GPS NAVIGATION PERFORMANCE

OF TIM GPS RECEIVERS

APPLICATION NOTE

u-blox ag • Zuercherstrasse 68 • CH-8800 Thalwil • Switzerland • Phone +41 1 722 74 44 • Fax +41 1 722 74 47 • www.u-blox.com

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Author :	GzB
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1 INTRODUCTION

This application note addresses the performance characteristics of the TIM GPS receiver [1] which is based on the SiRFstar™ II chip set.

The achieved results are based on measurements which have been carried out with free visibility (PDOP < 2.0) on the roof of u-blox ag headquarters in Thalwil / Switzerland where the precisely surveyed geodetic position information is known. All measurements refer to the static position accuracy, whereby u-blox ag cannot guarantee these accuracies for customer specific applications.

GPS receiver accuracy is a function of GPS receiver performance and satellite constellation. The Selective Availability1 (S/A) was switched off on 1 May 2000.

This document addresses following performance characteristics:

- Positioning accuracy in *Continuous Mode* with and without DGPS, and *TricklePower™ Modes*.
- Startup Behavior (Timing and accuracy development)
- Speed accuracy in *Continuous Mode*

[1] Selective Availability: An intentional inaccuracy of the GPS L1 system, control by the U.S. government. It was the main contributor to degraded GPS performance.

2 POSITION ACCURACY

2.1 Basics

In principle, statistical results are provided in this document for 2D, altitude and 3D positioning errors during *Continuous Mode* with and without DGPS and various TricklePower™ mode configurations. Details on the functionality of TricklePower™ modes are described in the application note on low power operation [3].

2.2 Statistical Measures (50%, Sigma-1, -2, -3, RMS)

2D performance data is based on the deviations on the Local Tangent Plane (LTP). In the Local Tangent Plane, the 2D coordinate system is based on latitude and longitude. The first four values (50%, Sigma-1, -2 and -3) indicate the radius of a circle centered at the true position where 50% (equivalent to Circular Error of Positioning CEP) , 63.8%, 95.5% (equivalent to R95) and 99.7% of all measured position fixes are contained herein.

The altitude is based on vertical deviations along the line perpendicular to the LTP. The first four values (50%, Sigma-1, -2 and -3) indicate the absolute envelope distance between the true altitude and 50%, 63.8%, 95.5% and 99.7% of all measured altitude fixes are in-between

3D performance data is based on a spherical model where latitude, longitude and altitude are taken into account. The four values (50%, Sigma-1, -2 and -3) indicate the radius of a sphere centered at the true position where 50%, (equivalent to Spherical Error of Positioning SEP) 63.8%, 95.5% (equivalent to R95) and 99.7% of all measured are contained herein.

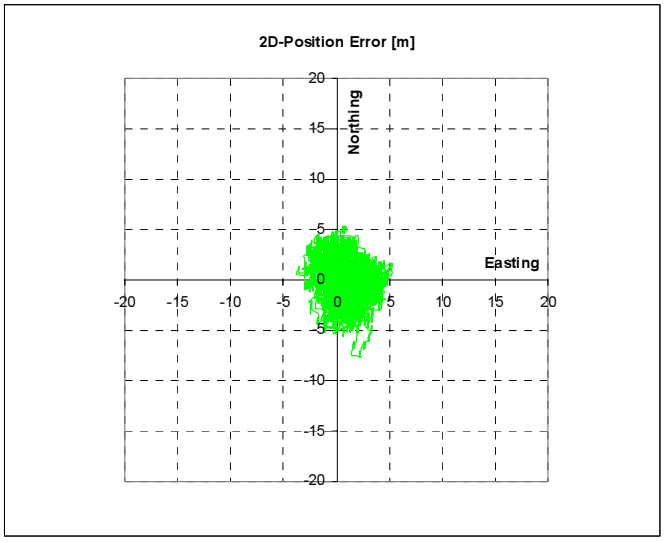
The Root Mean Square (RMS) figure is calculated as sqrt($\Sigma p_i^2 / n$), where p_i = individual position errors and n = number of position fixes.

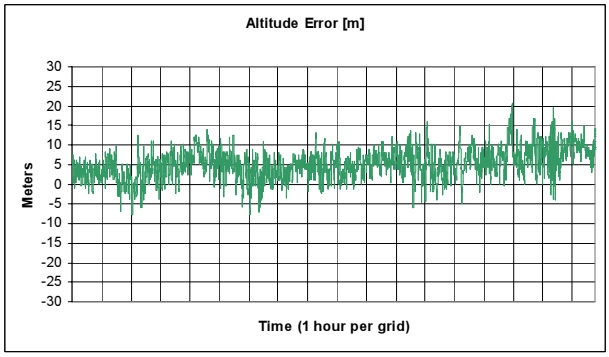
Unless specified otherwise, all results are based on 24-hour measurements, allowing to take two orbital rounds of all satellites into account and balancing out atmospheric influences. The atmospheric influences affect the propagation delay of satellites signals, reducing the positioning accuracy

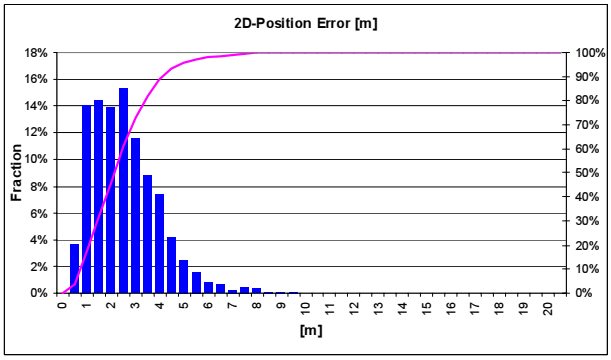
2.3 Continuous Mode

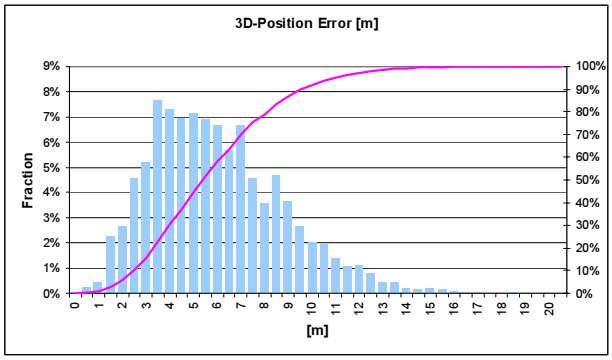
Continuous Mode is understood as normal full-power operation where both RF part and CPU are actively running. Output interval is 1 second.

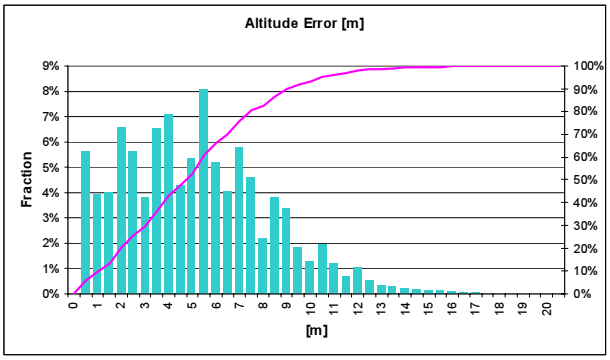
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	2.1 m	4.6 m	5.4 m
Sigma-1 (68.3%)	2.8 m	6.1 m	6.8 m
Sigma-2 (95.5%) eqv. R95	4.9 m	10.9 m	11.2 m
Sigma-3 (99.7%)	7.9 m	15.2 m	15.4 m
RMS	2.4 m	5.8 m	6.4 m









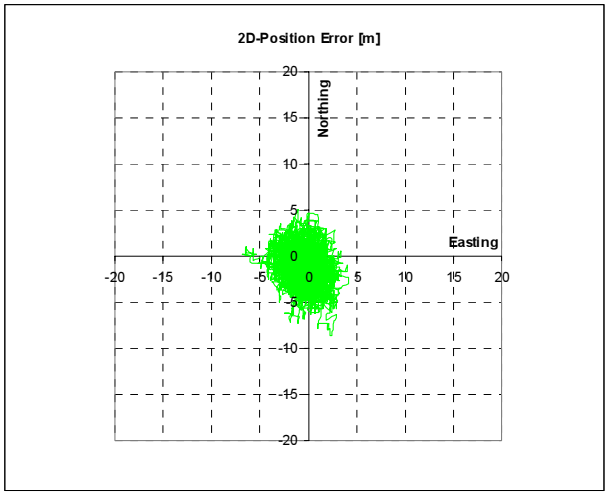


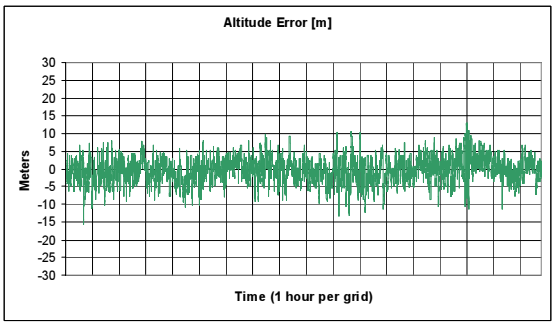
2.4 Continuous Mode with DGPS

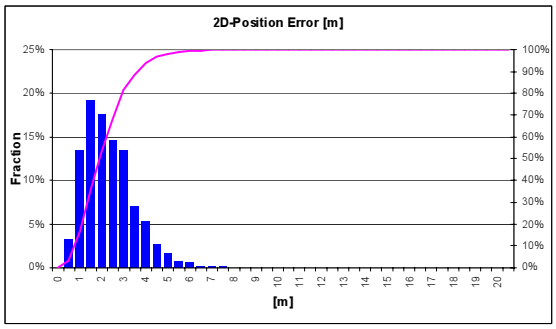
In DGPS mode, a GPS receiver is fed with correction data, usually provided by a third party. Age and accuracy of this datastream has the most significant impact on the position accuracy. Additionally, the distance from the base station where the correction data is being generated, and the GPS receiver consuming this data (commonly referred to as "baseline") does have an impact on the quality that can be achieved.

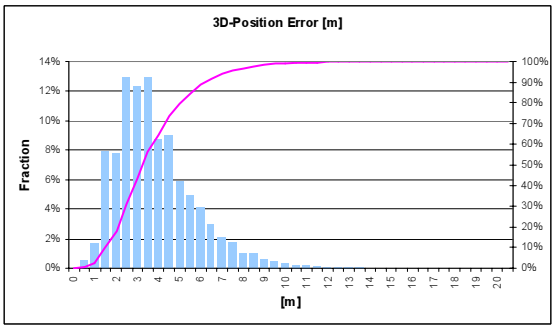
The following performance characteristics are based on the TIM module running in *Continuous Mode* with real-time reception of a DGPS RTCM-signal[2] to improve positioning accuracy. Output interval is 1 second.

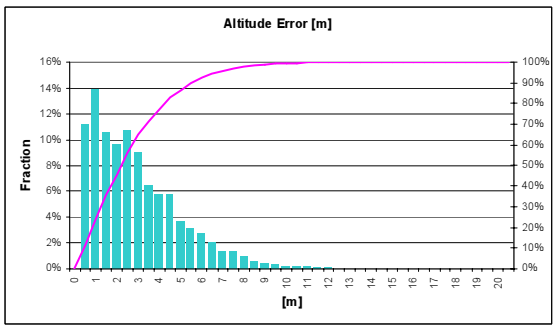
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	1.9 m	2.2 m	3.3 m
Sigma-1 (68.3%)	2.5 m	3.3 m	4.2 m
Sigma-2 (95.5%) eqv. R95	4.2 m	6.9 m	7.4 m
Sigma-3 (99.7%)	6.5 m	10.5 m	11.3 m
RMS	2.4 m	3.4 m	4.1 m











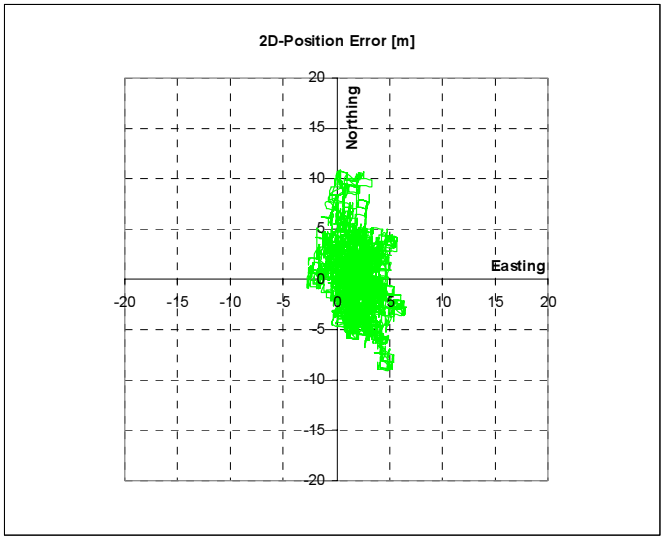
[2] The RTCM signal used was provided by SWIPOS (Bundesamt für Landestopographie) with reference site in Bern / Switzerland. The DGPS signal is transmitted via "Radio Data System", a digital sub-band provided along with public FM broadcasts. The service quality is called 'Premium Service' and broadcasts RTCM Message Types 1, 2 and 9.

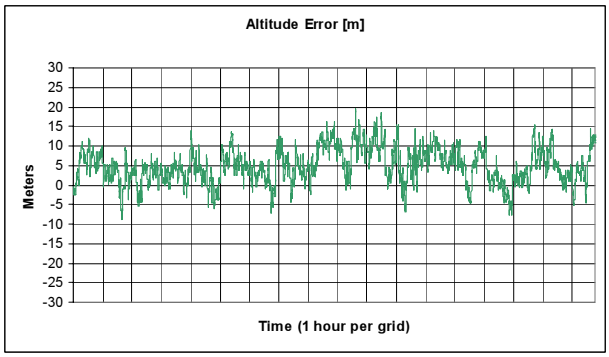
2.5 TricklePower™ Mode (200ms Tracking / 1 s Interval)

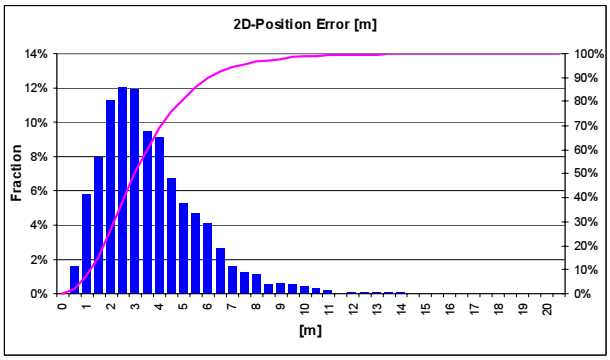
The following results provide positioning accuracy for TricklePower™ mode with following parameters:

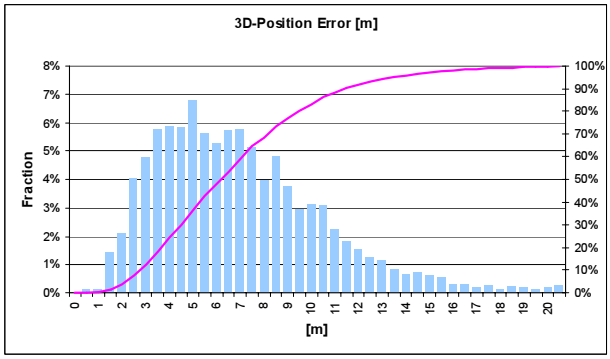
OnTime = 200ms (duration while satellite tracking takes place) and
Interval = 1s (Tracking, navigation and output interval)

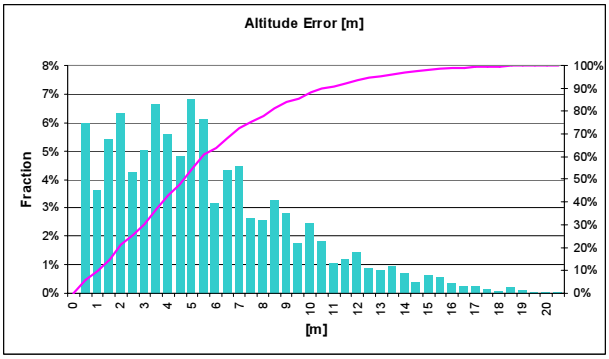
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	2.9 m	4.6 m	6.1 m
Sigma-1 (68.3%)	4.0 m	6.5 m	8.0 m
Sigma-2 (95.5%) eqv. R95	7.5 m	13.1 m	13.8 m
Sigma-3 (99.7%)	12.9 m	18.2 m	19.6 m
RMS	3.1 m	5.2 m	6.1 m









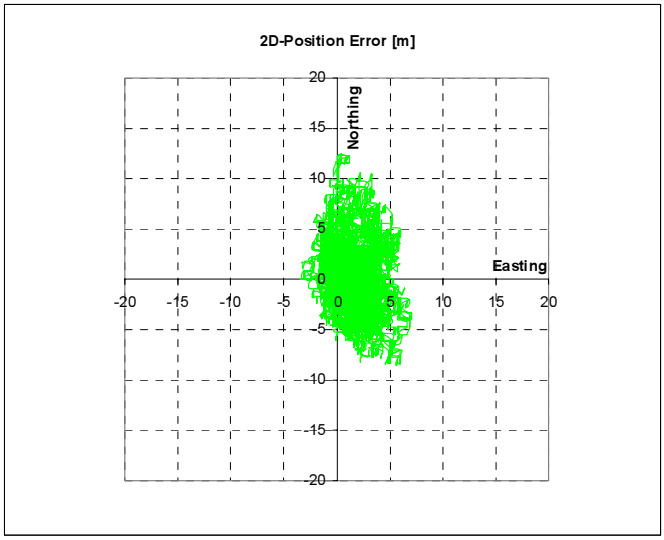


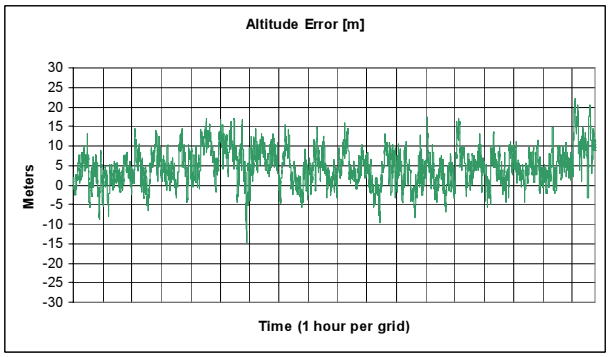
2.6 TricklePower™ Mode (200ms Tracking / 2 s Interval)

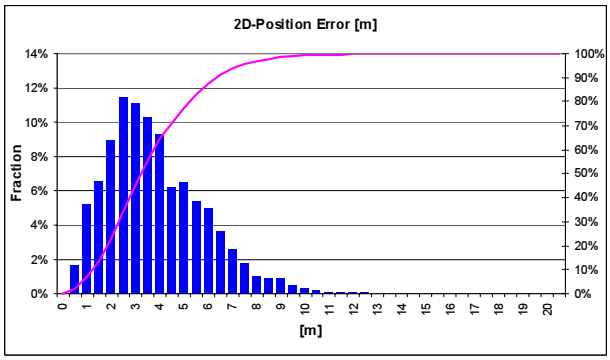
The following results provide positioning accuracy for TricklePower™ mode with following parameters:

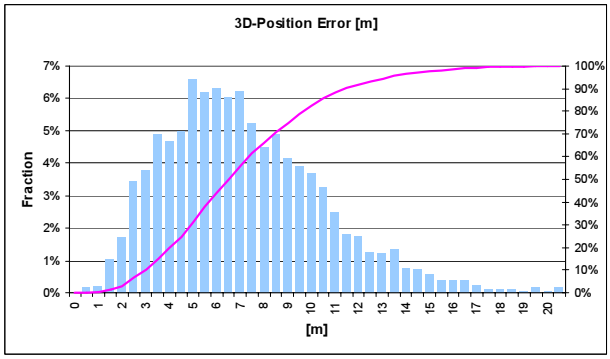
OnTime = 200ms (duration while satellite tracking takes place) and
Interval = 2s (Tracking, navigation and output interval)

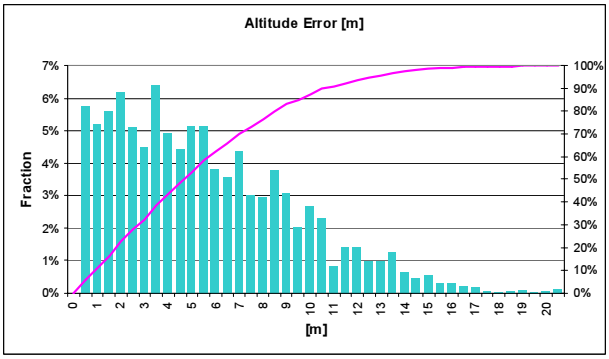
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	3.2 m	4.6 m	6.5 m
Sigma-1 (68.3%)	4.3 m	6.8 m	8.2 m
Sigma-2 (95.5%) eqv. R95	7.5 m	12.9 m	13.4 m
Sigma-3 (99.7%)	11.1 m	18.8 m	19.3 m
RMS	4.1 m	6.6 m	7.8 m









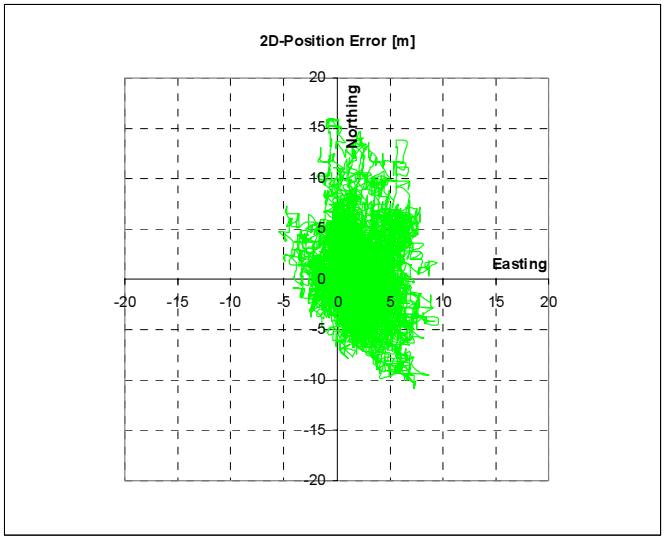


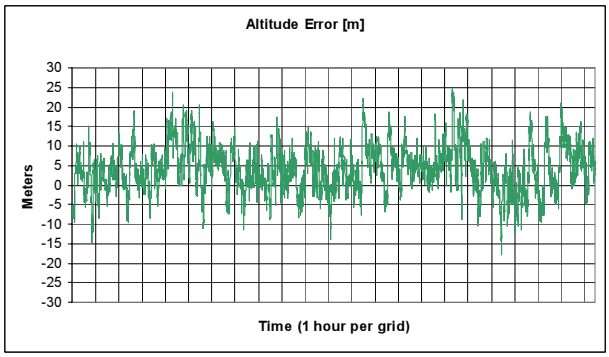
2.7 TricklePower™ Mode (200ms Tracking / 5 s Interval)

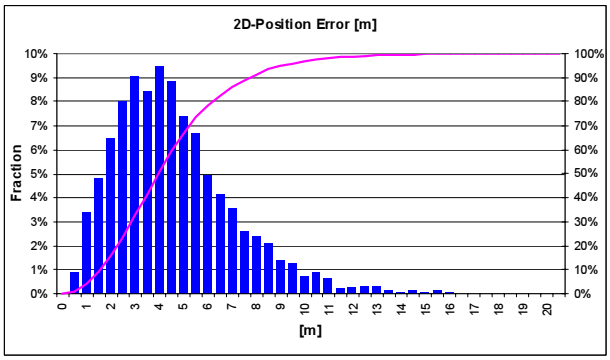
The following results provide positioning accuracy for TricklePower™ mode with following parameters:

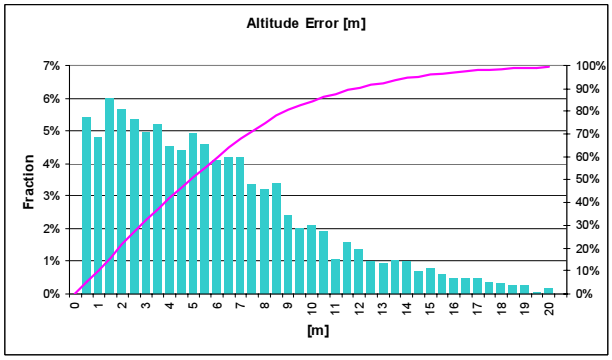
OnTime = 200ms (duration while satellite tracking takes place) and
Interval = 5s (Tracking, navigation and output interval)

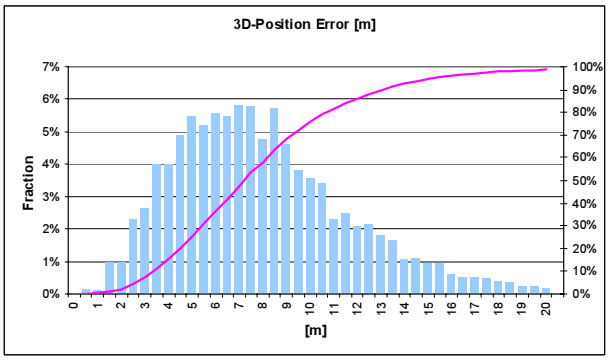
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	4.0 m	4.9 m	7.3 m
Sigma-1 (68.3%)	5.1 m	7.0 m	9.0 m
Sigma-2 (95.5%) eqv. R95	9.3 m	14.7 m	15.5 m
Sigma-3 (99.7%)	14.3 m	21.8 m	22.6 m
RMS	5.0 m	7.2 m	8.8 m









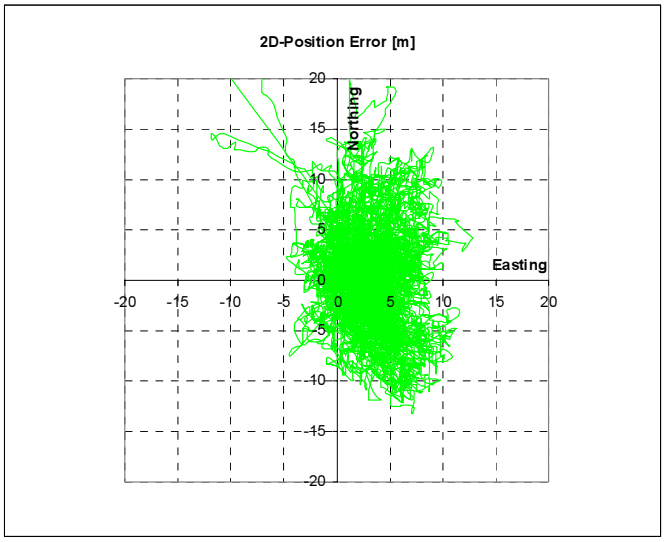


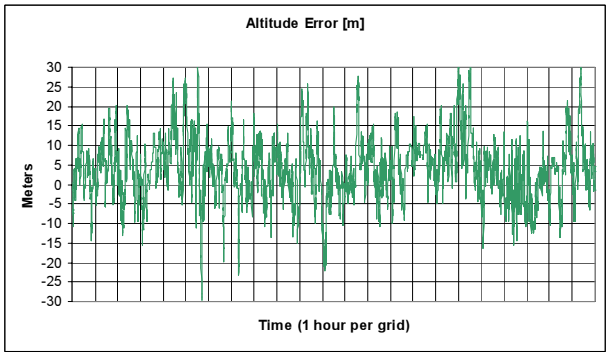
2.8 TricklePower™ Mode (200ms Tracking / 10 s Interval)

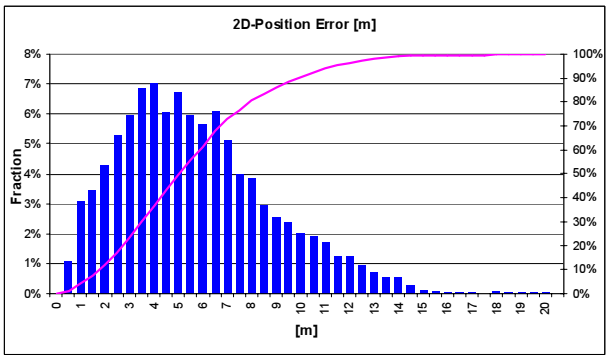
The following results provide positioning accuracy for TricklePower™ mode with following parameters:

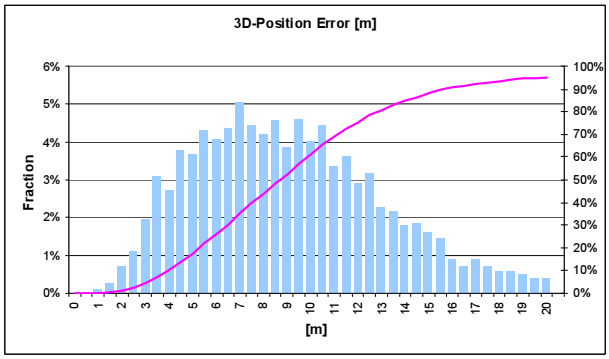
OnTime = 200ms (duration while satellite tracking takes place) and
Interval = 10s (Tracking, navigation and output interval)

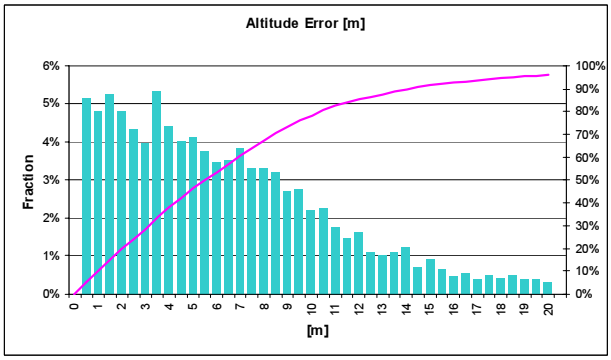
Statistical Overview	2D (LTP)	Altitude	3D
50% eqv. CEP (2D), SEP (3D)	5.0 m	5.5 m	8.7 m
Sigma-1 (68.3%)	6.6 m	8.1 m	10.9 m
Sigma-2 (95.5%) eqv. R95	11.6 m	19.1 m	20.3 m
Sigma-3 (99.7%)	16.8 m	30.2 m	31.8 m
RMS	6.3 m	8.9 m	10.9 m











3 START-UP MODES

3.1 Basics

A GPS receiver has different start-up scenarios. They differ significantly in the Time-To-First-Fix (TTFF).

These start-up scenarios depend on the amount of knowledge the GPS receiver has regarding its positions and the availability of satellites. Just like GPS accuracy, startup times for GPS receivers are another field where every manufacturer has his own naming scheme, and therefore, comparison between receivers is difficult.

For our definition of start-up modes, please refer to the individual sections in chapter 3.

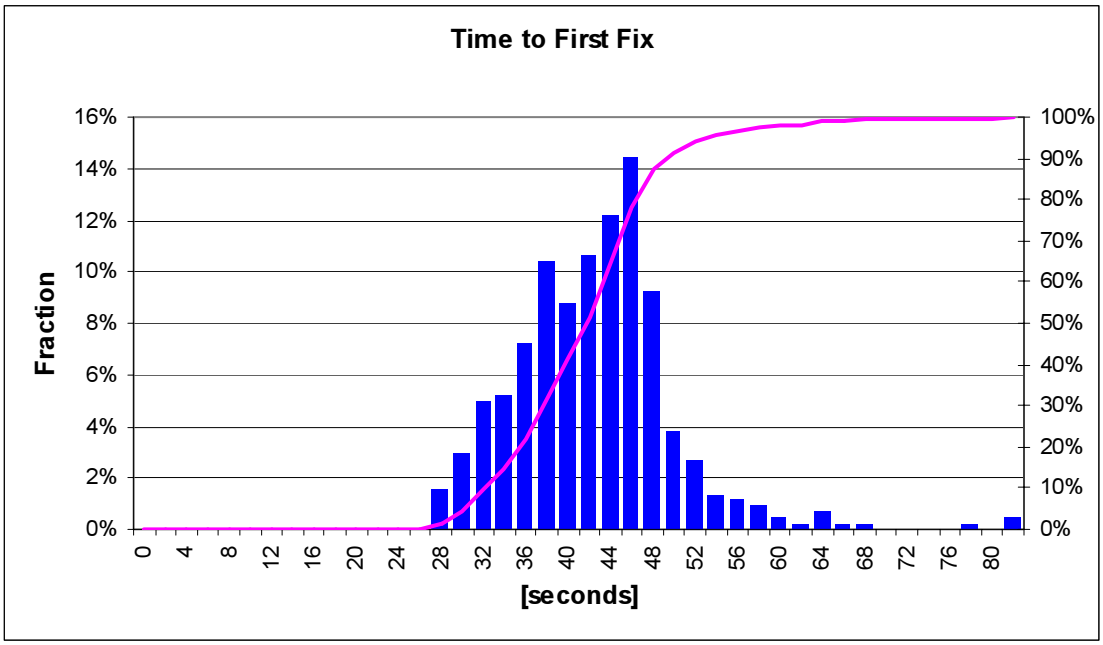
Please note that these numbers were measured over a 24-hour period with good visibility (open view to the sky). Obstructed view will result in longer start-up times.

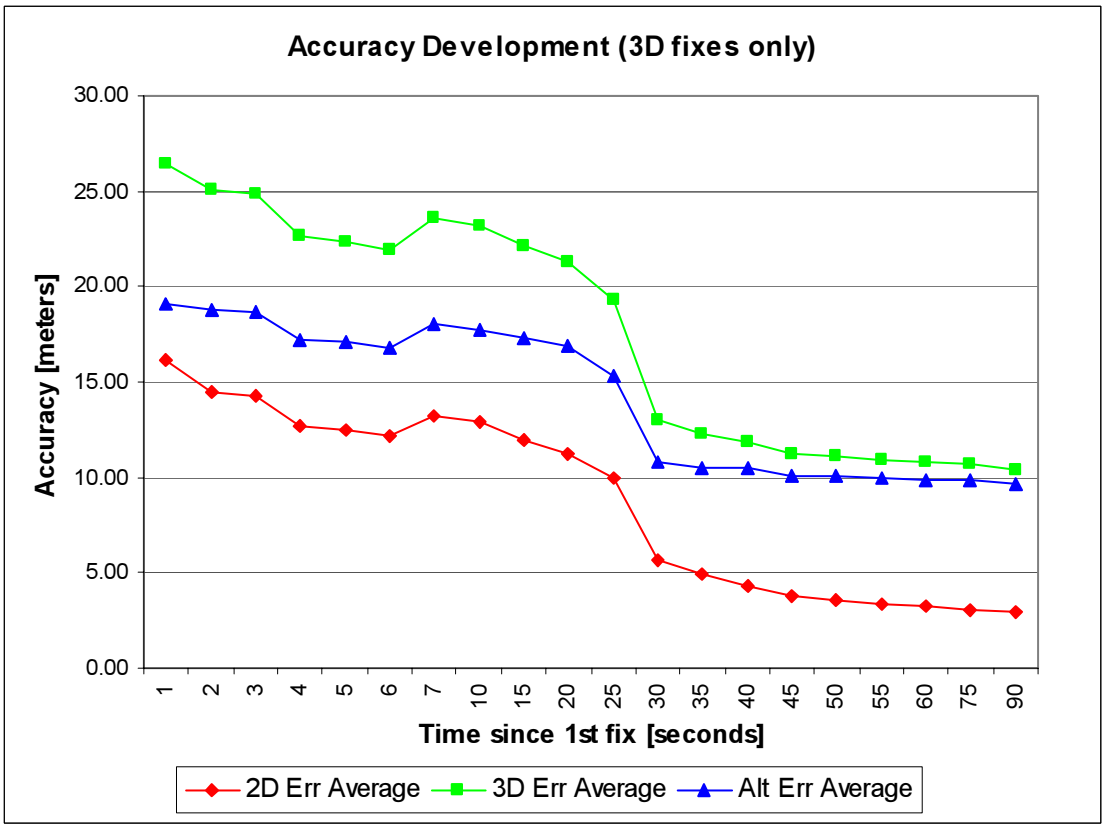
Statistical Overview	**Cold Start**	**Warm Start**	**Hot Start** (see [1])
Minimum measured	28 s	22 s	1 s
50%	42 s	33 s	1 s
Sigma-1 (68.3%)	45 s	36 s	1 s
Sigma-2 (95.5%) eqv. R95	55 s	40 s	1 s
Sigma-3 (99.7%)	81 s	40 s	1 s
Maximum measured	91 s	40 s	2 s
RMS	43 s	33 s	1 s

[1] For interruptions less than 10 seconds

3.2 Cold Start

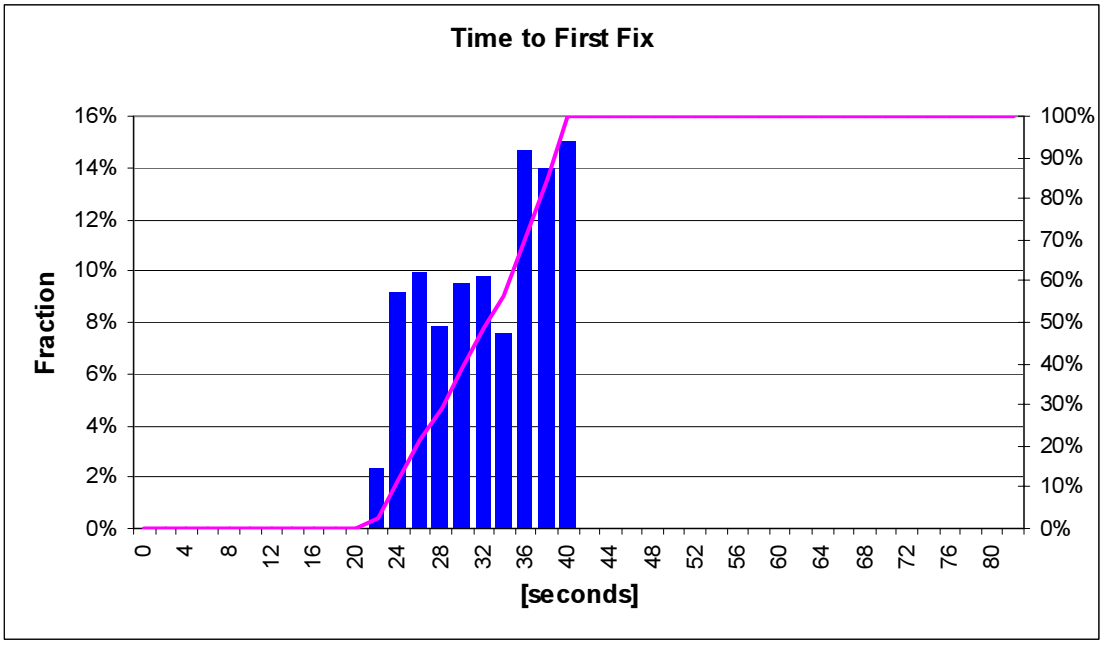
In Cold Start Scenario, the receiver has no knowledge on last position, approximate time or satellite ephemeris and almanac data. The receiver starts to search for signals blindly using no aiding data. This is standard behavior, if no backup battery is connected. Cold Start time is the longest startup time for GPS receivers.

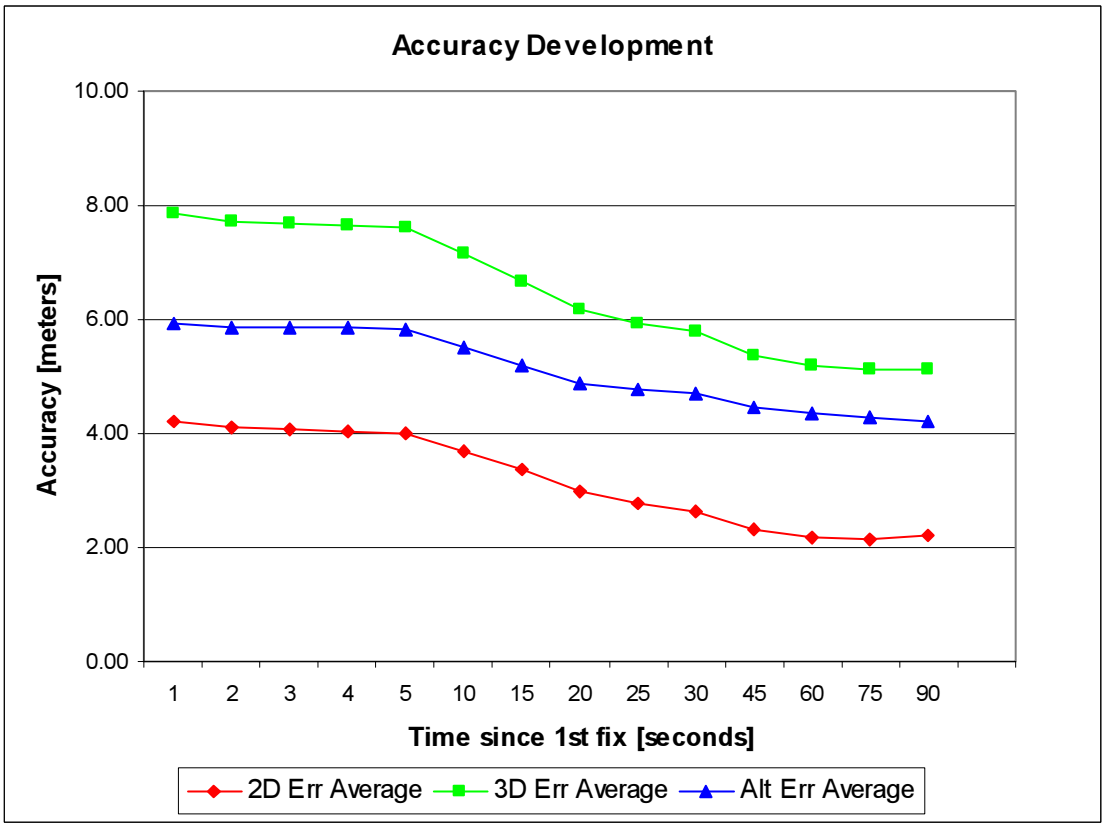




3.3 Warm Start

In Warm Start Scenario, the receiver knows - due to a backup battery – his last position, clock offset, approximate time and almanac information. Thanks to this, it can quickly acquire satellites, obtain new ephemeris information and get a position fix faster than in cold start mode. Theoretical minimum for warm start is 18 seconds, which is achievable under most optimal conditions. The only difference to a hot start is that the receiver does not have knowledge on precise satellite ephemeris.



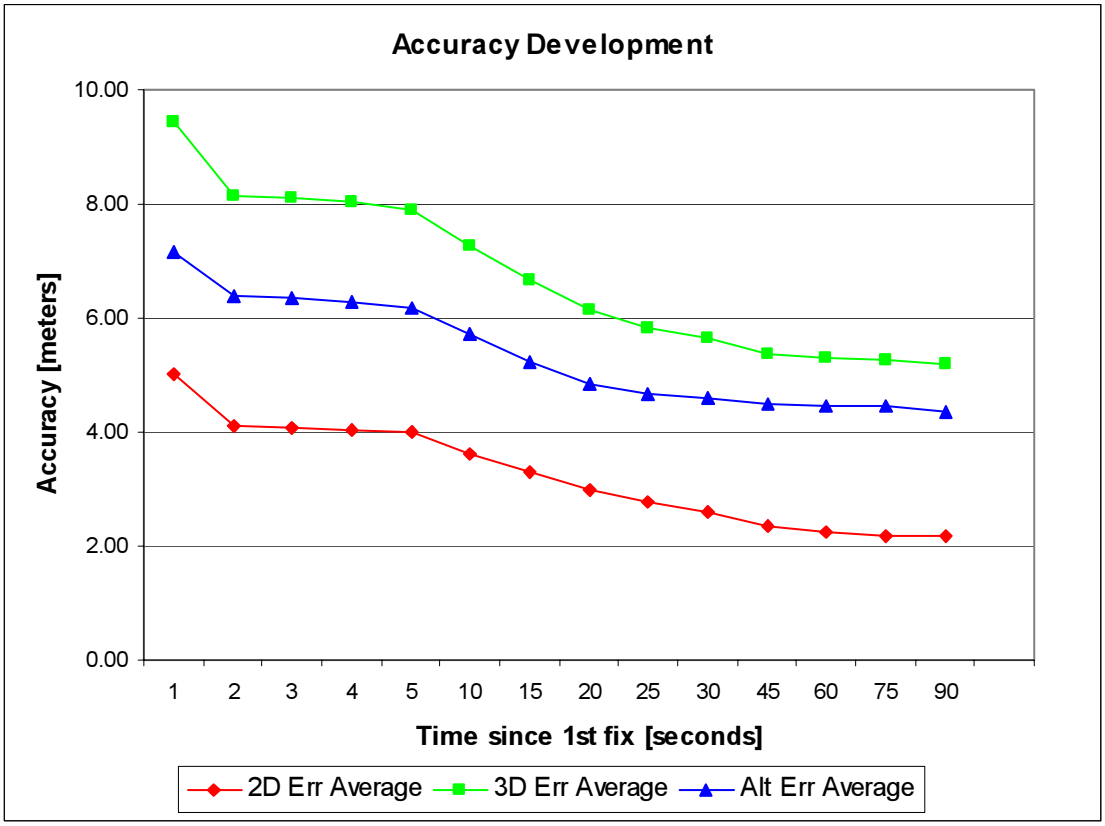


3.4 Hot Start

Hot start is executed if the GPS receiver starts with known current position, clock offset, approximate GPS time, all ephemeris and almanac data are valid. This condition is normally met if the receiver was off for less than two hours. It uses its last Ephemeris data to calculate a position fix. There are basically two different startup methods: Snapstart™ and Hot Start. The receiver will automatically try the best possible mode.

If the receiver was turned off for relatively short intervals (several tens of seconds), it will try to power-up in SnapStart™ mode. In this mode, the receiver assumes that its local time is (through the battery-powered RTC circuitry) that accurate, that the receiver can predict code phase for each of the satellites in view precisely. Through that, it does not need to go into a search mode. Depending on the accuracy of the local RTC clock (which is dependent on e.g. temperature changes) and user motion, this may or may not succeed. If it succeeds with sufficient number of satellites, it will be able to calculate first position fixes within a single second.

If SnapStart™ fails for 2 seconds, then the receiver will force a restart, this time with a conventional hot-start. A normal hot start under good visibility takes 4 to 6 seconds, since the receiver needs to re-do frame-sync on the data frames.



4 DYNAMIC NAVIGATION PERFORMANCE

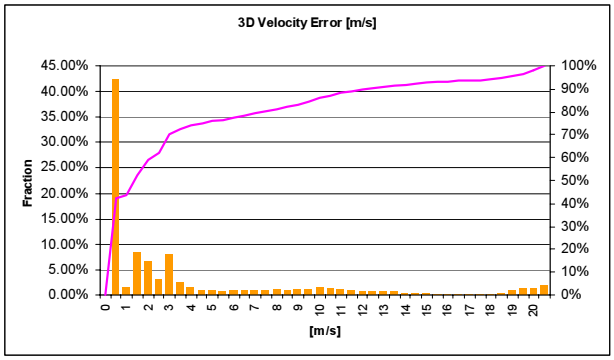
A dynamic navigation performance measurement has been made with a GPS simulator. The simulation scenario involves a virtual automobile driving a series of "8"-shaped patterns over two hours near the intersection of the equator and the zero meridian. The route and driving characteristics are described below:

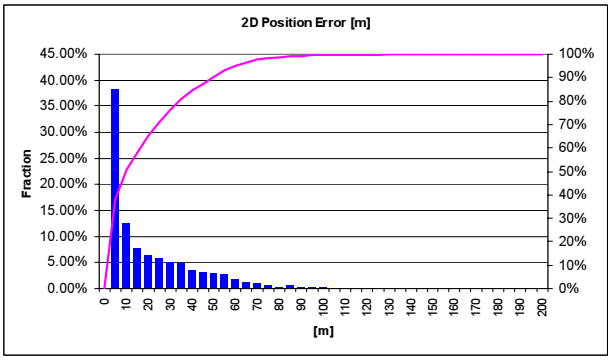
- Length of "8"-shaped lap is roughly 2.5 Km
- Width of "8"-shaped lap is roughly 800 m
- Altitude changes between sea level and 150 above sea level. Car ascends in one curve and descends in the opposite curve
- Car travels accelerates and decelerates between 112 and 162 Km/h

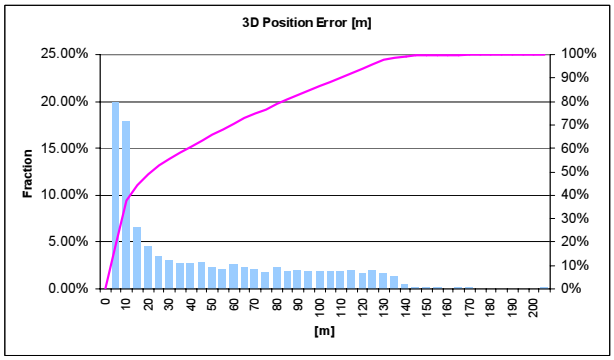
These measurements were carried out with a receiver that had the 'Altitude Constraint' Filter enabled. This filter basically limits the maximum change in altitude to at most 10% of the 2D-position change. Through that, in a scenario where rapid changes in altitude occur, this filter will result in sub-optimal accuracy during these phases. The scenario used for this performance measurement shows such fast changes in altitude.

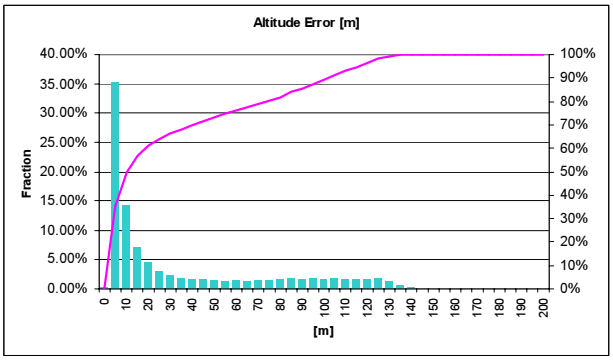
If the user application requires altitude changes exceeding 10% of the 2D position change (e.g. helicopters, parachutes), then the user is advised to disable this filter using appropriate input commands to the receiver.

Statistical Overview	2D (LTP)	Altitude	3D	3D Velocity
50% eqv. CEP (2D), SEP (3D)	9.5 m	10.2 m	22 m	1.4 m/s
Sigma-1 (68.3%)	22.4 m	35.3 m	56 m	2.8 m/s
Sigma-2 (95.5%) eqv. R95	61.5 m	118 m	124 m	19.0 m/s
Sigma-3 (99.7%)	120 m	132 m	162 m	21.2 m/s
RMS	28.9 m	51.0 m	58.6 m	6.6 m/s









A Glossary

Please refer to the GPS dictionary from u-blox [2].

B Related Documents

[1] TIM Data Sheet, GPS.G2-MS2-01001

[2] The GPS Dictionary, GPS-X-00001

[3] TIM Low Power Modes - Application Mode, GPS.G2-X-02003

All these documents are available on our homepage (http://www.u-blox.com).

C CONTACT

For further info, please contact us:

Headquarters

u-blox ag
Zuercherstrasse 68
CH-8800 Thalwil
Switzerland

Phone: +41 1 722 74 44
Fax: +41 1 722 74 47
E-mail: info@u-blox.com
www.u-blox.com

Subsidiaries

u-blox Deutschland Gmbh
Berliner Ring 89
D-64625 Bensheim
Germany

Phone: +49 (0) 6251 17566-0
Fax: +49 (0) 6251 17566-11
E-mail: info_de@u-blox.de
www.u-blox.de

Tech. Support:

Phone: +41 1 722 74 74
support_de@u-blox.de

u-blox Asia Pacific Ltd.
22/F., City Landmark I
68 Chung On Street
Tsuen Wan, Hong Kong

Phone: +852-2941-8877
Fax: +852-2615-2285
E-mail: info_ap@u-blox.com
www.u-blox.com

Tech. Support:

Phone: +41 1 722 74 74
support_ap@u-blox.com

u-blox Europe Ltd.
Barham Court
Maidstone, Kent ME18 5BZ
United Kingdom

Phone: +44 1622 618628
Fax: +44 1622 618629
E-mail: info_uk@u-blox.co.uk
www.u-blox.co.uk

Tech. Support:

Phone: +44 1622 618628
support_uk@u-blox.co.uk

u-blox America, Inc.
13800 Coppermine Road
Herndon, VA 20171
USA

Phone: +1 (703) 234 5290
Fax: +1 (703) 234 5770
E-mail: info_us@u-blox.com
www.u-blox.com

Tech. Support:

Phone: +1 (703) 234 5290
support_us@u-blox.com