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Authors: Casaer, Jim, Hermy, Martin, Verhagen, Ron, and Coppin, Pol

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SHORT COMMUNICATION

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Appropriateness of the linear correction method for GPS positional fixes in wildlife studies

Jim Casaer, Martin Hermy, Ron Verhagen & Pol Coppin

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This paper describes the results of tests performed to evaluate linear correction of GPS measurements as an alternative to differential correction of GPS positional fixes. Differential correction requires information which is not provided by the existing animal-borne GPS systems for smaller mammals. Therefore, linear correction, by means of a second GPS rover, has been suggested as an alternative to differential correction. To test the accuracy of linearly corrected measurements, we compared the position estimates of raw, linearly corrected and differentially corrected GPS positional fixes with the true (known) geodetic position. The tests indicate that the accuracy of linear correction is highly unstable and is related to differences in the satellite constellation used by the GPS receivers. Linear correction is consequently strongly discouraged. If differential correction is not possible, we recommend the use of raw GPS measurements, of which the error is well known and more predictable.

Key words: animal-borne GPS, GPS correction methods, mammals

Jim Casaer, Martin Hermy & Pol Coppin, Laboratory for Forest, Nature and Landscape Research, Vital Decosterstraat 102, B-3000 Leuven, Belgium - email : jim.casaer@agr.kuleuven.ac.be
Ron Verhagen, Evolutionary Biology Group, Groenenborgerlaan 171, B-2020 Antwerpen, Belgium

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Although still quite innovative, the application of the Global Positioning System (GPS) technology in wildlife research has been reported by several authors over the last couple of years. The weight of collar-borne GPS receivers has, however, limited their use to the tracking of larger animals. Almost all published literature concerns larger mammals such as moose *Alces alces* (Rodgers & Anson 1994, Rempel, Rodgers & Kenneth 1995, Moen, Pastor, Cohen & Schwartz 1996, Rodgers, Rempel & Abraham 1996 and Edenius 1997), or bear *Ursus* sp. (Obbard, Pond & Perera in press), and most of it concerns non-differentially corrected GPS positioning. The first experimental results of GPS tracking with post-processing differential correction on moose were published only very recently (Moen, Pastor & Cohen

1997, Rempel & Rodgers 1997). Differential correction involves the use of a second GPS (base station) on a known position to collect satellite information from all visible satellites. The information is used to remove the errors in the data collected by the GPS operating in the field. The errors may be due to Selective Availability, atmospheric interference, satellite ephemeris errors and clock errors. To enable differential correction it is required that the satellite information collected by the base station covers all the satellites used to calculate the position of the GPS in the field, and that the distance between the two GPS units does not exceed 500 km.

Such differential correction requires more information than is stored by the first-generation animal-borne GPS collars (Rempel et al. 1995, Moen et al. 1996), necessitating more complex collars, higher data storage capacities, higher battery capacity, and thus increased collar weight. Miniaturisation is the natural solution, especially where the collaring of smaller mammals is concerned. While receivers for this group are under development, they will not, as of yet, allow differential correction. In the meantime, an alternative, linear correction method has been suggested by some wildlife researchers and collar manufacturers (Moore, Hart & French 1997). This method encompasses the correction of animal-borne GPS-derived positions with simultaneously acquired positional errors of a known stationary location.

We tested the accuracy of the linear correction method as an alternative to differentially corrected GPS data. The present paper aims to describe the accuracy of linear correction, to find out if and why there is a difference between linear and differential correction, and to evaluate the use of linear correction as a GPS correction method.

Methods and material

During 12 data sessions, we collected at least 30 positional fixes at two geodetic points using a Trimble Pro-XL GPS receiver. To process the data files we used PFINDER V.3.0 software. The operational parameters were a time interval of 15 minutes between sessions, a logging rate of five seconds (interval between individual fixes) and a maximum positional dilution of precision (PDOP) of six. The GPS was in manual 3D position fix mode, meaning that the elevation was computed by the GPS itself, and measurements were only taken when at least four satellites were available. Based on the spread of the raw data it is evident that Selective Availability was active during the data collection sessions. One of the geodetic points was situated in open field, the other in a forested area. The experiment was carried out during winter with only woody matter (stems and branches) obstructing the reception of the GPS satellite signals. Data acquired simultaneously from a base station, located less than 20 kilometres away, were used to differentially correct the locational fixes for the two points. The base station's own position, computed every five seconds using the combination of the four satellites that resulted in the best PDOP, was used to linearly correct the field data. For each observation of the base station we first calculated the difference between the measured and the known northing (respectively easting) and subsequently subtracted these differences from the raw field GPS data (northing respectively easting). We then compared the locational error (LE) of the raw, the linearly corrected and the differentially corrected measurements (three correction methods) according to the formula of Rempel et al. (1995). They defined the LE as the Euclidean distance between the estimated and the true location of the fixes.

As an estimator of accuracy, the median of the LEs was calculated for each location and correction method, for each data session separately and for all sessions combined. We used the median in stead of the mean LE as a descriptive statistic because of the non-normal distribution of the data. The Friedman test is recognised for its robust non-parametric capabilities, allowing multiple comparisons between groups using average ranks (Siegel & Castellan 1988). Therefore, we selected this to test the statistical significance of the observed differences in the LEs obtained for each of the locations with the different correction methods.

To evaluate the effectiveness of the linear and differential correction methods we then computed the estimator (EF). EF portrays the estimation of the accuracy (median) for the linearly and differentially corrected measurements as a percentage of the estimation of the accuracy (median) of the raw measurements and is calculated as follows

$$EF = 100 \cdot \frac{\text{median}_{.c}}{\text{median}_{nc}}$$

where $\text{median}_{.c}$ = median of the LEs of the corrected

Table 1. Medians of the positional errors for the six data sessions, in open and forested areas, given in metres from the true position; sample size equals or exceeds 30.

	Session	Raw measurements	Linearly corrected	Differentially corrected
Open area	1	37.67	43.85	0.56
	2	29.91	11.92	0.87
	3	33.60	15.00	0.76
	4	31.36	29.90	0.08
	5	13.34	6.69	0.55
	6	8.70	4.49	0.60
	All	26.98	12.88	0.61
Forested area	1	59.52	49.91	9.94
	2	27.72	22.87	2.77
	3	13.83	22.5	4.54
	4	28.25	41.96	6.07
	5	34.87	22.99	8.41
	6	43.13	50.24	5.10
	All	38.90	29.87	4.85

measurements with '.' = l for linear correction and '.' = d for differential correction, and $median_{nc}$ = median of the LEs of the raw measurements.

We used the Wilcoxon Matched-Pairs rank test to compare the EFs of the linear and differential correction method (Siegel & Castellan 1988).

Results

The median values of the LEs for each data sample are summarised in Table 1. The Friedman test clearly illustrates the existence of statistically significant differences between the LE values for the three methods (no correction, linear correction and differential correction), both with respect to the open field ($P < 0.01$) and to forested conditions in winter ($P = 0.01$). In both cases the LE of the differentially corrected measurements is significantly smaller than the LE of the raw measurements, but there is no statistically significant difference in LE between raw measurements and linearly corrected measurements.

The EF, as previously defined, can be calculated from Table 1, by dividing the third (linear correction), respectively, the fourth (differential correction) column of Table 1 by the second column (raw measurements). Multiplying the result by 100 gives the EF as a percentage. For the linear correcrion the EF (correction effectiveness) varied between 0.39 and 1.16 for the open area and between 0.65 and 1.62 for the forested area. This shows that linear correction might both reduce and increase the LE by as much as 60%. The EF for differentially corrected measurements never exceeded 0.33, which means that when comparing differentially corrected to raw measurements, the net improvement, even in the worst case, is about 70%. The Wilcoxon Matched-Pairs rank test indicated that in the open ($P < 0.05$) as well as in the forested area ($P < 0.05$), the results of the differential correction method are statistically better than those of the linear correction method.

Discussion and conclusions

We demonstrated the unreliability of the effect of the linear correction procedure on the accuracy of GPS measurements. A non-parametric multiple comparison test revealed a statistically significant difference in accuracy between linear and differential correction, with a reduced residual positional error in the latter case. This can be explained by the difference in mathematical algorithms and data input procedures.

To correct differentially, the base station calculates the expected time-lapse a signal needs to travel from a satellite to its receiving antenna. The difference between this expected travel time and the time actually measured (pseudo range) is the time error. This time error is computed at regular intervals (depending on the logging rate of the base station) for every 'visible' satellite and this information is stored. To adjust the raw measurements of a receiver (or rover) in the field, positional fixes are recomputed taking into account these time errors. Note that it is a prerequisite that all satellites used by the rover are equally 'visible' to the base station, so that the computed time errors are valid for the respective field fixes. Linear correction, on the other hand, is based on the principle of calculating a positional error. The rover, as well as the base station, uses the best combination of four available satellites (depending on the PDOP). Due to possible obstructions in the rover's line of sight, the satellite combination is not always the same as for the base station, resulting in inappropriate corrections often returning larger errors than those implicit in the original raw measurements. It is possible to control whether the same satellite constellation is used by both GPS receivers and to ensure that only measurements obtained this way are used. This means that, depending on the distance between the receivers and the operational conditions of the GPS in the field, a certain number of observations would have to be omitted. Not once was the same satellite constellation used by both receivers on the location in the forested area. In the open field between 10 and 100% of observations used the same satellite constellation. This means that none of the observations in the forested area could have been linearly corrected, as it was a condition that both GPS receivers should use the same satellite constellation. Therefore, this condition was abandoned and we tested the accuracy (using the median) of linear correction performed on the total number of observations used in each data session because this best reflects the reality of using linear correction to correct animal-borne GPS fixes.

Though we used the median of the locational errors as an approximate estimator to compare the accuracy of the different methods, one must not lose sight of the fact that, in wildlife research, it is very often a single fix, and not the median of multiple fixes that is used to determine the animal's positions, resulting in even larger locational errors.

We therefore conclude that, because of the unpredictable outcome of the linear correction procedures, it is more appropriate to use raw GPS measurements, knowing that 95% of the positions are expected to fall within 100 m of the true planimetric location.

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