Seasonal Effecf of Tree Foliage *on GPS Signal Availability and Accuracy for Vehicular Navigation*

G. Lachapelle J. Henriksen, and T. Melgard

Department of Geomatics Engineering
The University of Calgary

ABSTRACT

The seasonal effec! of deciduous tree foiiage on GPS signal availibility and accuracy for vehicular navigation is investigated. GPS signals in the upper UHF part of the spectrum are line-of-sight and suffer much attenuation under tree branches and their leaves. An important question is to whether significant variations will occur between seasons due to the presence or absence of deciduous foliage. Two types of performance variaticns are investigated, namely signal availability and accuracy. In the presence of leaves, signal availability is expected to decrease. Since multipath is expected to increase, accuracy is expected to decrease as well. In order to investigate this aspect and possible correlation with different receiver technologies tests were conducted at normal cruising speeds along selected tree-lined streets of Calgary under both seasonal conditions with multi-channels wide and narrow correlator spacing C/A code receivers. Tine tests were conducted in DGPS mode to assess effectively repeatable positioning accuracy. Test results are presented and analysed. They reveal that the effec! of foliage on signal availability is a function of the number of channels available and, to some a lesser extent, on receiver characteristics. Foliage is also found to have a significant effect on positioning accuracy. Narrow correlator spacing technology produces significantly better positioning accuracy under foliage conditions due to its better multipath rejection capability.

INTRODUCTION

GPS signals, in the upper part of the UHF range, propagate in straight line and thus provide the user with a high level of accuracy. An important propagation limitation in that part of the electromagnetic spectrum however is very rapid attenuation due to signal masking. Foliage constitutes one type of masking which is especially important and interesting. It is important because of the potential of GPS for vehicular navigation in urban areas. The question is also interesting because foliage does not mask signals completely. A single tree leaf is sufficiently thin to allow some signal to go through and reach the antenna underneath. In addition, if the antenna is moving, unobstructed line of sight between leaves will generally be achieved for very short (<1 s) period of time. The overall consequences on satellite availability, signal quality and ultimately, on positioning accuracy will be a function of parameters such as

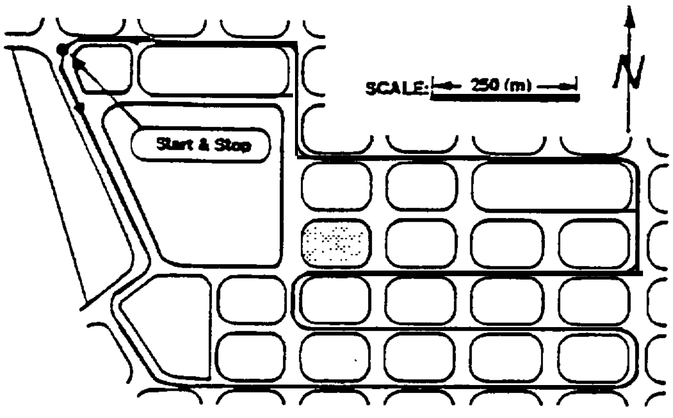
- thickness of leaves and branches
- density of foliage
- humidity
- season in the case of deciduous trees
- number cf GPS receiver channels
- tracking loop robustness
- code accuracy
- re-acquisiticn time

The purpose of this investigation is to analyse the above parameters, while focusing on two specific objectives. The first is to assess the impact of deciduous foliage on signal availability and accuracy and the second to intercompare various C/A code receiver types. The above parameters will be examined through an analysis of the following measurable or derivable quantities obtained through a series of DGPS field tests conducted with several receivers under spring and summer conditions

- code
- carrier phase
- HDOP
- trajectory across-track and height accuracy
- least-squares range errors

METHOOOLOGY

A series of vehicular tests was conducted in Calgary on April 20, June I and June 17, 1994, along selected tree-lined streets in a residential area of Calgary as shown in Figure I. A mixture of 10 to 20 m high evergreen and deciduous trees lined the 5km trajectory which was successively driven five times during each test. Repeating the same trajectory several times enables one to examine the repeatability of the GPS-derived trajectories.



5-km Trajectory Selected for Field Tests
FIGURE 1

The masking angle of the top of the trees varied between 20' and 40' across track. The deciduous trees consisted mostly of elms and birches. During the April test, the leaves on the deciduous trees were not out. During both June tests, the foliage was mature. June 1 was a RAINY day while June 20 was dry. All three tests were time synchronized so that the same satellites in approximately the same positions were observed in order to eliminate constellation geometry effects. Nine satellites above the horizon were available during the period selected and the theoretical PDGP was c 3.

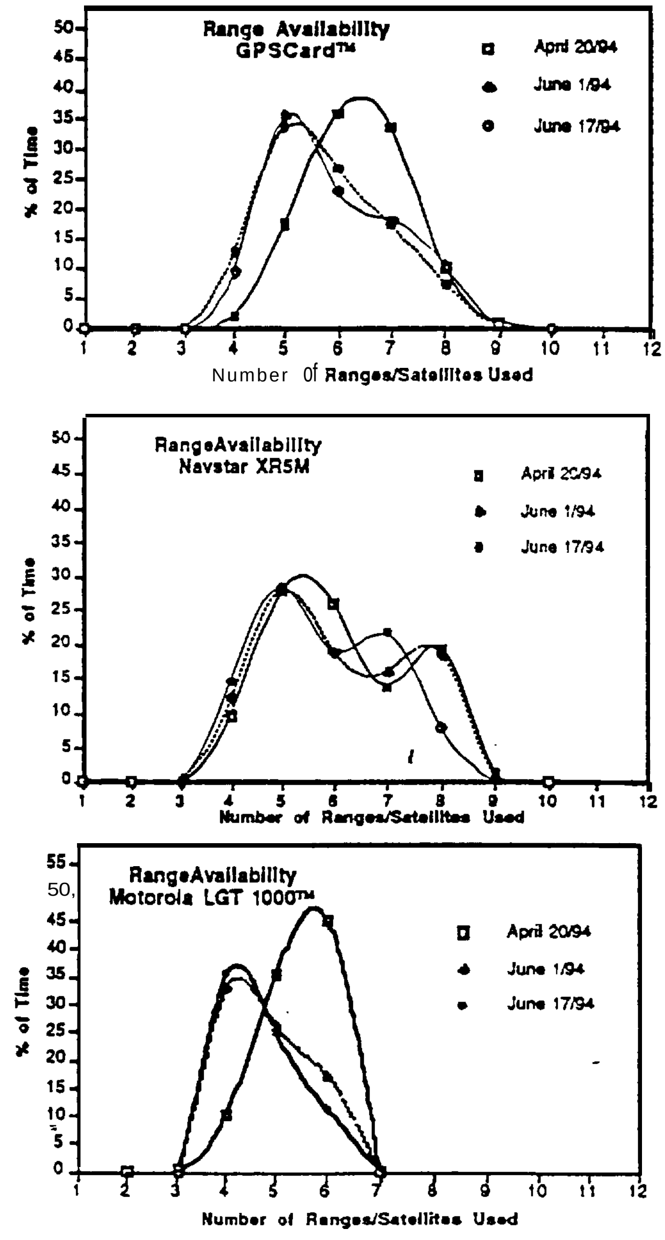
All tests were conducted in DGPS mode and the reference station-s were located a few km away on an unobstructed section of the Engineering building roof of The University of Calgary. The driving speed varied between 30 and 60 km h^{-1} and the driving of the 5-km trajectory five times during each test required approximately 50 minutes. The following three receivers were used simultaneously, each one with its own manufacturer's antenna:

- Type #1: Wide correlator spacing all-in-view C/A code LI receiver, namely the 12-channel Navstar XR5M.
- Type #2: Wide correlator spacing 6-channel C/A code LI receiver, namely the Motorola LGT 1000™ which is equipped with a PVT-6 engine.
- Type #3 Narrow correlator spacing all-in-view C/A code LI receiver, namely the lo-channel NovAtel GPSCard™ 951 R.

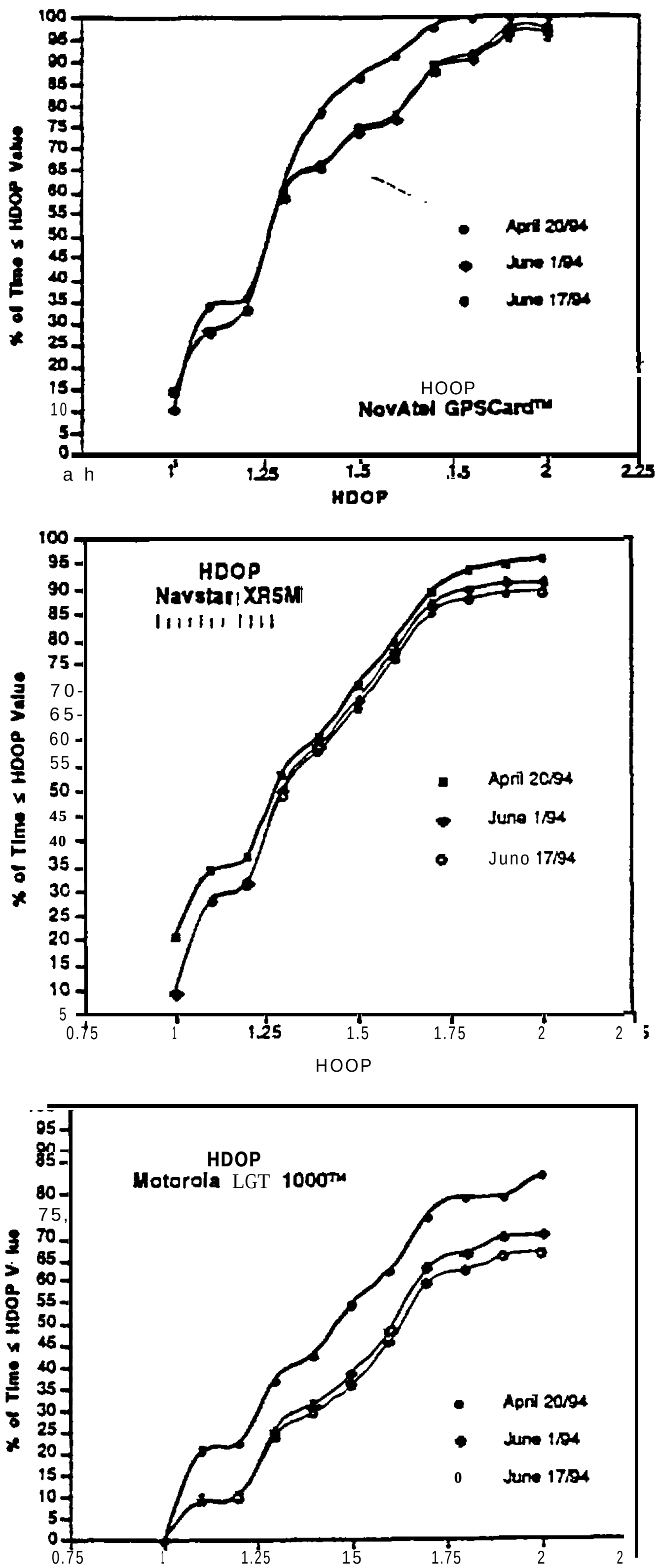
During the June 17 test, another Type #1 receiver was added for intercomparison purpose, namely the 12-channel C/A code LI Magnavox 9212. All the antennas were mounted on the roof of a passenger vehicle and were therefore exposed to practically the same masking and multipath conditions.

RESULTS AND ANALYSIS

The range availability during each test was obtained for each one of the first **three receiver types used.** The results are shown in Figure 2 The **noncumulative percentage of time a** given number of ranges/satellites are available is shown. **The effect of the** deciduous foliage is clear Range availability is superior in all cases during the April 20 test prior to foliage growth. For each receiver, the availability is about the *same* during the June 1 and 17 tests. The high level of humidity caused by the rain on June 7 therefore had no significant effect in this case.



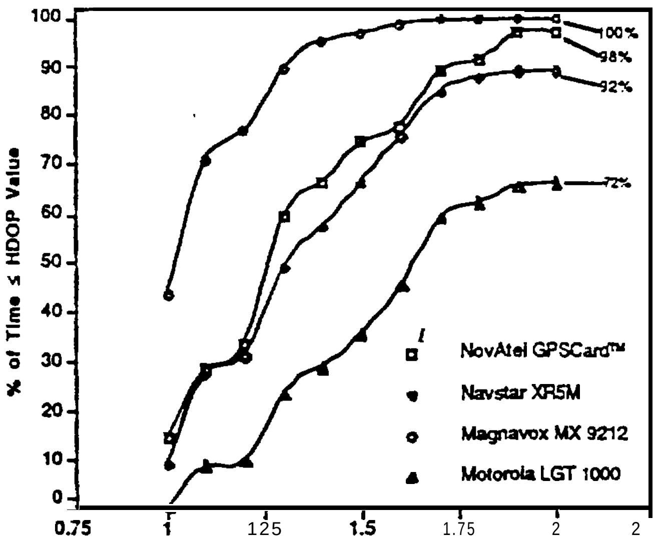
Seasonal Range Availability
Figure 2



HDOP Availability
Figure 3

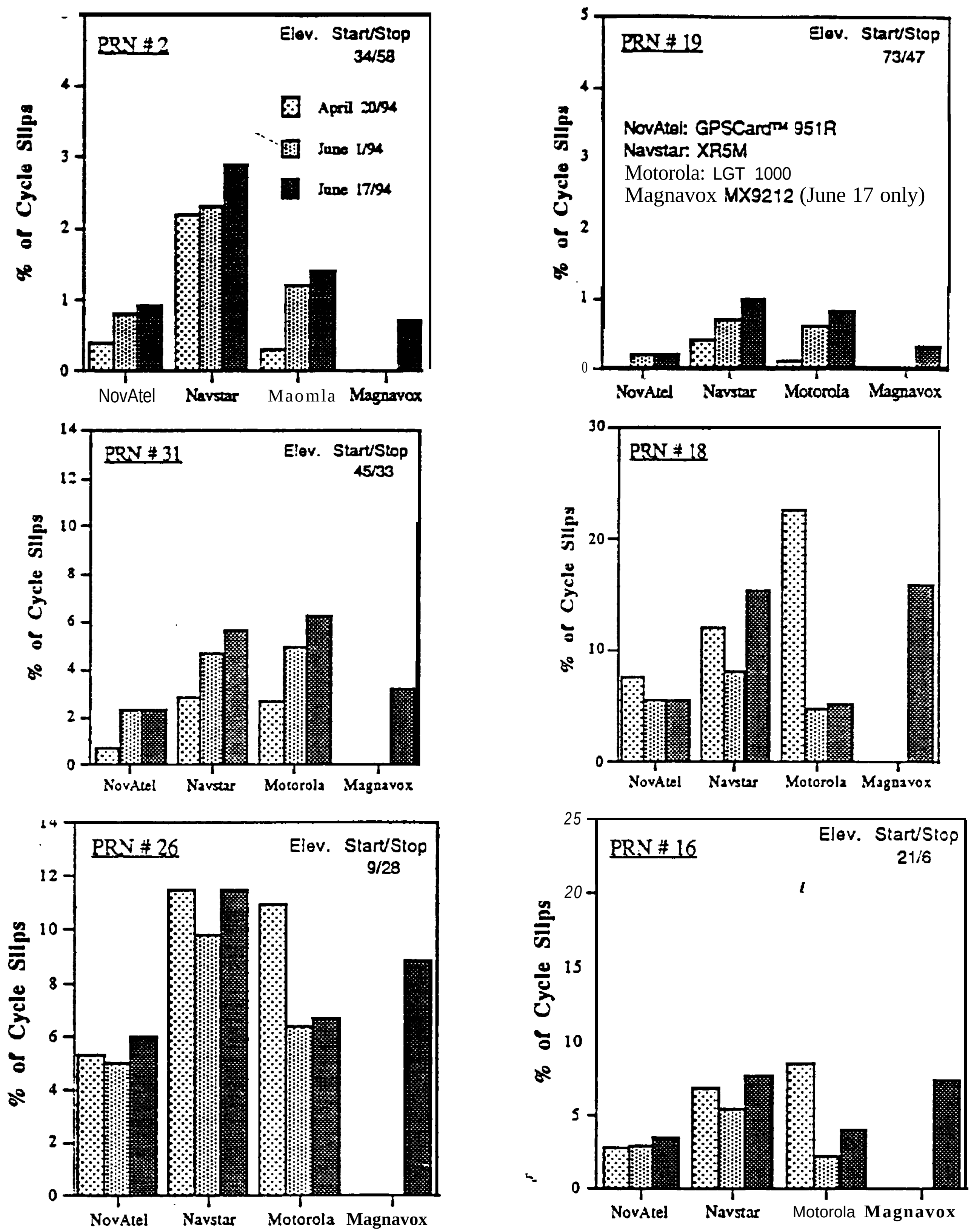
The corresponding HDOPs available during each test are shown in Figure 3. In the case of the 12-channel XR5M and the 10-channel GPSCard™, the difference in availability of an HDOP ≤ 2 between the April and June tests is less than 5%. During the April test, availability was above 95% in both cases. Overall availability is however significantly lower in the case of the 6-channel LGT 1000™ receiver. During the April test, HOOP availability was only at 95% and a further drop of 15% occurred in June. Possible reasons for this lower level of performance include slower re-acquisition time and satellite searching scheme after immediate loss of a satellite. In the latter case, the searching scheme becomes important when the total number of satellites available above the horizon is larger than the number of channels. A receiver with a lesser number of channels than the number of satellites available above the horizon appears to have an intrinsic disadvantage under such conditions.

The four receivers used simultaneously on June 17 are intercompared in Figure 4 in term of HDOP availability. The MX9212 and GPSCard™ yield the best performance in this case, with an HDOP (≤ 2) availability of 100% and 98%, respectively.



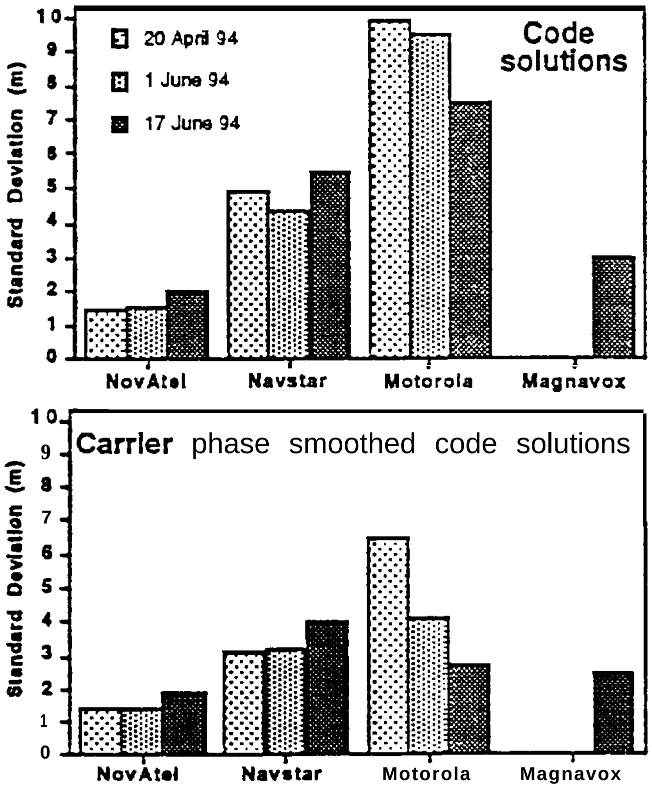
HDOP Availability - Receiver Intercomparison - June 17
Figure 4

The next characteristic analysed is carrier phase tracking stability. Cycle slip statistics for representative satellites are given in Figure 5. In most cases, cycle slips are more frequent during the June tests when the foliage is full. The difference is however small at less than 0.5% The best performance is obtained with the GPSCard™.



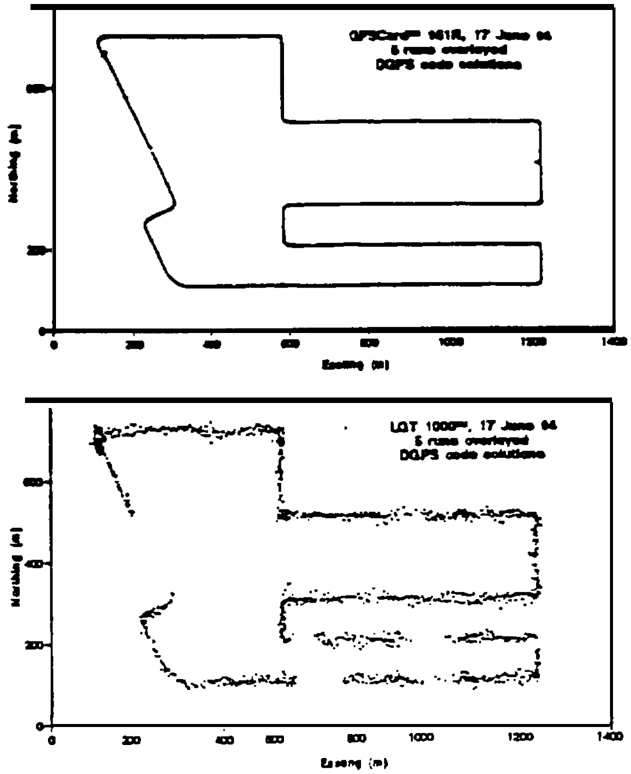
Cycle Slip Statistics
Figure 5

The five repeated trajectories obtained during each test can now be intercompared to analyze the repeatable accuracy. Two types of three-dimensional solutions were derived, namely a DGPS least-squares code solution and a corresponding carrier phase smoothed code solution. No filter was used on purpose to analyse the effect of code or carrier phase smoothed code errors on the positions. The measurements were processed using software C³NAV™ [Cannon 8 Lachapelle 1992]. The across-track error statistics for both the code and the carrier phase smoothed code solutions are given in Figure 6. These statistics were derived using an average trajectory based on a combination of ail trajectories. The errors are weakly dependent on the foliage but strongly dependent on the type of receivers used. The most substantial relative accuracy gain when comparing the code and carrier phase smoothed code solutions is achieved with the LGT 1 000™. The code solutions obtained on June 17 for the horizontal component of the trajectory are shown in Figure 7 for the best and worst cases, namely the GPSCard™ and the LGT1000™ respectively

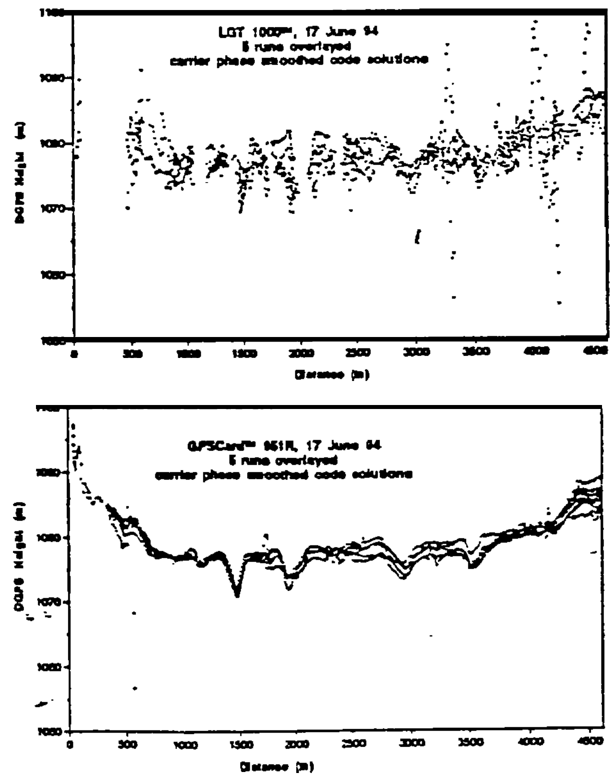


Across-Track Error Statistics
Figure 6

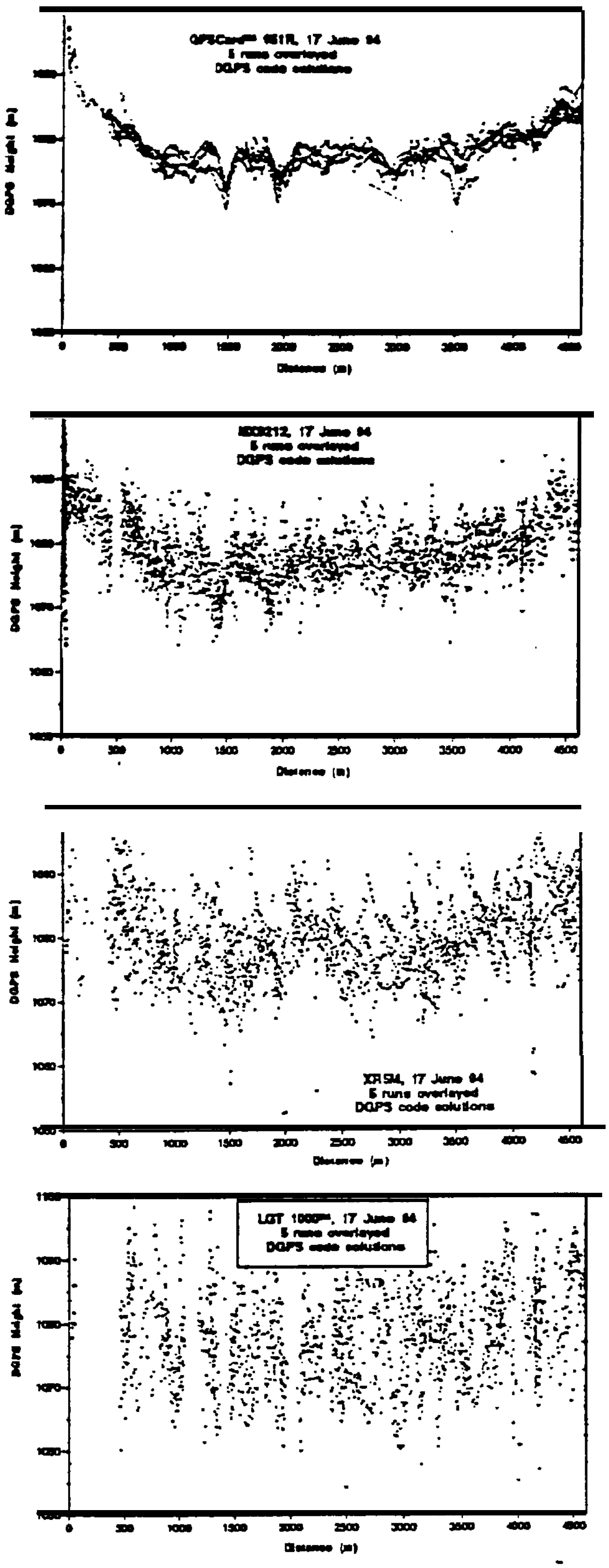
The carrier phase smoothed code height solution repeatability for June 17 is depicted in Figure 8 for the GPSCard™ and the LGT1000™ receivers. The corresponding code repeatability for all four receivers is shown in Figure 9. Again, the best results are obtained with the GPSCard™. The narrow correlator spacing capability of **this** receiver resuits in lower noise code and better multipath rejection, as described by Van Dierendonck et al [1992]. Again, the relative accuracy gain is the most substantial in the case of the LGT 1000™ receiver



Horizontal Trajectory Repeatability
Figure 7

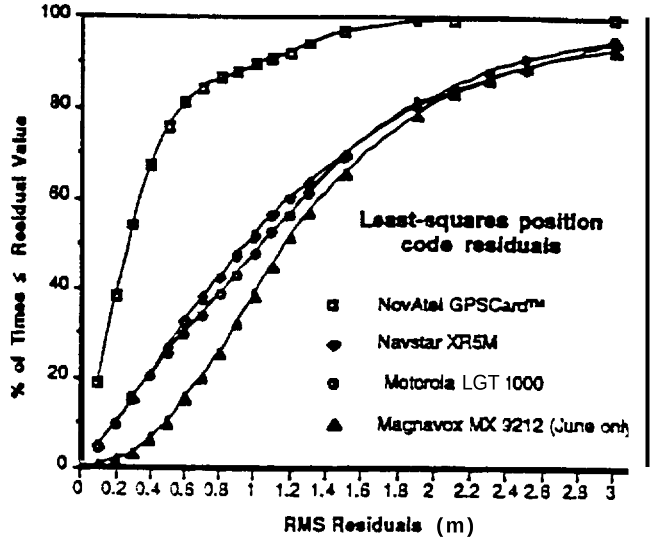


Height Repeatability - DGPS Carrier Phase Smoothed Code Solutions
Figure 9



Height Repeatability - DGPS Code Solutions
Figure 9

A further insight into positioning accuracy can be obtained by examining the residuals derived from the least-squares estimation of the positions. These residuals obtained using the June 17 code data data are shown in Figure 10. The smallest code errors. as anticipated, are obtained with the **GPSCard™**. The **MX9212**, which yields the best HOOP **availability according** to figure **4, also yields the largest residuals. This** is **probably because this receivers accepts weaker, and consequently,** noisier signals.



Least-Squares DGPS Code **Residuals**
Figure 10

CONCLUSIONS

The results presented in this case study show that deciduous foliage has an effect of up to 5% in term of HDOP availability in the case of an all-in-view receiver. The effect is however much larger in the case of a receiver with less than 'all-in-view capability. The positioning accuracy, although not significantly affected by the full foliage, is a function of the receiver characten'stics used, especially the number of channels and the code correlator spacing method utilized.

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