Seasonal variation of global positioning system (GPS) accuracy within the Tokyo University Forest in Hokkaido

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Introduction

Researchers have been conducting long-term and large-scale experiments of the stand-based forest management system (SFMS) at the Tokyo University Forest in Hokkaido since 1958. The idea behind the SFMS is that forest management should be adaptive to the conditions of each stand for maximizing multiple public and economic functions of forest ecosystems (Takahashi, 2001). A natural forest can be classified into several stand types according to the difficulty of natural regeneration, site conditions, and timber quality (The Tokyo University Forest in Hokkaido, 1997). In-depth ground surveys are essential for stand classification. At the Tokyo University Forest, surveying has been conducted using a pocket compass with a measuring rope. Although this method is reasonably accurate, it requires much time and effort. Therefore, new surveying technology with high accuracy and labor economy is necessary for maintaining the SFMS experiments.

The Global Positioning System (GPS) is a useful tool for forest surveys (Tsuyuki et al., 2006). Each GPS satellite transmits a coded signal. A GPS receiver receives the signal and uses the code to determine its distance from the satellite. If the distances from a single point in the forest to four different satellites can be measured simultaneously, the receiver can calculate its precise position in real time. Because a traverse survey using GPS does not accumulate positional errors, it is a suitable method for mapping large areas (Tachiki et al., 2004). GPS has been utilized in the University Forest since 1995. However, its use has been limited to the establishment of reference points for compass traverse surveys. Prior to the adoption of GPS traverse surveys as an alternative to the conventional system, their applicability and expected positioning accuracy should be carefully examined.

Although we previously evaluated the positioning accuracy of portable GPS receivers in the University Forest in summer (Oikawa et al., 2008), ground-based forest surveys are normally conducted in winter when thick lower vegetation (e.g., *Sasa* spp.) is covered by snow. Defoliation may affect GPS signal reception and positioning accuracy (Sigrist et al., 1999; Tachiki et al., 2005).

Therefore, to evaluate the positional accuracy in the defoliated season, we conducted field tests at the same ten points with the same GPS receivers in both summer and winter. We compared the positioning accuracy in the two seasons. On the basis of the results, we discuss practical guidelines for GPS surveys in the University Forest.

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Materials and methods

Study site

   The field tests were conducted during mid-July and mid-December of 2007 in sub-compartment 13A of the Tokyo University Forest in Hokkaido (43º17'N, 142º36'E, 590–620 m a.s.l.). Our study site (Fig. 1) was located on a steep, north-facing slope with a slope angle of approximately 30º. Measurements for the field tests were taken at ten positional points. The points were located on a forest road. Intervals between points were 20–75 m, and the overall length was 390 m. The sky over all points was primarily obscured in summer by the natural, mixed forest coniferous and deciduous tree canopies that dominated the study site; in winter, the broadleaved trees were defoliated.

Data collection

   Two types of GPS receivers were tested (OIKAWA *et al.*, 2008): MobileMapper Pro (Magellan Navigation, Inc., CA, USA) and GPSMAP 60CSx (Garmin Ltd., KS, USA). Both receivers are small, handy, and easy to use; these features are suitable for forest traverse surveys (TSUYUKI *et al.*, 2006). MobileMapper Pro has a post-processing option for differential correction. According to the product specifications, this allows for sub-meter (<1 m) accuracy. The GPSMAP 60CSx is equipped with the high-sensitivity GPS chipset of SiRFstar III (SiRF Technology, Inc., CA, USA) that allows for relatively easy GPS signal reception in a forested area (TSUYUKI *et al.*, 2006). Even though differential correction by post-processing is not possible, the specifications for the
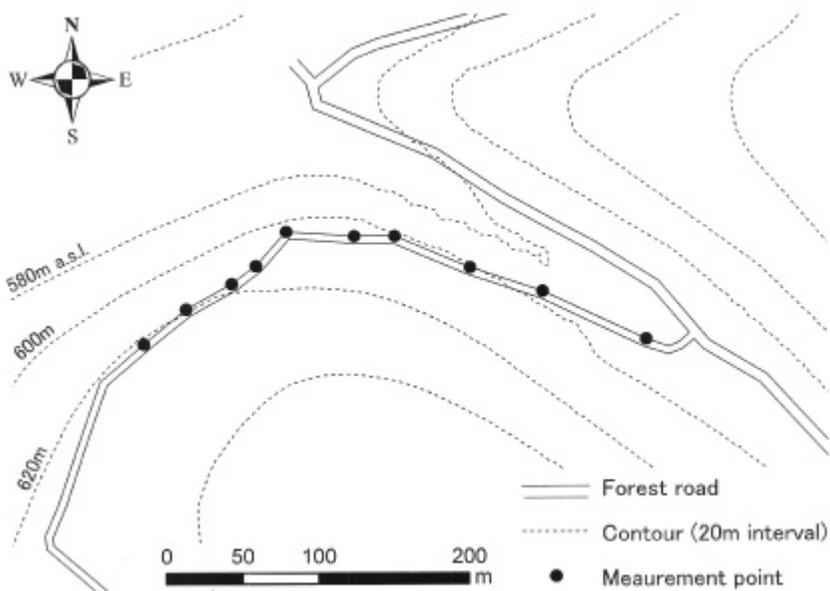

Fig. 1.   Study site.

GPSMAP 60CSx claim that its positioning accuracy can be within 5 m after real-time correction using the multi-functional transport satellite (MTSAT)-based satellite augmentation system (MSAS).

The field tests were conducted using two MobileMapper Pro receivers (with external antenna) and one GPSMAP 60CSx receiver and logging positions at an interval of 1 sec.. The durations of observation were 30 and 120 sec. for the MobileMapper Pro receivers and 30 sec. for the GPSMAP 60CSx receiver. Each point location was averaged over time. With all the GPS receivers, the data were collected at a standard height of 1.8 m above the ground surface. Prior to the field tests, the number of visible GPS satellites was predicted using almanac data. In each season, all points were measured three times in one day, when the satellite visibility was relatively good, moderate, and poor. All data from the MobileMapper Pro receivers were post-processed using MobileMapper Office software. The observation data from the nearest GPS-based control station (Minami-Furano) at a distance of approximately 13 km south of the study site was used for differential correction. The MSAS real-time correction option was enabled for the GPSMAP 60CSx receiver.

The canopy condition above each point was measured using hemispherical photography at a 1.8 m height, with a COOLPIX 880 digital camera and a FC-E8 fisheye converter (Nikon Corporation, Tokyo). Canopy openness (%) was then computed using imaging software Gap Light Analyzer version 2.0 (FRAZER *et al.*, 1999).

Data analysis

GPS positional errors were calculated by the following equation (OIKAWA *et al.*, 2008):

$$d = \sqrt{(X_{true} - X)^2 + (Y_{true} - Y)^2} \tag{1}$$

where d : positional error (m)
             X, Y : measured X, Y coordinates
             X_{true}, Y_{true} : true X, Y coordinates

The true coordinates were obtained through a static GPS survey with a ProMark 3 receiver (Magellan Navigation, Inc., California). All points were surveyed in mid-July and then post-processed using GNSS Solutions software. The data from three GPS-based control stations (Furano, Kami-Furano, and Minami-Furano) of the Geographical Survey Institute were used for the baseline analysis. Although only one point indicated a fixed solution, the mean positional errors calculated by the software were 11.3 cm (0.2–18.1 cm).

We employed three-way analysis of variance (ANOVA) to identify the factors that affect GPS positioning accuracy. The dependent variable was the GPS positional error (d), to which the Box-Cox transformation was applied to normalize the values and to adjust the variances before carrying out the three-way ANOVA (TACHIKI *et al.*, 2004). The independent variables were season (summer or winter), receiver setting (MobileMapper Pro with 30 or 120 sec. observation, or GPSMAP 60CSx with 30 sec. observation), and satellite visibility, classified as good, moderate, or poor.

Table 1. Summary of the three-way ANOVA

Source of variation	Sum of squares	*df*	Mean square	*F*-statistic	*p*-value
Season (S)	6.808	1	6.808	9.841	0.002
Receiver setting (RS)	3.101	2	1.550	2.241	0.110
Satellite visibility (SV)	0.407	2	0.203	0.294	0.746
S x RS	3.665	2	1.833	2.649	0.074
S x SV	0.030	2	0.015	0.022	0.979
RS x SV	2.195	4	0.549	0.793	0.531
S x RS x SV	13.801	4	3.450	4.987	0.001
Error	112.080	162	0.692		
Total	142.087	179			

Results

For all of the measurements (n = 180), signals from GPS satellites were received sufficiently. Using the MobileMapper Pro receiver, the mean position dilution of precision (PDOP) values were 3.5 in summer and 2.4 in winter, and the differential correction by post-processing was successfully completed. The GPSMAP 60CSx receiver succeeded in real-time correction using the MSAS for 20% of the measurements in both seasons.

Table 1 presents a summary of the three-way ANOVA results. The GPS positional errors were significantly affected by season ($p < 0.01$), while the main effects by receiver setting and satellite visibility were not significant. The interaction of season, receiver setting, and satellite visibility was also found to be significant ($p < 0.01$).

Figure 2 shows the mean GPS positional errors for three receiver settings in summer and winter. The positioning accuracy of two receiver settings (MobileMapper Pro with 120 sec. observation and GPSMAP 60CSx with 30 sec. observation) was significantly improved in winter, and the mean positional errors were 3.0 m and 3.6 m, respectively. Although the positional errors for the MobileMapper Pro receiver with 30 sec. observation were significantly lower than the other two receiver settings in summer ($p < 0.05$, Fisher's LSD test), no significant differences were found between any receiver settings in winter.

Figure 3 shows the mean GPS positional errors for three satellite visibility conditions. The positioning accuracy under moderate and poor satellite visibility was significantly higher in winter, and the mean positional errors were 3.2 m for both visibility settings. In both seasons, we found no significant differences between any satellite visibility conditions.

Figure 4 shows the mean canopy openness of the ten measurement points. The 24.1% canopy openness in winter was significantly higher than the 12.0% canopy openness in summer. Figure 5 presents the relationship between canopy openness and positioning accuracy. Compared to the measurements in summer, the positional errors were less scattered in winter. We observed a significant negative correlation ($r = -0.32$) between canopy openness and positional error ($p < 0.05$).
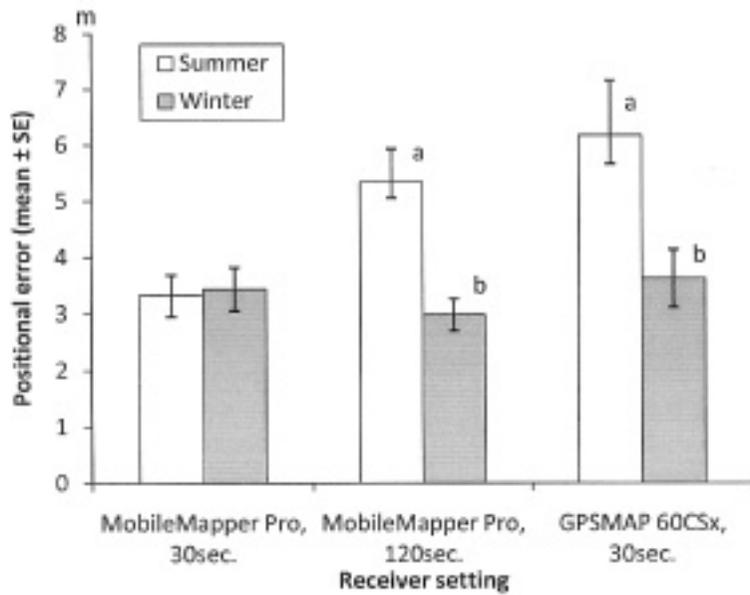
Fig. 2.   GPS positioning accuracy by receiver setting in summer and winter. Means followed by different letters differ significantly according to Welch's t-test (p < 0.05).
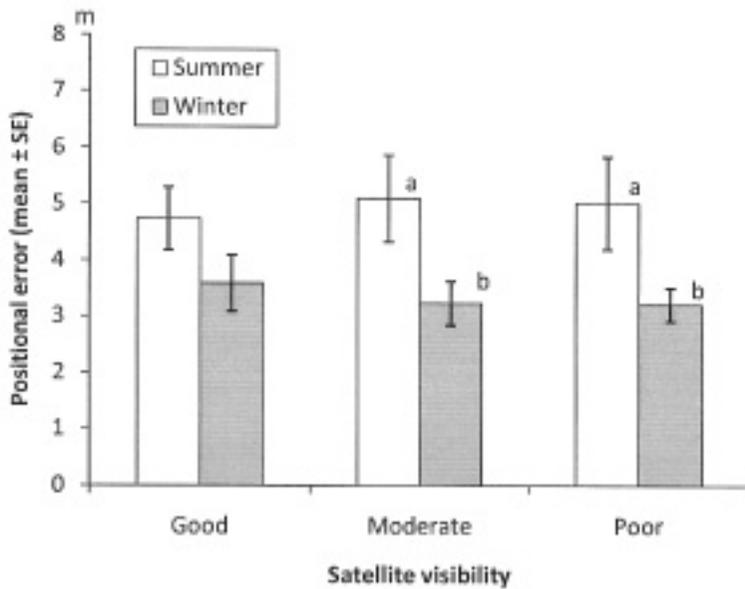

Fig. 3.   GPS positioning accuracy by satellite visibility in summer and winter. Means followed by different letters differ significantly according to Welch's t-test (p < 0.05).

Discussion

Our results indicated that seasonal variation was a significant factor for determining the accuracy of GPS measurements. Additionally, the lower frequency of positioning errors in winter agreed with the results of SIGRIST *et al.* (1999) but disagreed with the findings of TACHIKI *et al.* (2005) who reported fewer positional errors in the summer. In the present study, the openness of the forest canopy above the measurement points doubled following defoliation. We attributed the increased positioning errors to multi-path effects produced by the presence of foliage between the measurement point and the satellite (SIGRIST *et al.*, 1999). Consistent with this idea, GPS forest surveys conducted during winter resulted in fewer irregular measurements (Fig. 5). Therefore, to avoid multi-path effects and improve the regularity and accuracy of GPS measurements, ground surveys in forests should be performed during defoliated periods such as winter.

Fewer multi-path effects attributed to the presence of summer foliage were observed with the MobileMapper Pro than with the GPSMAP 60CSx, while in winter both GPS receivers performed equally well. The least expensive receiver was the GPSMAP 60CSx, but we preferred the MobileMapper Pro because more stable measurements (i.e., smaller standard errors) were obtained using this receiver (Fig. 2).

When using MobileMapper Pro in summer, 30 sec. observations provided better positioning accuracy than did 120 sec. observations, while in winter positional errors were unaffected by the observation time. Considering operational efficiency for forest surveys, 30 sec. observation is probably sufficient for stand classifications.
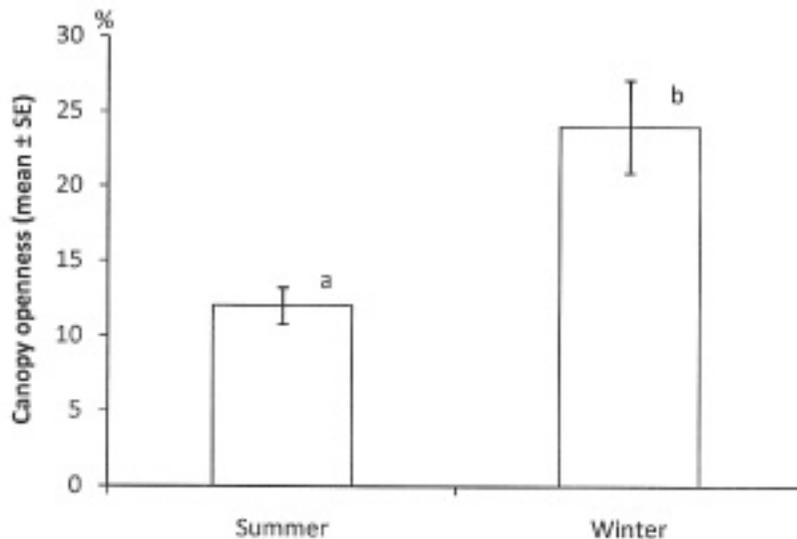

Fig. 4.   Canopy openness above measurement points in summer and winter. Means followed by different letters differ significantly according to Welch's t-test (p < 0.01).

Satellite visibility did not affect positioning accuracy in summer or winter (Fig. 3) most likely because signals were received from at least five satellites even in times of poor visibility. Since satellite visibility was not a significant factor for positioning accuracy, we suggest it may have been an irrelevant factor in this study.

Finally, satellite signal reception by both GPS receivers used in this study was successful for all of the measurements even though some measurement points were located on a steep, north-facing slope. This was not the case in the study by SIGRIST *et al.* (1999), where the presence of the forest canopy actually blocked reception of GPS signals in some cases. Positioning accuracy aside, both the MobileMapper Pro and the GPSMAP 60CSx receivers were considered to be usable for most areas in the University Forest System in Hokkaido.

Conclusions

Based on the results and discussion, the following suggestions should be considered when planning GPS traverse surveys under a forest canopy: 1) Winter or times of defoliation are the best periods for accurate positioning measurements. 2) Observation times of 30 sec. using the MobileMapper Pro receiver are the best alternative for summer or periods of foliation. 3) Satellite visibility is not a reliable indicator of positioning accuracy for either the MobileMapper Pro or the GPSMAP 60CSx GPS receiver. This study compared the positioning accuracy of two handy GPS
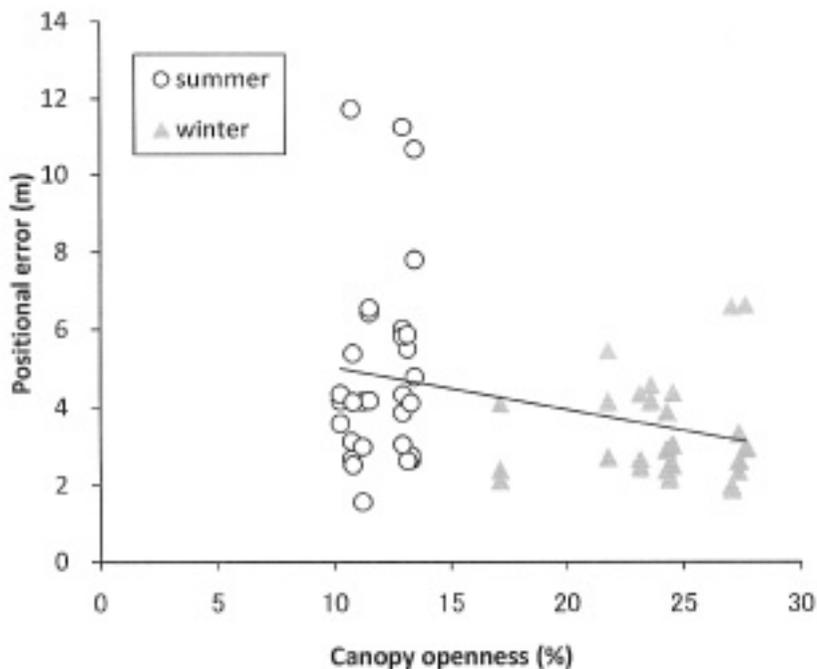

Fig. 5.　Relationship between canopy openness and GPS positional errors. Each dot indicates the mean error of three repetitions by the same receiver setting with different satellite visibility conditions.

receivers in summer and winter. Because the performance of GPS receivers continues to improve drastically, ongoing field tests of new GPS receivers are needed for maintaining and improving the stand-based forest management system in the Tokyo University Forest in Hokkaido.

Acknowledgements

Summary

In-depth forest ground surveys are indispensable for experiments on the stand-based forest management system at the Tokyo University Forest in Hokkaido. The Global Positioning System (GPS) offers an innovative surveying technology with high accuracy and labor economy. This study compared the positioning accuracy of handy GPS receivers in summer and winter to obtain practical suggestions for the use of GPS in ground-based forest surveys. In July and December 2007, field tests measured the positions of ten points under the forest canopy with two GPS receivers (MobileMapper Pro and GPSMAP 60CSx). Three-way ANOVA was employed to identify factors that affected positioning accuracy. Results indicated that the season was a significant factor for the GPS measurements. Relatively few GPS positional errors were observed during winter. The presence of foliage probably negatively affected positioning accuracy. Among the receiver settings tested, the MobileMapper Pro receiver with a 30 sec. observation time seemed to be a reasonable choice. Despite the severe terrain on which our measurement points were located, both GPS receivers had good satellite signal reception. We concluded that both the MobileMapper Pro and the GPSMAP 60CSx were suitable receivers for GPS survey applications in most areas of the University Forest.

Key words: Canopy openness, Defoliation, Forest survey, Handy GPS receiver, Positioning accuracy

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東京大学北海道演習林における GPS 測位精度の季節変動

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要　　　旨

　東京大学北海道演習林における林分施業法の実験では，詳細な現地森林測量が不可欠となっている。全地球測位システム（GPS）は高精度化と省力化とを可能にする革新的な測量技術である。森林測量に GPS を利用する際の実践的な示唆を得るため，本研究では夏季と冬季における携帯型 GPS 受信機の測位精度について比較を行った。2007 年 7 月と 12 月に林冠下の 10 測点を 2 機種の GPS 受信機（MobileMapper Pro および GPSMAP 60CSx）で測位した。GPS の測位精度に影響を及ぼす要因を明らかにするため，三元配置の分散分析を行った。分析の結果，季節が有意となり，測位誤差は冬季においてより小さくなった。林冠の落葉によって測位精度が改善されたためと推察される。本研究で試験を行った測位方法のなかでは，MobileMapper Pro で 1 測点につき30 秒間測位する方法が適当と考えられた。地形的に測位が困難な条件下ではあったが，衛星からの電波は問題なく受信できたことから，両機種とも同演習林内のほとんどの場所で利用が可能と思われる。

　キーワード： 開空率・落葉・森林測量・携帯型 GPS 受信機・測位精度