plane and a closer reference base station. Computational possibilities also exist to increase the accuracy of 3D locations with high *DOP*, by degrading them to 2D locations with fixed height value [3,6,7].

The choice between GPS modes (non-differential versus differential) will be determined by the scale needed in a particular study. If GPS is taken as an alternative to other techniques (such as classical VHF radiotracking) to study annual home ranges or migrations, the non-differential mode is probably accurate enough without the drawbacks induced by differential correction. We must recognize, as other GPS-users have [3–5,7,9], that working with differential GPS is more expensive (cost of a reference base station, maybe several for large migration studies), that data post-treatment requires more time and technical capabilities, and that collars need a greater memory capacity to store pseudorange data. We agree with [7], that differential GPS allows us to study animal-habitat relationships at a very fine spatio-temporal scale, never achieved yet with other techniques, thus opening new approaches to wildlife research. Studies on daily habitat use by individual animals will be possible, even in very fine scale patchy environments.

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