ASSESSMENT OF THE GPS ACCURACY OF MOBILE DEVICES

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I. Introduction

Carried out by CartONG, this brief analysis assesses the accuracy of GPSes which are found in commonly-used mobile devices. The primary objective is to assess the differences in accuracy between devices, and thereby better identify their potential limitations for use in humanitarian data collection. While there are studies which analyse the impact of specific survey conditions (e.g. forest cover) on GPS accuracy, there are comparatively few studies that review the differences in GPS accuracy between devices. The interest of this study stems from a dearth of manufacturer-published GPS accuracy data, as well as a lack of replicable protocols or methods for such comparisons that could inform humanitarian actors.

This study has two goals: firstly, to provide a review of the accuracy of commonly handheld GPS devices used by CartONG and its partners. Secondly, and most importantly, the study describes a replicable methodology for GPS accuracy assessment that can be deployed by any actor.

This study is divided into several parts: an introduction to the concepts used in the study, a presentation of the methodology which was applied, a general analysis based on the observations made, and the steps to follow to test one's own devices.

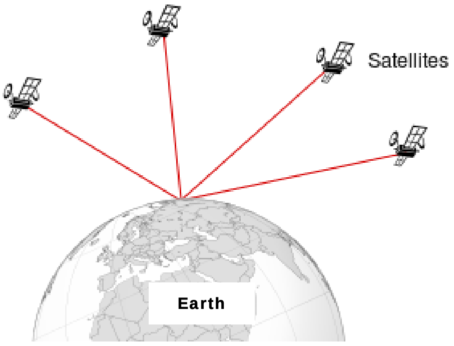
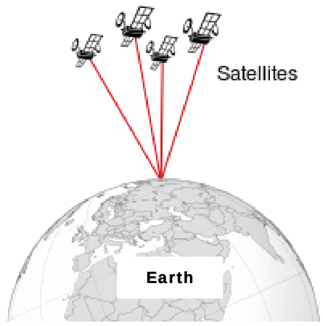
This study also focuses on one of the known criteria for position accuracy (HDOP), which was tested and whose analysis may seem surprising.

II. General information and definitions

GNSS (Global Navigation Satellite System) refers to satellite geo-positioning systems, "a set of components that provide a user with their 3D position, speed and time." [Translated from French Wikipedia]. In lieu of GNSS, we rely on the more commonly used acronym GPS (Global Positioning System). Yet GPS represents a particular type of satellite positioning system developed by the United States, and is merely one among others (GLONASS and Galileo are the best known alternatives, and the Russian and European equivalents of the term "GPS").

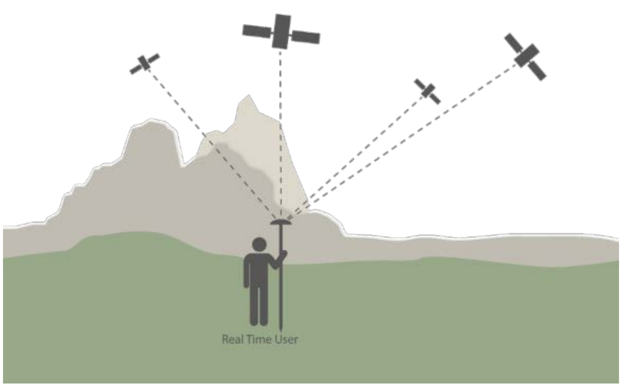
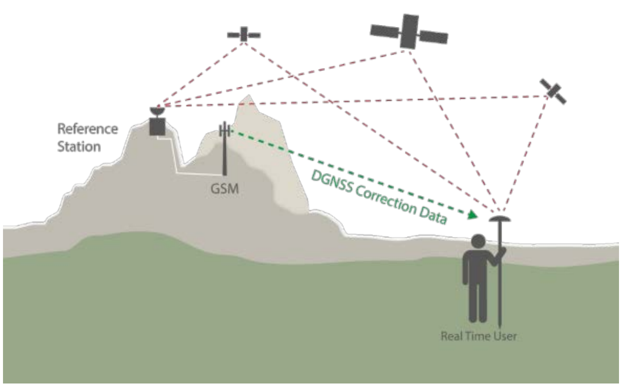
Under the same measuring conditions, the accuracy of positioning can vary widely from one device to another; the quality being determined by the positioning system used (GLONASS, GPS, etc.) and the quality of the GPS receiver of the device used. The receiver calculates its position by trilateration[1] from signals received from at least four satellites. However, since the atmosphere is not a homogeneous environment, trilateration with only four satellites rarely gives a calculation that is accurate; the accuracy is much better if you can pick up at least six or seven (or more) signals from satellites.

HDOP (horizontal dilution of precision) reflects the impact of the satellite constellation at the time of measurement on the position accuracy calculated by the GPS receiver. The further apart the satellites are from each other in the sky, the more accurate the trilateration calculation and, therefore, the position. HDOP is one of the variables used to estimate accuracy.

	
Favourable constellation, HDOP close to 1 (source: Wikipedia)	Adverse constellation, high HDOP (source: Wikipedia)

Finally, different types of systems exist to measure the device's position from satellite constellations. The most widely used is real-time GPS, the second being real-time differential GPS. These two systems are used in this study, and they are described in more details below.

[1] Trilateration allows the relative position of points to be calculated based solely on the distance between them, while triangulation also uses angles.

	
Real-time GPS: The receiver directly calculates its position based on the received satellite signals (illustration source : swisstopo)	Real-time differential GPS: A reference station, whose position is known, calculates its position on the basis of received satellite signals. From these two positions, one known and the other calculated, it is possible to calculate a position and/or correct locational errors (illustration source : swisstopo)

III. Presentation of the methodology used

An accuracy assessment of mobile device positioning systems was carried out in February 2018 in Chambéry. It took place in several stages:

- 1st step: field collection of geo-referenced tracks with various commonly used devices,
- 2nd step: collection of these same tracks with a high-precision, differential GPS device,
- 3rd step: analysis and comparison of the collected data.

III.1. General step-by-step presentation

III.1.A. Collection of data

a. Device configuration

For the study, we chose the devices available in our office in Chambéry, which also permitted the installation of the applications used for this type of analysis (applications selected based on CartONG's experience). None of these devices had been set up with a SIM card, but the study relied on the GPS Sensors only.

Applications which were installed:

- GPSlogger for tracks recording

https://play.google.com/store/apps/details?id=com.mendhak.gpslogger&hl=en

- GPS-Status to load satellite ephemerides[2], allowing to accelerate the signal detection

https://play.google.com/store/apps/details?id=com.eclipsim.gpsstatus2

- GeoCam for geotagged photography: these photos were taken "in parallel" with the other records, the smartphone that took the photos was not analysed in this study

https://play.google.com/store/apps/details?id=com.myway

The settings used for GPSlogger are presented in the appendix.

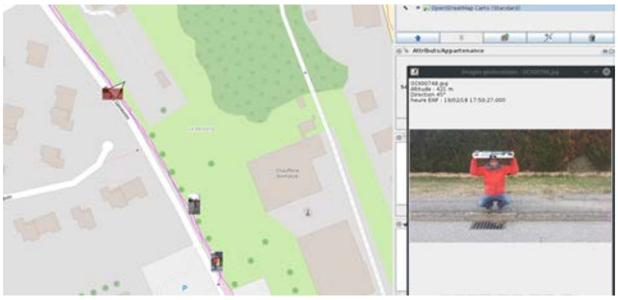
b. Installation of devices on a recording board

The devices were fixed horizontally on a rigid cardboard panel less than 1 m², in order to limit interference between devices (which could exist in the event that the devices were to be placed vertically on the board) and signal losses. Four identical devices were distributed at the four corners of the board, in order to test the impact of board position on the accuracy of the recorded track.

[2] Ephemeris are tables that, in our case, describe the position of satellites in the sky at a given time.

c. Field collection

The recording took place on 19 February 2018 at the end of the day (between 17:45 and 18:10) and consisted of repeating exactly the same journey twice (one round trip). The collection was carried out under good weather conditions (relatively clear sky), partially under vegetation cover, close to houses (i.e. in a residential area) and to a cliff. It took place over a length of 650 metres (1,300 m for the round trip).


Locating stopping points by taking geo-referenced photos

Before the collection started, the track recording application was launched through the GPSlogger application on all devices placed on the board, after activation of their own GPS.

During the recording, the board was kept horizontal and as far away as possible from the body of the person doing the tests to avoid interference (i.e. at least 4 cm from the body). A few spots on the route have been subject to pause and longer recording times.

At each "stopping point", a photo was taken with the GeoCam application, which allows geo-referenced pictures to be taken to keep track of their location and facilitate control recording (the "stopping point" being therefore documented and easily identifiable).

III.1.B. Control recording

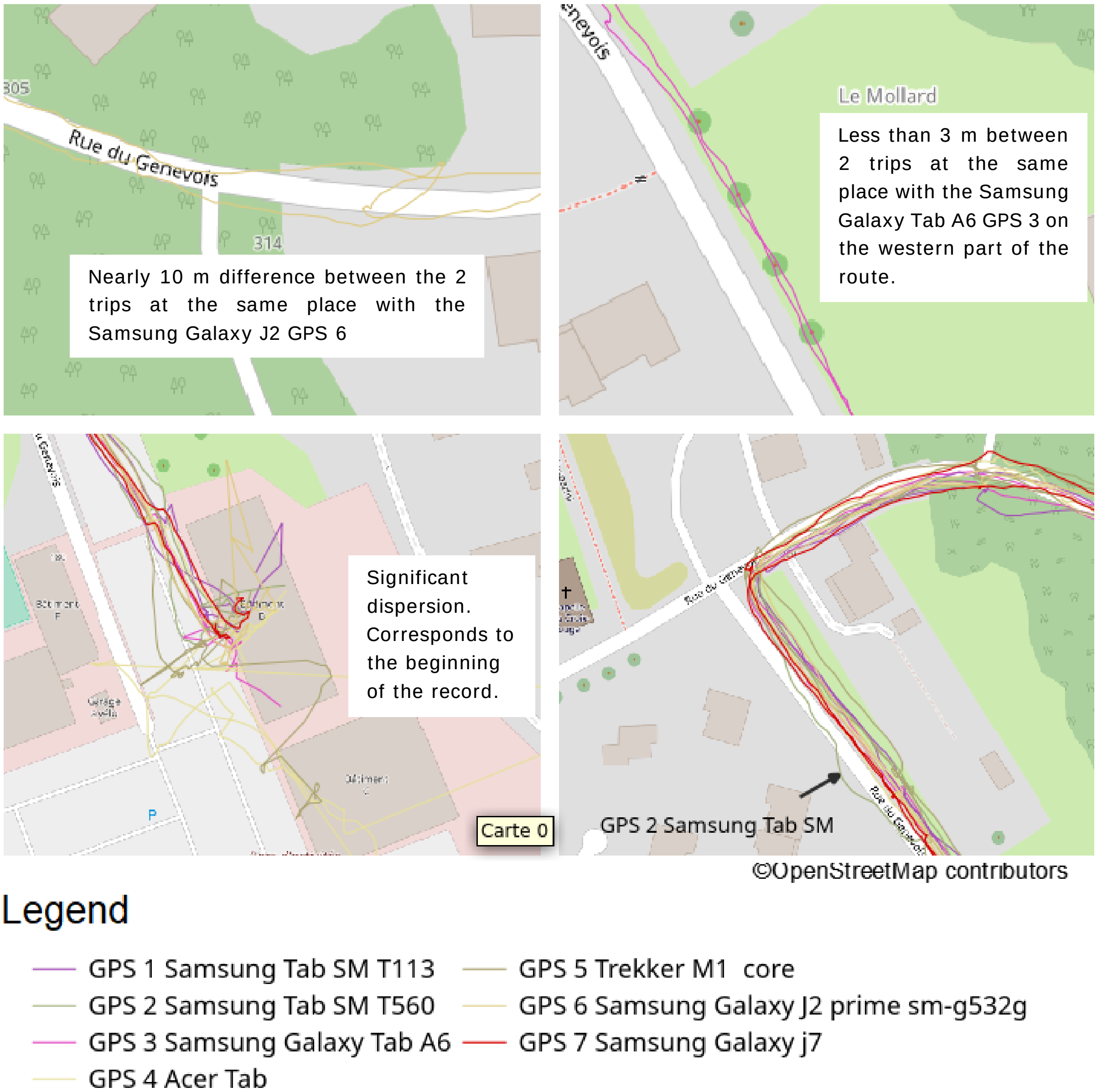
In order to be able to analyse the accuracy of the tracks issued from mobile devices, reference data was required. We chose to use a dual-frequency RTK differential GPS for its high level of accuracy (exceeding most mobile devices' GPS). The model used is a Topcon's GRS-1. The same "stopping points" were measured, as well as the curb line intermittently (sporadic and not continuous record). This record with a "topographic accuracy level" was carried out with the voluntary help of Mr. George Kauffmann, geomatics engineer (*géomètre expert DPLG* in French)

III.1.C. Analysis

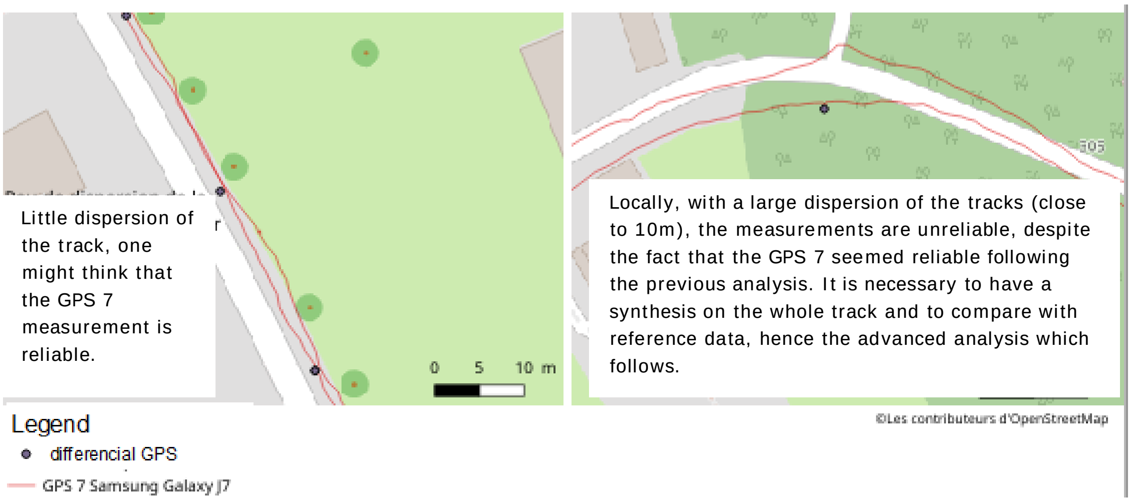
a. Visual analysis

This step aims at visualizing in a GIS software (in our case QGIS) the recorded tracks and the reference data in order to observe the reliability of the tracks recorded by the mobile devices. It is a simple visualization with distance measurement at a few remarkable points. This step is not exhaustive and cannot allow conclusions to be drawn about the equipment tested. However, it does give an overview and initial insights.

Observations without taking into consideration the reference data (RTK differential GPS):



Observations compared to the RTK differential GPS reference data:



b. Advanced

The advanced analysis initially aims at calculating the errors of each device in relation to the reference data. This step was carried out with R statistical software.

This analysis consisted of calculating the distance difference between a position of the RTK GPS and the average of the equivalent positions recorded by the given mobile device.

The errors calculated as such were then analysed:

- first, by analysing their distribution,
- then second, by comparing them with HDOP. Considering that HDOP provides an estimate of accuracy under optimal measurement conditions, we wanted to analyse the correlation between HDOP and errors in our measurement conditions.

It would have been interesting to study the relationship between our calculated errors and the accuracy reported by smartphone manufacturers in order to verify the quality of the smartphone accuracy analysis. However, time constraints precluded such an analysis.

Likewise, it is important to remind that HDOP constitutes a different measure from the "GPS accuracy" automatically calculated by the Android system and often displayed in applications (such as ODK/Kobo[3]). This latter parameter was also not tested in this study.

The results of this analysis are presented in Sections IV and V.

III.1.D. Main limitations of this methodology

This study is the first of its kind at CartONG, and the conditions under which it was conducted necessarily limit its scope. This study therefore should not be considered as rigorous or definitive. However, it provides methodological clues and initial results, taking into account the following limitations:

- the number and diversity of devices tested remain low (making it difficult to draw conclusions on the factors influencing GPS quality)
- the test iterations between devices were unequal (for some models several devices have been tested while for others only a single one)
- data collection did not cover the range of possible environmental conditions (meteorological, topographical, etc.), nor variability in satellite constellations (preferred tests at different times of the day)
- and finally the study could be enhanced by testing additional devices.

[3] https://forum.opendatakit.org/t/odk-community-how-is-gps-accuracy-calculated-in-odk/2208

IV. Analysis of the GPS accuracy of mobile devices

IV.1. Feedback on observations

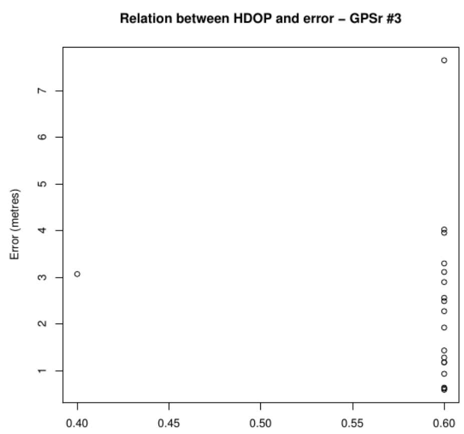
IV.1.A. Errors observed

The errors observed are from less than 1 m to a maximum of 10 m. Depending on the device, more or less frequent errors can be observed. For example, for one mobile device, most errors are below 4m, while for another, they are below 10m.

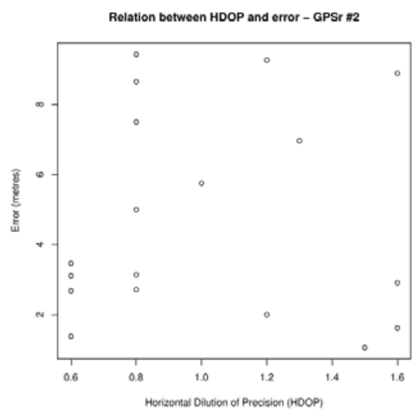
IV.1.B. Correlation between HDOP and errors

We could not find a correlation between the calculated errors and the HDOP.

To demonstrate a correlation between two variables, a mathematical function must be observed, generally of the linear function type (a line that would connect these points). It was not the case. On the other hand, we observed in some cases, a constant HDOP regardless of the error observed. These observations indicate that HDOP is not a reliable estimation of accuracy, regardless of device used. Nevertheless, this observation is to be put in perspective, the HDOP could actually be representative of the accuracy under optimal observation conditions (clear sky, good weather, clear area).



Case 1 - A single HDOP for all errors found



Case 2 - No significant correlation between HDOP and errors

IV.2. Hypothesis that may explain such differences

Since we cannot access the GPS receiver chip to analyse the impact of the sensor on the positioning accuracy, our contributions in this regard remain limited.

On the other hand, we could not observe any impact on access to satellite constellations on the quality of the measurement. Indeed, the two smartphones tested represented extremes in device accuracy (representing both the most accurate as well as the least accurate), despite using the same satellite constellations.

In the end, the positioning seems to depend on the quality of the receiver and the algorithm used for calculating the accuracy, but these criteria unfortunately cannot be distinguished in this context due to the lack of available information from the manufacturers.

For recommendations on how to optimize the use of mobile devices in GPS coordinate collection, see ***"Optimization of GPS data collection and troubleshooting tips when having GPS issues with a devices during a MDC".***

IV.3. Individual assessment of different mobile devices

The analysis of errors by device allows to extract a mean, a median and a 9th decile error. The mean error is an average of the errors observed. The median error indicates that when using the device, we are as likely to have a lower error as a higher one. The error at the 9th decile gives an indication such as: "when using device 1 (Samsung Tab SMT113), I have a 90% chance of having an error of less than 5.6m". The 9th decile error thus gives an idea of the error that can be "expected" by using a device.

Below is a summary of results:

GPS No.	**Model**	**Median error (metres)**	**Mean error (metres)**	**9th decile error (meters)**
1	Samsung Tab SM T113 sg-003	2,8	3,2	5,6
2	Samsung Tab SM T560	3,3	4,8	9
3	Samsung Galaxy Tab A 2016	2,3	2,4	4
4	Acer Iconia Tab 10 A3-A40	2,9	4	7,3
5	Trekker M1 Core	4,7	4,5	6,3
6	Samsung Galaxy J2 bonus SM G532G	3,9	4,6	7,6
7	Samsung Galaxy J7	2,2	2,7	5,5

The error distribution diagrams (see appendix) also highlight the difference of accuracy between devices. It would also have been interesting to carry out a larger number of measurements, in an attempt to find a mathematical distribution law as a reference for all the devices analysed.

Finally, it should be noted that all tested smartphones offer a GPS accuracy within 10 m, which is sufficient for most mobile data collection or base mapping activities carried out by CartONG and its partners in humanitarian contexts (such as recording of health infrastructures or water point coordinates). Specific activities such as recording building locations in dense urban or camp areas, plot surveys of agricultural lands, etc., may nevertheless require higher accuracy, depending on the expected analysis, and therefore particular attention to the GPS quality.

V. Steps to follow if you want to test your own mobile device

If you are interested in the analysis presented above and want to test your devices but without starting to code in R, there are different options depending on time frame and available tools (100% on smartphone, or with the use of additional software on computer).
These suggestions are not equivalent to the above test but offer more accessible (and less advanced) options to test your own devices, thus providing an initial overview of the quality of that device's GPS.
This analysis can be useful if you have to use devices that you do not know and for which you are unsure of the GPS quality, or if you want to know more about your devices to better manage their limits and uses, as it was the case with CartONG.

V.1. Minimal solution

1) Download the latest ephemerides to the smartphone, for example with GPS-Status Apps.
2) Use a smartphone navigation application that allows you to record a gpx track and display it on a background map (for example GPSlogger or OSMAnd for which activation of the track recording plugin is required): start recording your track, and repeat the same route as many times as possible.
3) Visualize the dispersion of the tracks (i.e. the maximum variability between the same assumed positions) on your application. The more your tracks are scattered, the less you can rely on the quality of your recorded GPS coordinates. Be careful: this is only an indication, as the dispersion in a given place can vary from one place to another.

NOTE: Perform this test under the environmental conditions of normal use of your devices. For example, if you know that you will need to record data during the rainy season, you may want to record it during a cloudy weather. It should be noted that the conditions for optimal record quality are: good weather, open space (outside urban areas, far from topography, etc.) without vegetation cover.

V.2. Advanced solution

This option is an extension of what's depicted above: this will need to be taken into consideration before recording your data.

1. Install the GPS Averaging application (https://play.google.com/store/apps/details?id=org.destil.destil.gpsaveraging&hl=en)
2. Select several remarkable points from your previous track and then for each one:
    a. position yourself on the point and start calculating an average position,
    b. wait until you reach an accuracy of less than 2m and then export the position in gpx.
3. Open exported gpx points in your navigation application next to your tracks.
4. Analyse the differences between your tracks and the average position. The bigger the differences, the less reliable your device is.

V.3. Expert solution

1) Perform the above advanced solution with four different devices.
2) Calculate an average of the mean points of the different devices for the same position with a software such as Excel (the calculation can also be performed in GIS software, such as ArcGIS or QGIS)
3) View and/or calculate the average deviations per device from the previously calculated average (from the advanced solution above)

For more information: Selection of some existing studies/publications about the topic.

***Signal Research Groups**:* The study examines the sensitivity of A-GPS by comparing the five leading GPS component suppliers on the market (Broadcom, CSR, Qualcomm, ST-Ericsson and Texas Instruments) and ten different smartphone/component configurations, with phones from Nokia, HTC, Samsung and Sony.

http://signalsresearch.com/issue/chips-and-salsa-xx-when-iconic-meets-anechoic-part-ii/

An article from the **"Forestry: An International Journal of Forest Research",** April 2017, analysing the effects of the forest and their seasonal variations on the GPS accuracy of smartphones. *Julián Tomaštík, Julián Tomaštík, Šimon Saloň, Rastislav Piroh; Horizontal accuracy and applicability of smartphone GNSS positioning in forests, Forestry: An International Journal of Forest Research, Volume 90, Issue 2, 1 April 2017, Pages 187–198, https://doi.org/10.1093/forestry/cpw031*

Article GPSZAPP.NET

https://www.gpszapp.net/top-5-des-smartphones-avec-gps-integre/

Dual-frequency chip:

https://medium.com/@sjbarbeau/dual-frequency-gnss-on-android-devices-152b8826e1c

The dual-frequency chip provides a new reception frequency to the devices, and an improved algorithm for position calculation. These chips are recent on the mobile device market and raise many hopes because they work in a rather similar way than GPS equipment used for topographic survey (without using the same key frequencies).

https://www.gsa.europa.eu/newsroom/news/world-s-first-dual-frequency-gnss-smartphone-hits-market

According to suppliers, this chip called BCM47755 makes it possible to determine a position with a 30cm accuracy (even inside buildings) against more or less 5 metres today. This chip uses two satellite frequencies (L1 and L5) at the same time instead of L1 only. L4 has a higher bandwidth and is less subject to interference, which also improves accuracy in dense urban environments.

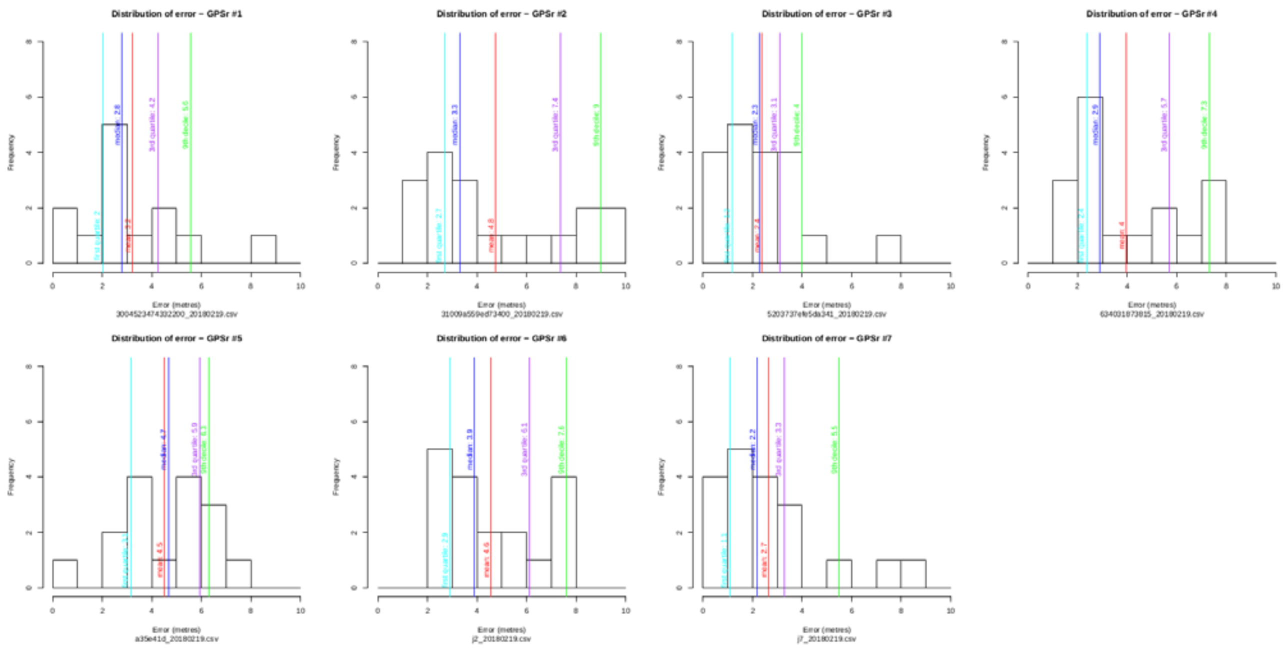
As this technology is still new, the benefit in terms of accuracy has yet to be proven and we must therefore be careful about its effectiveness. This chip is also more energy efficient (-50%) than the previous generation thanks to the presence of a duo of ARM processors. It should be noted that this chip is compatible with signals sent by Galileo satellites, the European satellite navigation system.

APPENDICES

Parameter settings for GPSlogger application:

Output file formats	gpx, csv, nmea and geojson	In the end, only the. gpx was used for display in QGIS and the.csv for analysis with R, the statistical computing software used)
Output name	add a prefix	To identify each device
Location providers / Positioning systems	GPS, GLONASS	Depending on the devices
Time before logging / Recording interval	minimum (0 or 1 second)	To maximize the number of record and detect as many errors as possible
Distance filters	disable	To maximize the number of record and detect as many errors as possible
Accuracy filter	disable	To maximize the number of record and detect as many errors as possible

Error distribution diagrams



Plots about correlation analysis between HDOP and calculated accuracy