Averaging Absolute GPS Positionings Made Underneath Different Forest Canopies - A Splendid Example of Bad Timing in Research

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Abstract

Dealing with data collection of natural resources for management planning purposes, there is an interest in capturing the spatiality, i.e. the geographical location of the features of interest. The Global Positioning System (GPS) provides a tool, both for navigation and positioning, although not without limitations. Several sources of errors have impact on the positional accuracy. Differential GPS increases the accuracy but might in certain applications be unavailable. Navigating in difficult terrain (e.g. mountain areas), where traditional maps give little or no guidance, highlights the benefits of GPS. By applying a not-so-advanced algorithm, arithmetical averaging, using absolute (non-differential) GPS measurements, it is possible to improve the positional accuracy. Initial horizontal mean errors are decreased by 50% after approx. 10 minutes of active logging of singular GPS-positions and averaging these. Improvement of the accuracy continues thereafter, although substantial improvements require long time of observation. The impact of the canopy was marginal, however assumed to cause longer time of logging in dense forests before a certain number of positions are obtained, compared to measurements made under a clear sky. However, it must be pointed out that the results are of somewhat doubtful value, since the conditions were drastically changed when the intentional distortion of the GPS-signals (the Selective Availability, SA) was stopped. In the current situation, the different structure of the remaining errors leads to a limited use of averaging. This study was carried out just before the SA was stopped, which happened quite unexpectedly in May 2000.

Keywords: forest inventory, in field-applications, real time-solutions, spatial information.

Introduction

Forestry has an important spatial dimension, where both the product (the trees) and the production (the growth of the trees) take place over large geographical areas. By conducting inventories, the spatial structure of the forest can be determined or at least estimated. Perhaps obvious, it is crucial information if a specific tree (or group of trees, e.g. a forest stand) is close or far away from other trees, from harvest machines, from roads, from industries, etc. This is the case in many planning situations dealing with natural resources.

The introduction of the Global Positioning System (GPS) facilitated the work within many different activities. The system was developed by the U.S. Department of Defence, with one part available for civilian users (the Standard Positioning Service (SPS), the PPS (Precise-) only for military use among NATO allied). With satellites as reference points, continuously transmitting signals, it is fairly easy for a receiver to calculate its position by trilateration (not triangulation since no angles are used, only distances, i.e. the pseudoranges). However, positionings made with the GPS will include errors. The major source of error is put into the system by the system-administrator, the U.S. DoD. This intentional distortion goes under the name Selective Availability (SA). The remaining part of the errors (approx. 20%) stems from such sources as atmospheric disturbances, multipath-signals, and (orbit-, clock-) errors in satellites and receivers.

Almost simultaneously with the development of the GPS, the usability of differential GPS (dGPS) became obvious. A receiver placed at a known position can 'calculate backwards' and derive the error from a specific satellite at a specific time. Such information can later on be distributed and used to correct data collected by a receiver in field. Many countries, including Sweden, have established a permanent network of reference stations, collecting correction data for the GPS (in Sweden the SWEPOS-system, managed by the National Land Survey). A further advance of dGPS is a real time-solution, instantly transmitting correction data by radio link. In Sweden, this corresponds to the EPOS-system (managed by Teracom). A user will here need both a GPS and a RDS receiver (communicating with each other).

Within the Swedish environmental monitoring programme (e.g. Ståhl et al., 1999), field data will be collected in the mountain areas. Of interest is the position of the measured field plot as well as the possibilities to find the plots with co-ordinates decided in advance (sampled in a map as a frame) to be inventoried. Navigation in mountain areas are generally troublesome since identifiable landmarks are sparse and the terrain tends to look similar over large areas (both on the maps and in reality). The permanent GPS reference stations are mounted and available in more central regions. Even though correction data from nearby stations can be used in differential positioning by post-processing, any real time-solutions are nearly impossible since this correction data are transmitted from radio links, and these are even more centralised to certain parts of the country. Furthermore, the great fluctuations in elevation, with high mountains and deep valleys, will prevent the use of differential GPS in real time, also when slave transmitters are used to enhance (boost) the radio signals. To navigate to a specific position under the conditions described could be done by using averaged GPS measurements. A single, absolute (non-differential) GPS position is known to include rather large errors, approx. ±100 m. But since the errors are mainly random over time, averaging several GPS measurements made at the same location should improve the positional accuracy. A field inventory crew could navigate their way to a place somewhere near the plot centre to be found, stop and collect GPS data for some time and derive an averaged position from the data. The final navigation could be done with compass and measuring tape from the averaged co-ordinate to the theoretical position of the plot.

The objective of this study was to evaluate the usability of arithmetical averaging, with an increasing number of observations, when positionings were made with absolute GPS. Evaluations were made for GPS data collected underneath three different types of forest canopies; Clear sky, Medium density, and Dense canopy, studying any impact on the positional accuracies depending on these conditions.

The 1st of May 2000, in the middle of this study, the U.S. government declared that the intentional dimming of the civil part of the GPS (the SA) would be stopped with immediate action. At following midnight, the jamming of the satellite signals ceased. The decision was said to follow upon development of new technology, making it possible to block the improved service to regions of the world where the U.S. perceives a military threat. At the same time, the decision will influence the ongoing discussion about the construction of a European satellite positioning system. For all civil users, the loss of the SA is of positive nature. However, the usefulness of the results of this study becomes somewhat limited, since the error levels to a great extent will be shifted downwards. Moreover, the errors still affecting the system have a different structure, showing high temporal autocorrelation. Averaging as a means to increase positional accuracy hence becomes less useful.

Materials and Methods

Field data

The Swedish National Forest Inventory (NFI) yearly collects data by field measurements of a sample of approx. 10000 circular plots (Ranneby et al., 1987). Both temporal (7 m radius) and permanent (10 m radius) plots are used and inventories are carried out on several land use classes, not only forest land (potential productivity ≥1.0 $m^3ha^{-1}yr^{-1}$). Several different variables are measured, related to the trees and other vegetation, the site, the ground, the wildlife, etc. NFI data are used in estimates of the natural resources on the national and regional level. Since all trees on the plot are callipered, it is possible to calculate the basal area (m^2ha^{-1}). However, the basal area used in this study, as a measure of the density of the canopy, is estimated by the inventory crew using the relascope (Bitterlich, 1947). This will give a better impression of the canopy density in the surroundings of the plot centre and not only limited to the actual plot. Other factors than the basal area have impact on the canopy, e.g. crown structure, tree height, and tree species. Since the inventory is carried out during the growth season, all broadleaves can be assumed to be in full leaf-condition. Assuming the basal area to be a sufficient measure of canopy, plots were separated into three classes:

- Clear sky (basal area <1 m^2ha^{-1}),
- Medium density (1≤ basal area <20 m^2ha^{-1}),
- Dense canopy (basal area ≥20 m^2ha^{-1}).

To ensure a more or less homogenous canopy at each plot, divided plots (due to, e.g., two or more different land use classes or forest stand types at the same plot) were omitted from this study.

GPS data

In the Swedish NFI, plot centres are marked on maps and located in the field by using compass and measuring tape. It is of course possible that, in the future, the field crew will find their way to the plots by using the GPS (for navigation). Today, the GPS is used to derive accurate positions of the plots. One reason for positioning of NFI plots is to enable the use of the data as reference material in remote sensing applications (e.g. Nilsson, 1997). The GPS receiver (i.e. rover, here Trimble's GeoExplorer) is put on the plot centre (or in a canopy gap in the vicinity, noting the distance and direction to the plot centre - such plots were however omitted in this study) to collect GPS data while other variables are measured. A GPS receiver has the ability to make a positioning approx. each second, provided that signals from a sufficient number of satellites (usually four, three for the trilateration and the fourth to get the correct time) reach the receiver simultaneously. Other criteria before a positioning will be made (in the Swedish NFI) are:

- Position Dilution of Precision (PDOP) ≤6 (to ensure a satisfactory geometry, i.e. a constellation of satellites well distributed in space),
- Elevation Mask = 15° (to avoid satellite signals with a relatively long route of travel through the ionosphere/troposphere),
- Signal to Noise Ratio (SNR) Mask = 4 (to avoid satellite signals of low strength).

A singular positioning is often referred to as a fix. The instruction in the NFI is to do at least 40 fixes, with an interval of 5 s, at each plot. However, the receiver is often left logging more data than 40 fixes, depending on the time spent on collecting other plot data (and a non-limiting memory-space in the receiver). In this study, plots with GPS data with 240 fixes (every 5^{th} second, i.e. 20 min) or more were used. A total of 308 plots were available (140

(33094 fixes) from 1997 and 168 (39898 fixes) from 1998). In the three canopy classes, the plots were separated and with number of observations, *n*, according to:

- $n = 134$ in Clear sky (average basal area = 0.0 m^2ha^{-1}),
- $n = 90$ in Medium density (average basal area = 13.2 m^2ha^{-1}),
- $n = 84$ in Dense canopy (average basal area = 26.7 m^2ha^{-1}).

The plot centre co-ordinates were derived by post-processing of differential GPS data (e.g. Hurn, 1989; 1993). These positions were, in the following analyses, regarded as true values, although known to show standard errors in the horizontal plane of 2-3 m (e.g. Deckert and Bolstad, 1996; Næsset, 1999). For the dGPS, correction data from the nearest of the 20 permanent reference stations (i.e. base stations) in Sweden were used. Post-processing was performed using the Pathfinder software. In Figure 1, the centre co-ordinates of the plots are shown. Superimposing the borders of Sweden, the lack of plots in the mountain areas can be seen, as well as the more sparse sample of plots in the northern parts compared to the south of Sweden. The lakes Vänern and Vättern and adjacent agricultural land appear as blank spots. One plot appears on the island of Gotland.

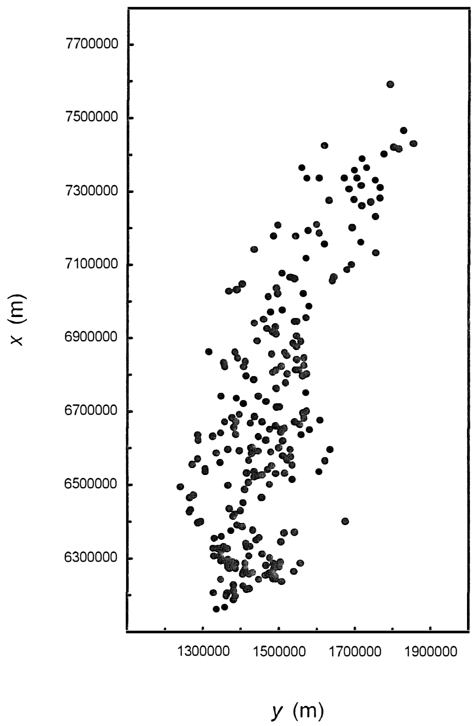

Figure 1. Plot centre co-ordinates, $n = 310$. Latitude (x) and longitude (y) in the Swedish National Grid (RT90).

Estimations

Arithmetic averaging to improve positional accuracy is a possibility when several fixes have been made at same location (e.g. Scrinzi et al., 1999). The method can be applied also in real time-solutions, by simple algorithms built in the GPS receiver. Absolute GPS fixes are used in this study to estimate a position by means of growing averages. For a certain plot centre, the first co-ordinate $\{x_t, y_t\}$ is derived at the time t equal to 0 s. For each plot, a sequence of co-ordinates will follow with t = 0, 5, 10, 15, ..., T since the interval between fixes was set to 5 s.

For all plots, T was at least 1200 s (20 min). It should, however, be observed that a new fix was not always obtained at every t (due to lost satellite-tracking etc.). In such cases, the co-ordinates for the previous fix were used, i.e. $\{x_t, y_t\} = \{x_{t-5}, y_{t-5}\}$. Arithmetical average co-ordinates were calculated for each plot at each time, t >0 s, from the absolute GPS positions (the fixes), in Northing and Easting respectively, i.e. $\{\bar{x}_t, \bar{y}_t\}$.

Evaluations

By regarding the post-processed, differential GPS position $\{x', y'\}$ at the plot centre as a true value, a horizontal deviation Δ was calculated at t = 0, 5, 10, ..., T for each plot according to:

$$\Delta_t = \sqrt{(\bar{x}_t - x')^2 + (\bar{y}_t - y')^2} \qquad (1)$$

Within each canopy-class separately, a horizontal mean error $\bar{\Delta}$ was calculated according to:

$$\bar{\Delta}_t = \frac{1}{n}\sum_{i=1}^{n} \Delta_{t,i} \qquad (2)$$

where n is the number of observed deviations at a specific time t in each class (i.e. 134, 90, and 84, respectively). Here, the errors correspond to horizontal deviations. The GPS estimates the position in three dimensions, i.e. also in the vertical direction (the z co-ordinate). If the deviation in z should have been included, the total errors would have increased, especially since errors in z usually are approx. twice as large as those in x and y (e.g. Sundberg, 1996).

As supplementary information, the standard deviation of the horizontal deviations at each time t was calculated according to:

$$Std_t = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n} \left(\Delta_{t,i} - \bar{\Delta}_t\right)^2} \qquad (3)$$

Results

The horizontal mean errors ($\overline{\Delta}$) in averaged absolute GPS positions at increasing time t for the three different canopy-classes are presented in Figures 2, 3, and 4. Only minor difference between the different classes can be observed. However, the Clear sky-class shows a more smooth decrease of the errors compared to the Dense canopy-class. Improvements of the positional accuracy by averaging continues to take place after t = 600 (10 min), although not with the same speed as between 0 and 600 s.

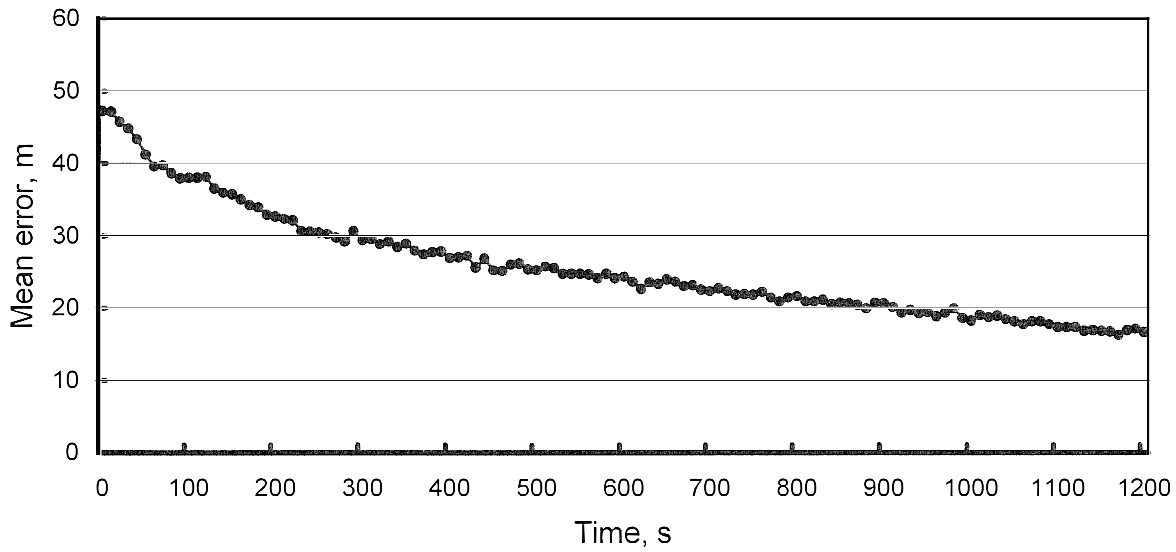

Figure 2. The horizontal mean errors $\overline{\Delta}$ (in meters) after averaging at increasing time t (in seconds) for the Clear sky-class.

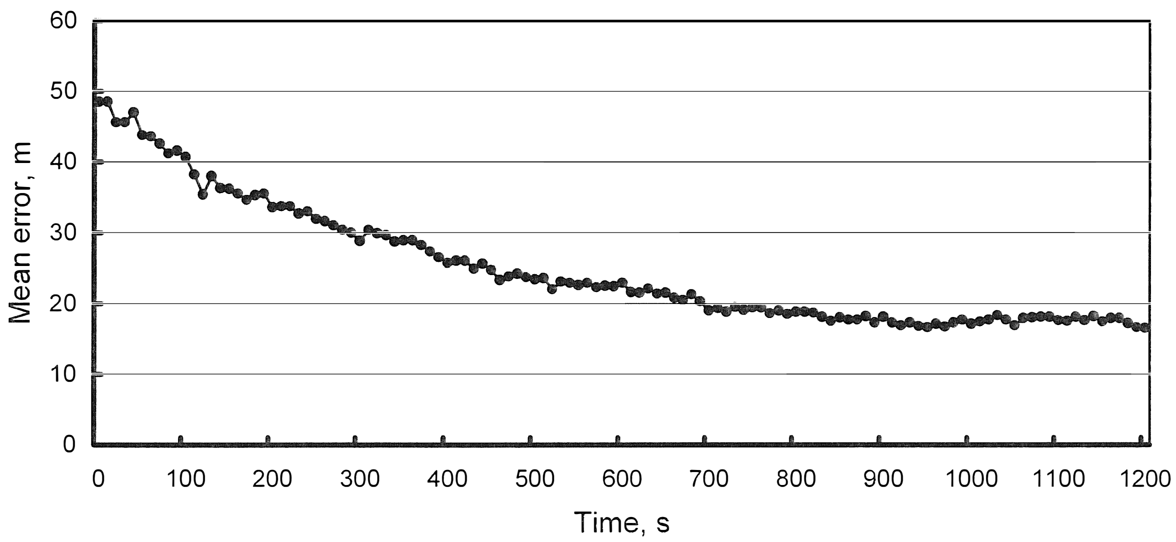

Figure 3. The horizontal mean errors $\overline{\Delta}$ (in meters) after averaging at increasing time t (in seconds) for the Medium density-class.

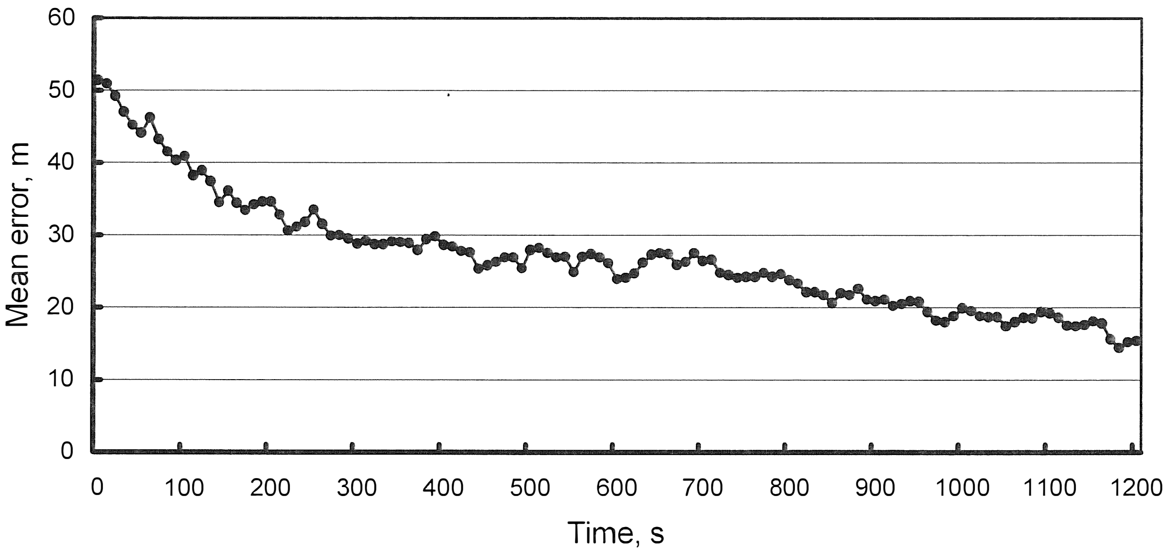

Figure 4. The horizontal mean errors $\overline{\Delta}$ (in meters) after averaging at increasing time t (in seconds) for the Dense canopy-class.

In Table 1, mean errors at different times t are presented for the three canopy-classes. The mean error at $t = 0$ is 4.2 m higher for the Dense canopy-class that the corresponding error for the Clear sky-class. However, averaging GPS positions to improve the accuracy is more efficient in the Dense canopy-class. The initial errors (at $t = 0$) are halved after 610 seconds (10.2 min) for the Clear sky-class, after 460 s (7.7 min) for the Medium density-class, and after 440 s (7.3 min) for the Dense canopy-class. The standard deviations (in average, 65% of the mean errors at $t = 0$ s and 61% of the mean errors at $t = 1200$ s) indicates a rather large variation among the horizontal deviations at a certain plot.

Table 1. Mean errors ($\overline{\Delta}_t$) and standard deviations (Std_t) for the three canopy-classes at different times t of averaging.

	$\overline{\Delta}_t$ (Std_t), m		
Time, s	Clear sky	Medium density	Dense canopy
$t = 0$	47.2 (36.3)	48.5 (27.6)	51.4 (30.5)
$t = 300$	29.3 (18.6)	28.8 (18.8)	28.8 (16.9)
$t = 600$	24.3 (16.6)	22.9 (15.3)	23.9 (11.5)
$t = 1200$	16.6 (10.1)	16.5 (10.9)	15.4 (8.7)

Discussion

Working in the field, real time-solutions are sometimes a necessity, considering, e.g., a specific object (a plot, a tree, a stand border, etc.) that needs to be found or a boundary of a certain area (a key habitat reserve, etc.) that needs to be located. Several studies evaluating the usability of GPS in such situations have been performed (e.g. Hellström, 1993; Hellström and Johansson, 1993; Bondesson et al., 1998), but almost always depending upon differential GPS. It has been stressed that correction data for GPS are not always available, hence field inventory crews might be restricted only to absolute (non-differential) GPS positions. The possibility to improve positional accuracy by averaging has been shown in this study. Some 5 to 10 minutes of active logging of GPS positions will narrow down the error of the current position with approx. 20 meters. The impact on the positional accuracy caused by a forest canopy was insignificant in this study, although measurements made under a dense canopy showed greater fluctuations compared to GPS data collected under clear skies. Stems and branches will probably be obstacles in establishing contact with the GPS satellites, but once this is obtained the positional accuracy is only marginally affected (cf. Sigrist et al., 1999).

The idea of averaging absolute GPS fixes to obtain an accurate position is based on the assumption that errors mainly are random over time. The dominant (approx. 80%) source of error was the Selective Availability (SA) distortion intentionally added to the system. Any systematics in the SA would have facilitated decoding and therefore this error had an 'unbreakable', random pattern. Nowadays, the errors are primary caused by atmospheric disturbances of the satellite signals. Figures 6, 7, and 8 are reprinted with kind permission from SWEPOS Control centre (values on the horizontal axes hardly visible, although the full length represent 24 hrs, from midnight to 23:59:59). These figures are based on GPS data from the same day as when the SA was stopped, at five o'clock in the morning (local Swedish time). It can be seen that the remaining errors in the GP system are heavily autocorrelated. Positive deviations can occur for hours (and vice versa for negative deviations). Averaging measurements for some 10 to 20 minutes will maybe help us from obtaining extreme outlier-values but the improvement of positional accuracy is limited.

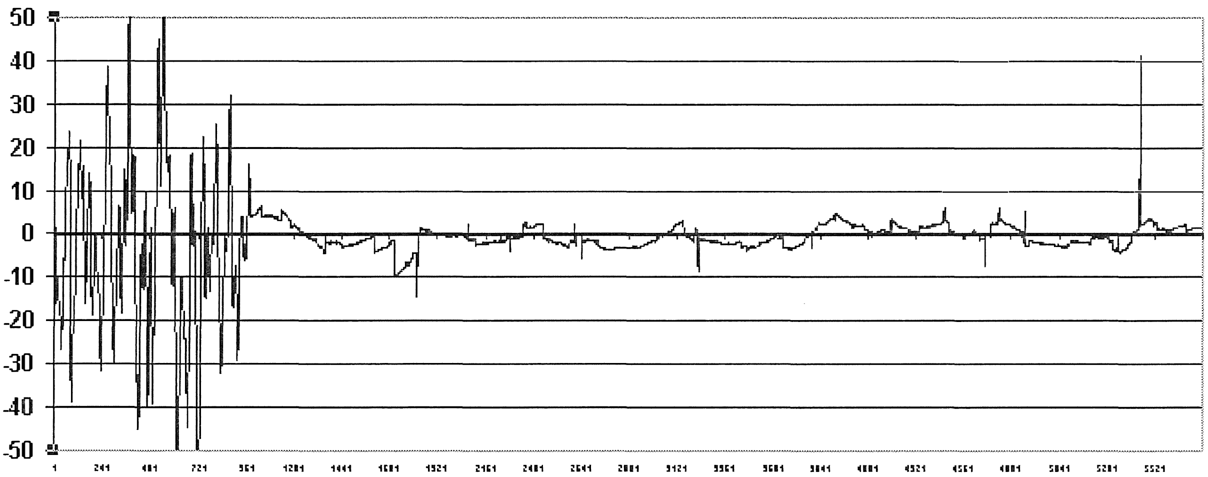

Figure 6. Deviation (in meters) in x co-ordinate (latitude) during May 2nd, 2000 (24 hrs) at Onsala reference station. At approx. hr 05:00 the SA was disabled.

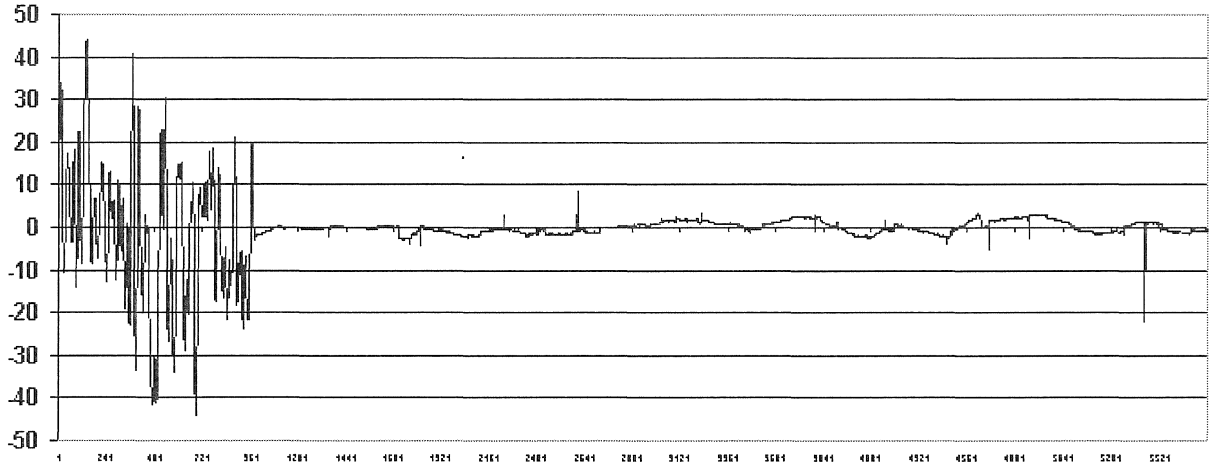

Figure 7. Deviation (in meters) in y co-ordinate (longitude) during May 2nd, 2000 (24 hrs) at Onsala reference station. At approx. hr 05:00 the SA was disabled.

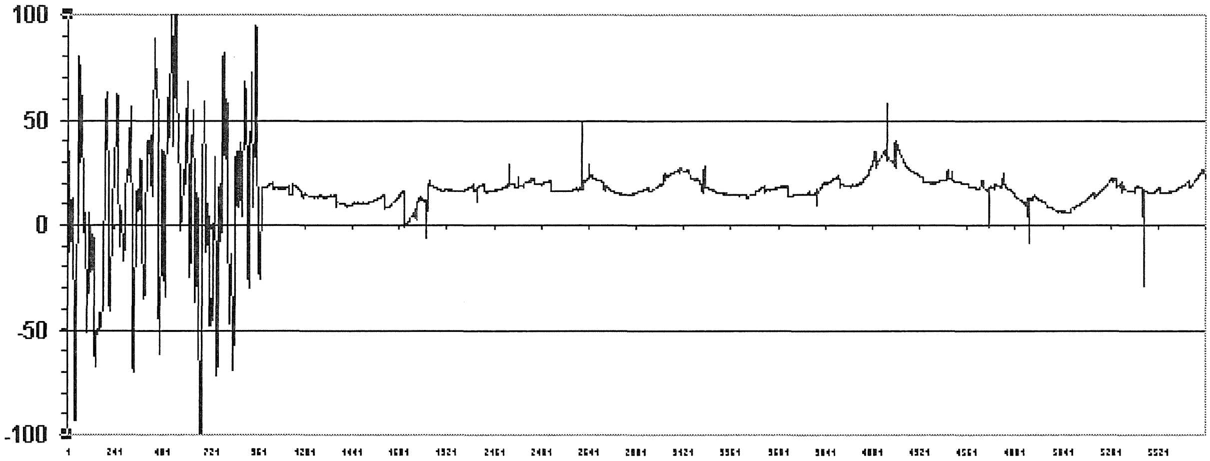

Figure 8. Deviation (in meters) in z co-ordinate (altitude) during May 2nd, 2000 (24 hrs) at Onsala reference station. At approx. hr 05:00 the SA was disabled.

A common way of handling errors caused by the atmosphere in GPS is by constructing models. The basic idea with GPS is to measure the time is takes for the signals to go from satellite to receiver. Multiplying the time with the velocity gives the distances (pseudoranges). The velocity is a constant, i.e. the speed of light, but only for radio waves passing through vacuum. The atmosphere (with, e.g., charged particles and water vapour) will slow the satellite signals and this is compensated for by construction of atmosphere-models. The models are then used to determine a more correct velocity. The true atmospheric conditions are likely to deviate from the models. Such deviations might be local, both in space and time, and hence causing systematic errors to the GPS positionings.

If averaging of absolute GPS was to be used, this should be done in combination with some sort of filter. Extreme outlier-values can be seen as peaks in Figures 6, 7, and 8. A simple filtering is achieved by calculating standard deviations in x and y, simultaneously with the averaged values. Then, after a certain number of fixes have been obtained, single positions deviating more than, e.g., 2 standard deviations from the mean co-ordinate are disregarded. No tests of filtering GPS data were, however, performed in this study. When the SA distortion was stopped, radically changing the scene, further investigations appeared as superfluous.

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Adequate information has been found on the following homepages:
http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
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