# Error sources in positioning using GNSS receivers

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**Abstract:** *Position determination using GNSS receivers in short measurement sessions - RTK is affected by inherent errors. Sources of error in positioning must be known so that their impact can be administered. This article aims to present error sources that affect the precise measurement process through satellite technology as well as positioning solutions delivered by software applications currently used with GNSS receivers and their practical significance.*

**Key words:** GNSS, RTK, land survey, satellite geodesy, positioning errors

## 1. Introduction

The positioning systems have evolved a lot since the lunch of the first American satellites, in 1978, until reaching the full capacity, on 17 July 1995. Actually, two systems are at the designed configuration, NAVASTAR-GPS and GLONASS, and other two systems, GALILEO and BEIDOU are in the completion phase of the constellation. Also, the positioning methods with these systems have evolved a lot, from the singular solutions in the '80s to the precise point positioning in the present – PPP..

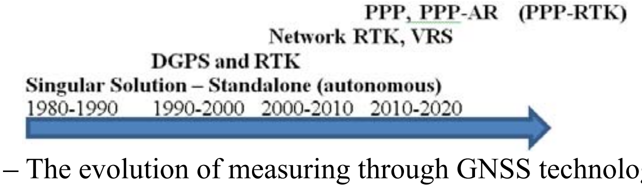


Fig. 1 – The evolution of measuring through GNSS technologies[1]

## 2. Errors that affect the GNSS measurements

GNSS measurements are affected by systematic errors that can be eliminated or significantly reduced in the measuring process and also by random errors, residuary, hard or impossible of eliminating. Errors are present in all three segments of a global positioning system, spatial segment, control and user segment. In the following we'll detail the errors that occur in the measuring process starting from the issuing of the satellite signal to the reception of it by the user.

### 2.1. Configuration errors

The minimum necessary number of satellites in GNSS positioning is four, but, to assure the land survey measurement precision that is imposed, unfavorable configuration sometimes, a higher number of satellites would be desirable.

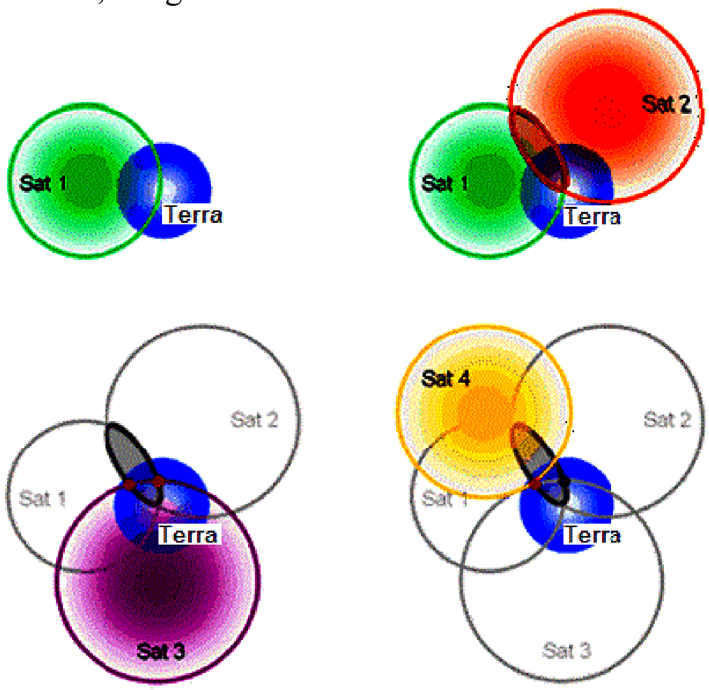


Fig. 2 – The minimum number of satellites in positioning

DOP – Dilution of precision, it's an index that estimates the precision of positioning by using satellite navigation systems receivers, GNSS – Global Navigation Satellite System. For some GNSS receiver, if the receiving satellites are grouped in a dial, the dilution of precision is high, the satellite geometry being weak. It's desired a low value for the DOP index. The right phrase is using GNSS satellite navigation system receivers, not GPS receivers, as these receivers use in positioning not only the American satellite constellation NAVSAR-GPS, but also Russia's constellation-GLONASS, E.U. constellation Galileo or that of China-BEIDOU.

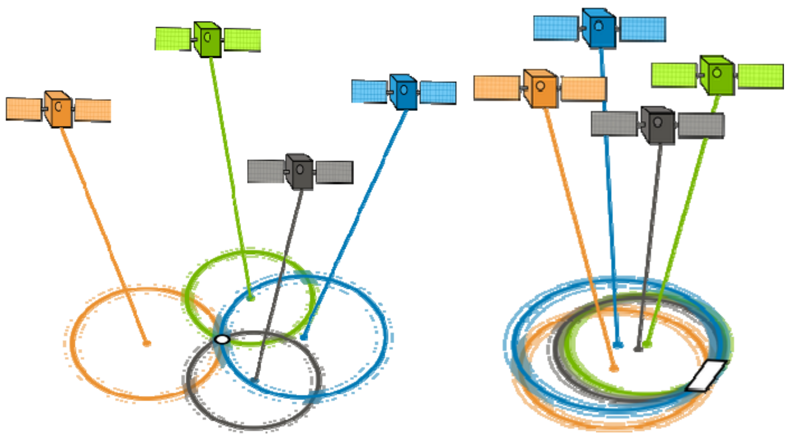

Fig. 3 – Good geometric layout (left) and poor geometric layout (right) – high DOP

The dilution of precision error, DOP, has components such as PDOP – position dilution of precision, GDOP – geometric dilution of precision, HDOP – horizontal dilution of precision, VDOP – vertical dilution of precision, TDOP – time dilution of precision.

PDOP – Position Dilution of Precision (3-D), known also as „spherical dilution of precision" is described by the following relation:

$$PDOP = \sqrt{HDOP^2 + VDOP^2} \quad (1)$$

Thus, the position dilution has two components, the horizontal dilution of precision (HDOP), regarding the latitude and longitude and the vertical dilution (VDOP).

$$HDOP = \sqrt{BDOP^2 + LDOP^2} \quad (2)$$

BDOP – dilution of precision regarding the latitude

LDOP – dilution of precision regarding the longitude

GDOP – Geometric dilution of precision, describes the impact of satellite configuration in the final precision of determining a point using GNSS technology.

$$GDOP = \sqrt{PDOP^2 + TDOP^2} \quad (3)$$

TDOP – dilution of precision regarding time

In most cases the related GNSS receivers software programs, such as Carlson SurvCE or Microsurvey Field Genius, utilizes the PDOP, HDOP and VDOP notions.

### 2.2. Errors of satellite ephemeris

Errors of satellite ephemeris refer to the difference between the real satellite position and the position gave by the GNSS navigational message. These errors are the result of small orbital deviation of the satellites caused by the gravitational influences of the Moon and Sun, radiations, as well as the segment of control – estimation errors, predictions, made by it, and the age of navigation data.

The segment of control determines ephemeris's parameters by using interpolations of the elliptical trajectory of the satellite. The ephemeris error takes values between 1m and 6m – the error in determining the position of the satellite and it induces an error of 0.8m – 2,5m in positioning on the terrestrial surface.

### 2.3. Satellite clock error

The atomic satellite clocks used in positioning are very precise time measuring instruments that unfortunately are affected by errors. An error of 10 nanoseconds in time determination can cause a 3m positioning error. Satellite clock are monitored by the segment of control and compared to the more precise clock used in the terrestrial control system. A method for compensating the satellite clock error is by utilizing the given information by the SBAS or PPP.

### 2.4. Errors caused by the ionosphere and troposphere

When passing through the atmosphere's layers, because of the inhomogeneous structure, the UV radiations and solar X-rays effects on the particles, the satellite signal suffers some kind of refraction-speed variation, mostly by passing through the ionosphere, the superior layer of the atmosphere between 85km and 690km high, as well as passing through the troposphere, the inferior layer of the atmosphere.

The ionosphere is the superior layer of the atmosphere where gases are rarified and charged with positive ions. The ionization phenomenon consists in releasing one or (much rare) more electrons from the outer shell of the atom. As a consequence, the electric balance is cut and the atom acquires one or more elementary charges, becoming positive ions. The ionizations is made through photoionization or through shock. Photoionization takes place when the radiation energy quanta that operates on the h gas $\gamma > W$ – ionization mechanical work, and the ionization thorough shock is done by crushing the electron with a particle that possesses a sufficient amount of kinetic energy. The main source of ionization is the Sun, through the U.V. radiations emitted. The ionosphere error is due to U.V. solar radiation influenced particles, that are devised and become positive electrical charged. The browsing of the satellite signal thorough the ionosphere produces a "delay" up to ±16 ns, which in terms of positioning can lead to an error up to 7m. The error due to the ionosphere is in correlation with the maximum solar period [2].

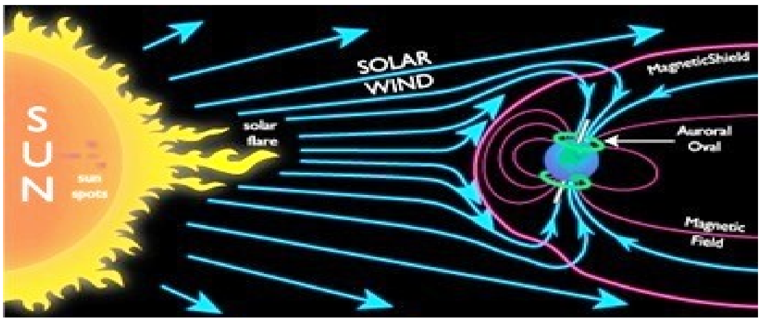


Fig. 4 – The U.V. solar radiation influence on the ionosphere

The troposphere is the inferior layer of the atmosphere with an average thickness of approximately 12km from sol level: 8km at the poles, 18km at the Ecuador; where you can find 75% of the amount of air from the atmosphere, fact owed to the gravitational force. The entire meteorological phenomenon takes place in the troposphere; there are the clouds that have a negative effect on the satellite signal.

Dried gases and water vapors induce smaller errors than the effect of the ionosphere, resulting in "delays" of up to ±1,5 ns that leads to a 2-3m error in satellite receiver distance determination, based on the altitude that the receiver is located and the local atmosphere conditions, the average positioning error is 1 m.

The error due to the troposphere has influences that depend on the altitude, elevation angle and day time [2].

$$\Delta t = N_R \frac{\Delta H * 10^{-6}}{\sin e} \quad (4)$$

Where: $\Delta t$ – Variation of troposphere error according to altitude;
$N_R$ – Total, dry and wet refraction;
$\Delta H$ – Altitude variation;
$e$ – Elevation angle.

The error due to the troposphere increases when the satellite elevation angle used in positioning is small.

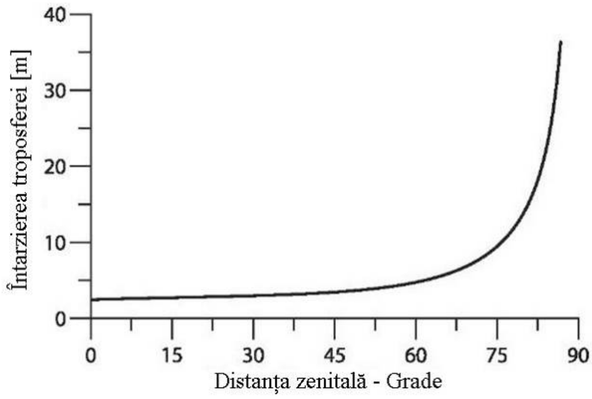


Fig. 5 – Correlation of tropospheric error-zenith distance

To minimize the ionosphere error, GNSS receivers use multiple frequencies, for example, at the NAVSTAR GPS system, for a civil user that utilizes a G.N.S.S receiver: L1C / A, L2E, L2C, L5. The delays due to the ionosphere are dispersive, inversely proportional to the square carrier frequency, thus the code is "delayed" and the phase is "advanced", and when using a multi-frequency receiver, the ionosphere error is easily attenuated by using the pseudo-distance concept. For the old generation receivers, with one frequency, models for ionosphere will be used – Klobuchar ionosphere model can reduce the ionosphere error to half [3]. In 90% of the cases the residual error associated with the satellite-receiver distance is <10 m.

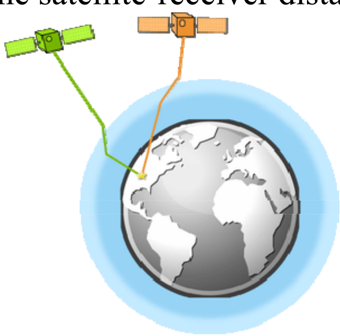

Fig. 6 – The refraction of the satellite signal crossing the ionosphere

The troposphere is a non-depressive environment, the code and phase are equally affected, by using multi-frequency receivers does not attenuate the tropospheric error that is dependent on atmospheric parameters such as atmospheric pressure, temperature, relative humidity. This error has two components: dry component, with an 80% share in tropospheric error, computable with good accuracy and wet component, with a 20% share in tropospheric error, the latter being much harder to approximate.

A well-applied correction tropospheric model can reduce this error by up to 90%.

The use of ground stations, permanent stations and geostationary satellites reduces these errors, the influence of which cannot be completely eliminated from the positioning process. The ground stations record long period data which generate corrections for “delayed” satellite signals, through statistical processing of random errors, resulting in average values.

### 2.5. Multipath error

The multipath error is due to a false signal reception by the GNSS receiver, reflected by obstacles or materials prone to such a phenomenon.

The local conditions that can induce a multipath error in situ are snow, rainfall, but also local vegetation, buildings, and various materials around the receiver.

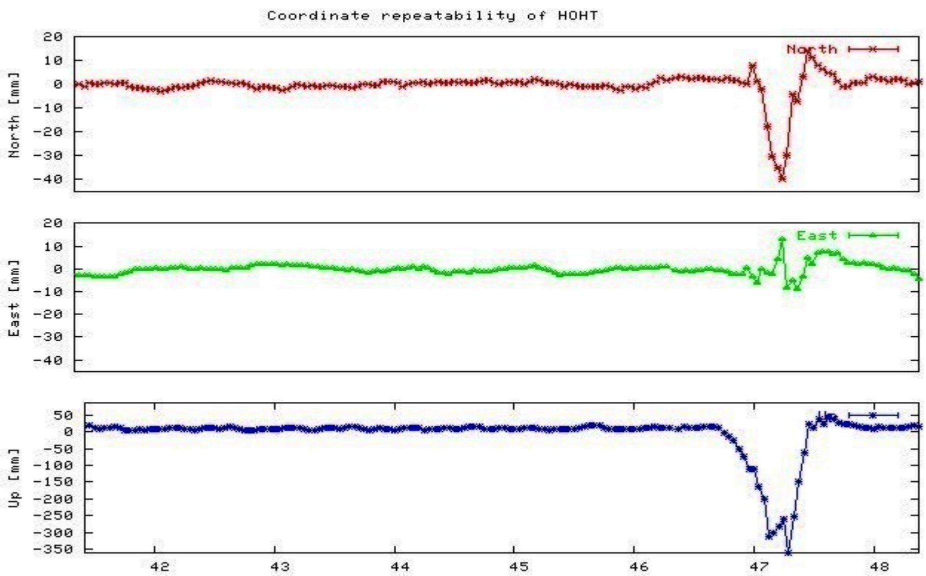


Fig. 7 – Multipath error due to massive snowing [4]

In the previous figure, for a short period of time, massive snowfalls have disrupted AGNES-Automatic GPS Network Switzerland System, the Hohtenn station in Switzerland. Position estimation errors have reached maximum of 40mm horizontally and 350mm vertically. Due to high temperatures in 2006, the fallen snow had quickly melted and the estimated coordinates have returned to the initial value, as it can be seen in the figure above [4]. The higher value delays of the satellite signal are solved by the GNSS receiver; meanwhile slow delays are solved by the GNSS antenna. The new generation receivers, of high quality, have a relatively good behavior in regards to multipath error.

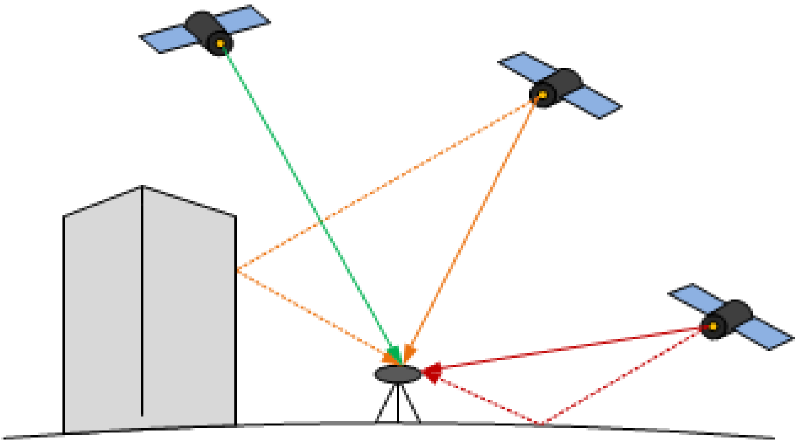

Fig. 8 – Multipath error [5]

### 2.6. Radio interference errors

The error due to radio interferences causes distress in signal receiving or even its complete obturation. Interferences lead to negative effects such as losing the satellite signal, a decrease in signal power, the increase of satellite signal “noise” and an increase of the time neded to get a fix solution.

These interferences can be intentional or not, as lately we could see a significative increase in jamming. Determining the disturbance of the satellite signal due to radio interference can be difficult, a sudden decrease in signal quality can be due either to radio interference or to a location that will not allow a qualitative satellite signal. Reducing these negative influences can be achieved by using multi-frequencies, encrypting the satellite signal, using a stronger signal, using signal processing methods [5][6].

Other errors that can influence satellite measurements are: errors due to terrestrial tides, errors due to ocean levels, errors due to seasonal height, errors due to antenna orientation, receiver code error, receiver phase error, hardware components errors, error of the receiver’s antenna phase center.

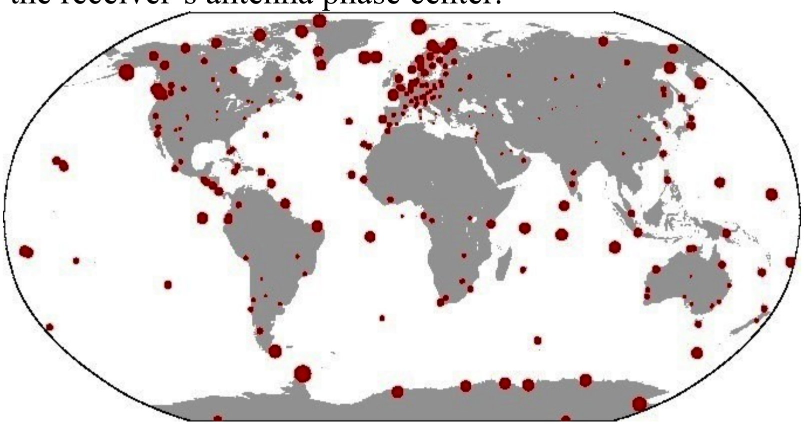

Fig. 9 – Tide variations [4]

In the previous figure it can be observed the variation between two series of 14 days observations, each and one of them for 250 network points from the IGS-International GNSS Service, variation influenced by tides [4]. The biggest variation was register in O'Higgins station in Antarctica.

**3. Given solutions by GNSS receiver software programs**

The GNSS receivers used in current engineering practice provide differential positioning solutions of the fixed, float, DGPS type but also singular - autonomous positioning as follows:

Fixed – solution having the ambiguities resolved, fixed, from the phrase "Ambiguity–fixed solution" or "Bias-fixed", in which the estimated parameters - the point coordinates, no longer contain ambiguities, which are being solved at a whole solution. This type of solution is desirable in positioning, the estimated parameters being the closest to their actual value.

Float – solution still having ambiguities, coming from the phrase "Ambiguity–free solution", representing that positioning solution in which estimated parameters, the coordinates of the point to be measured still contain ambiguities, these being unresolved or in the course of solving.

DGPS – Differential GPS – positioning solution of centimetric order used in positioning. From the metric level, to the decametric offered by GNSS technology, DGSP provides a precision that can achieve in best conditions the 10cm precision. DGPS method is required for the use of a fixed station, the ground station being used in the past to remove the availability selection, SA, and after removing this coding of the satellite signal to the NAVSAR-GPS constellation in May 2010, the DGPS method has still been use due to the diminution of certain errors that affect the satellite signal.

The high precision measuring DGPS methods are as follow:

- SBAS-Satellite-based augmentation systems – WAAS, EGNOS, SDCM, GAGAN, MSAS, QZSS-SAIF or SBAS Global as Starfire, Veripos and TerraStar, OmniStar and STARFIX.

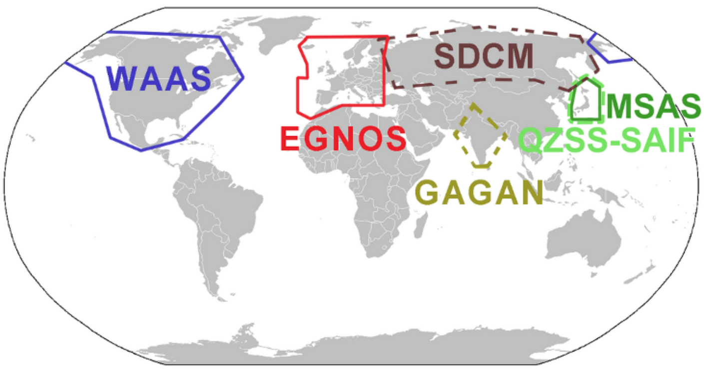


Fig. 10 – SBAS areas

- RTCMv2 – Correction messages are sent from a permanent station by inducing an accurate positioning to 40-80 cm;

- RTK – The correction messages are received by the receiver from a permanent station so that the precision obtained is centimetric.

Autonomus - Low, metric, sometimes decametric positioning precision, applicable in applications requiring precision in low positioning – GIS applications, but unsustainable for high precision requirements.

## 4. Considerations regarding the use of combined GNSS solutions

The next figure presents results obtained from the study of Onsala base, Halland region, Sweden and Wettzel, Bayern region, Germany. As it can be observed much higher error could be seen through the use of GLONASS system, as a consequence of a lower satellite orbital quality. By using NAVSTAR-GPS system, the results are superior, however, better results were given through combining GNSS solutions [4].

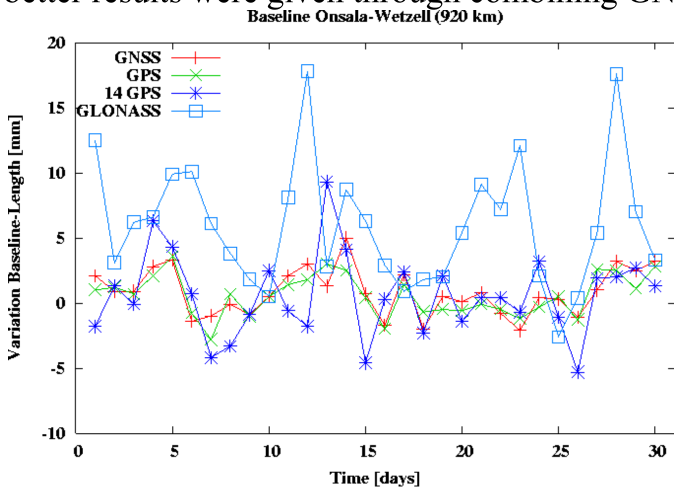


Fig. 11 – Leng variations for the Onsala-Wettzell base for four types on GNSS solutions[4]

The use of combined solutions in positioning, the use of multiple frequencies, comes with a reduces in ionospheric error, better geometry for a long time, but also induces new problems such as determining and offsetting the time between positioning systems, calibration, correction of system distortions, that is essential in bringing observations from different satellite constellations to a precise positioning solution.[8]

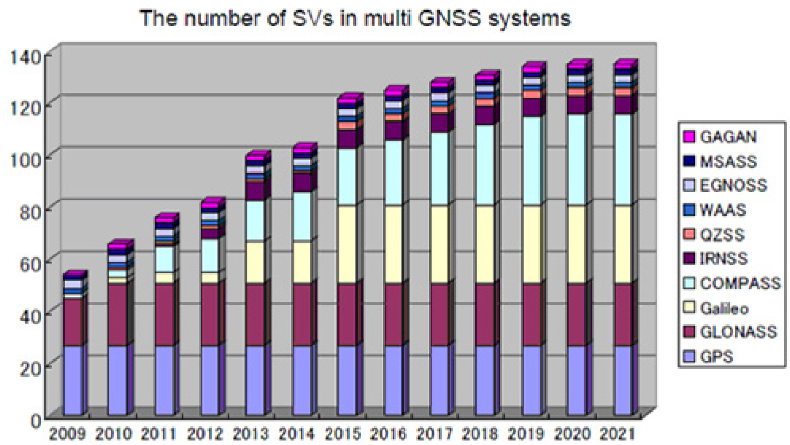


Fig. 12 – Number of satellites of global and regional positioning systems

A practical example made in Australia has demonstrated that RTK measurements based on a single frequency using GPS + BDS + Galileo + QZSS (Japanese regional system) have a 100% success rate in terms of instantaneous ambiguities resolving for an angle opening of 35 degrees, with a centimetric solution, while using only the NAVSTAR-GPS system the success rate in ambiguity resolving is at 8%, not always a solution could have been achieved [9].

A conducted study in our country highlights the fact that not always the use of combined GNSS systems can bring higher precisions than using a single system [10]. Thus, following the measurements made in 15 minute, 1h, 3h and 7h sessions, it was observed that the closest results from the known coordinates of the point were obtained in the 3h measurement session, using the NAVSTAR-GPS system, compared to only using the GLONASS system or the satellites from both GNSS systems.

## 5. Conclusions

Satellite signal is weak, usually much less than 100 watts are send on a distance up to 25000 km, when receiving the signal its power can be 160 dBW (decibel watt), meaning $1x10^{-16}$ Watts.

The errors influence that affect GNSS measurements were centralized in the following table. As it can be observed, the error with the highest value is that of the ionosphere; not taking into account and not decreasing these errors will reduce the positioning accuracy with GNSS receivers at the meter level or if we cumulate all the errors in a certain sense, the error can reach the decametric level. Also the operator is an important source of errors in the mesurement process.

*Table 1*

**The values of the errors that affect the satellite signal**

| Error tipe | Value[m] | Source |
|---|---|---|
| Ephemeris error | 0.8-2.5 | Spatial source |
| Satellite clock error | 0.3-4.0 | |
| Ionosphere error | 7 | |
| Troposphere error | 0.2-0.5 | |
| Receiver clock error | 1.1 | |
| Multipath error | ≤1 | Local source; Calibration. |
| Antenna error - receiver noise | ≤1 | |

The study of errors that can affect the GNSS measurements is in a constant evolution, reducing the effects of these errors evolved a lot also, concrete results in reducing the various errors are appearing continuously. Apart from GNSS positioning systems evolution there have been developed new GNSS measuring methods that bring an upgrade to positioning precision, DGPS, RTK, VRS, PPP, in present, these also being in a constant evolution. Utilizing combined positioning solution, GPS-

GLONASS and in the future GALILEO and BEIDOU brings superior results as against to positioning using a single positioning system, for example NAVSTAR-GPS. The advantage of utilizing these combined systems is that in urban areas with many obstacles they perform much better than single GNSS systems. In some cases when the number of satellites is sufficient, so a favorable geometry, the solution given by a single GNSS system can be much better than the combined one. Also a longer measuring session of a point is not equivalent with a better precision, the configuration has a word to say in this case also, a prolonged session could result in a poor configuration over certain short time slots, and so the solution is weaker than a shorter time slot with an optimal satellite configuration.

## Bibliography

[1] Andrey Veytsel, Ph.D, Moscow Technical University – ”GNSS Accuracy Improvements through Multipath Mitigation with New Signals and services”, 10 Meeting of the International Committee on Global Navigation Satellite Systems (ICG-10), November 2015, Boulder

[2] Hegarty Christopher – ”GNSS Measurements and Error Sources”, Workshop on GNSS Data Application to Low Latitude Ionospheric Research, 6 - 17 May 2013

[3] http://www.navipedia.net/index.php/Klobuchar_Ionospheric_Model#cite_note-Klobuchar-1

[4] U. Hugentobler, H. van der Marel, T. Springer - ”Identification and Mitigation of GNSS Errors”, IGS Workshop, Mai 6-11, 2006, ESOC, Darmstadt, Germany

[5] Pedro Filipe Faria Nogueira Ferrao – “Positioning with Combined GPS and GLONASS Observations”, M.Sc. Degree Thesis, Tecnico Lisboa University, may 2013 https://fenix.tecnico.ulisboa.pt/downloadFile/395145496449/thesis.pdf

[6] Peter F. de Bakker – ”Effects of Radio Frequency Interference on GNSS Receiver Output”, Delft University of Technology, Faculty of Aerospace Engineering

[7] Laura Ruotsalainen, Dr.eng., Research Manager, Department of Navigation and positioning, Finnish Geospatial Research Institute (FGI), National Land Survey – ”Other error sources including jamming and spoofing”, NKG Summer School 2016

[8] D. Pandey, R. Dwivedi, O. Dikshit, A. K. Singh – “GPS AND GLONASS COMBINED STATIC PRECISE POINT POSITIONING (PPP)”, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLI-B1, 2016, XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic

[9] http://www.insidegnss.com/node/4275

[10] Păunescu Cornel., Vasile C. și Ciuculescu I. C. – ”CONSIDERATIONS FOR GNSS MEASUREMENTS”, RevCad 18/2015, ISSN 1583-2279