Farm/Agriculture Machinery Guidance

Galileo Information Centre for Mexico, Central America and the Caribbean

Implemented by:

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a LEONARDO and THALES company

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1.1 Introduction

Farm machinery guidance is one of the multiple applications of GNSS. It uses a Global Navigation Satellite System receiver to know the position of the vehicle in which it is installed to then support the guidance path of the farming machinery. This application allows farmers optimizing farming tasks such as ploughing, sowing or even fumigating.

Table 1 summarizes the main content of this technical note. It presents three levels of autonomy this machinery guidance may have for the faring machines. Next sections describe each autonomy level with an analysis of the technology needed to be used (listed in the second row of the table). Finally, last section considers some technology vendors already existing in Mexico, Central America and the Caribbean and any possible needed steps in order to promote the use of GALILEO constellations in this type of application.

Farm machinery guidance			
	Autonomy level		
	Low: Manual guidance	**Medium: Assisted guidance**	**High: Integrated auto-guidance**
Technology needed	Application SW + display GNSS receiver	Application SW + display GNSS receiver Navigation controller Electro-mechanical motor Accuracy improvement facility	Application SW + display GNSS receiver Navigation controller Vehicle interface Accuracy improvement facility
Existing technology	The technology needed for all three levels is already present in Mexico, Central America and the Caribbean although not all using the GALILEO constellation		
Next steps	Increase the system performance and also introducing GALILEO constellation in the solutions already on the market		

Table 1: Farm machinery guidance

1.2 Farm machinery guidance types

According to the level of autonomy of the farming vehicle when using this technology, it is possible to distinguish three different levels: manual guidance (low), assisted guidance (medium) or integrated auto-guidance (high). The former one consists of providing this application as an aid to the farming vehicle driver; while the second and the third levels will support guidance of autonomous farming vehicles, where the 'driver' is not on the vehicle in the third one.

Table 1 below shows different examples of machine guidance applications. As it can be seen, several vehicles can benefit from this solution, each of them with a different level of autonomy, depending the technology used. The figure shows the following different hypothetical situations:

- **Manual guidance**, such as the one available in the blue tractor at the bottom left part of the figure, carrying on tasks like ploughing in which it is only necessary the first level of autonomy.

- the green tractor at the middle left part of the figure, in which **assisted guidance** allows the driver to pay attention to other tasks like plants treatment when autonomous driving is performed without needing assistance of the driver. And finally,

- **Integrated auto-guidance** vehicles that can be of different types depending on the intended task to be achieved. There could be unmanned vehicles following other vehicles, like the red harvester at right of the figure, to perform farming tasks in parallel; or there could be completely autonomous vehicles,

The highest level of integration would be reached by the use of applications for the reception, integration and analysis of all the data generated in each process, by the farmer who may be controlling all machinery from the office or from a mobile device such as a tablet or smartphone (like in the figure).

Above farming guidance cases can be complemented by other applications using GNSS (e.g.: unmanned aviation for agriculture) as the black drone shown at bottom right part of the figure. This drone can be used for different purposes like for the analysis of different aspects of the quality of the fields and grains, to be used to optimising the use of pesticides, for example, so that the fully autonomous vehicle may sprinkle pesticides only on the needed areas formerly analysed based on the images captured by the drone. These drones or other technology can be used to support the previously needed field delimitation in support of the basic machine guidance.

Figure 1: Example of a whole farm with machine guidance at different autonomy

The three autonomous levels need the following minimum technology set:

- GNSS receiver (see below), integrated in the vehicle or external to it, to be complemented with other devices in case of assisted guidance or of the integrated auto-guidance levels.
- Application SW + display to show the positioning and guidance aids.

The more autonomy is required, the more technology will be needed. For both of assisted guidance and the integrated auto-guidance, in addition to the minimum technology set, the following technology will be required being more or less sophisticated depending on the autonomy levels:

- Navigation controller
- Electro-mechanical motor or a vehicle interface
- Accuracy improvement facility

1.3 Manual Guidance

In this level, the driver of the farming vehicle is aided to keep the path in order to reduce skips and overlaps.

The system needed is composed by a GNSS receiver, installed in the vehicle or external to it, and a monitor (commonly simply showing lightbars) (composed by the application SW and the display) indicating the correctness of the path according to the ideal path to follow, set with previous passes, and intended to sign the need to make steering adjustments by the driver. The display showing lightbars can be replaced by foam marker, allowing to have a better awareness of the vehicle from inside the cabin.

Figure 2. Example of an external GNSS receiver (Trade mark by JohnDeere with offices in Mexico - https://www.deere.com.mx/es/agricultura-de-precisión/receptores-y-monitores/receptor-starfire-6000/**)**

Figure 3. Example of a simple lightbar (Bandertbit by Artbitingeniería https://arbitingenieria.com.ar/banderillero.php)

Figure 4. Example of a more sophisticated lightbar (EZ-Guide 250 de Trimble https://trl.trimble.com/docushare/dsweb/Get/Document-699587/Sistema%20EZ-Guide%20250%20-%20Hoja%20de%20datos%20-%20Espa%F1ol%20%28Spanish%20EU%29.pdf multiconstellation

One of the most important aspects to consider when selecting these devices is the *positional accuracy,* that depends on both the quality of the method used to obtain the vehicle situation (usually through differential correction), and the driver's ability to "follow the lights". Consequently, their prices depend on the desired accuracy of the GNSS receiver, and/or the additional information the application SW could offer to the driver (being from a simple lightbar to a whole map with the soil type and the path already covered).

For the manual guidance, this technology set can also be placed directly in a mobile device such a smartphone or tablet, or even a computer.

1.4 Assisted guidance

At this level, the system has the same capabilities as for the manual guidance, but with an additional technology, allowing to automatically guide the vehicle (still requiring the driver to remain inside the cabin). This capability is supported by an upgrade in the vehicle to include now an electro mechanical motor together with a navigation controller.

Figure 5 presents an overview of a general auto-guidance system. As previously explained, the guidance SW application and display and the reception antenna are needed as are common to all autonomous levels, but to be able to have an assisted guidance a navigation controller and an electro mechanical motor devices are also needed. In addition, the more accuracy is needed, the GNSS receiver antenna may differ and could need some extra (non GNSS) antenna to have RTK corrections (explained below).

The navigation controller is the part of the system engaged of determining the actions needed to keep the path of the vehicle in the correct track. These actions consist of electrical signals that are sent to the electro mechanical motor to be later converted into the necessary change in the steering to correct the trajectory. It may vary depending on the available vehicle’s steering interface.

The electro mechanical motor converts the electronical signals into the needed steering for the vehicle in each moment. It acts directly on the steering wheel and can be deactivated to use manual guidance.

The figure below shows different technology elements needed for this assisted guidance. Different examples of guidance displays, navigation controllers and electro mechanical motor elements are shown (each row means different examples of these systems, including all the supported display models).

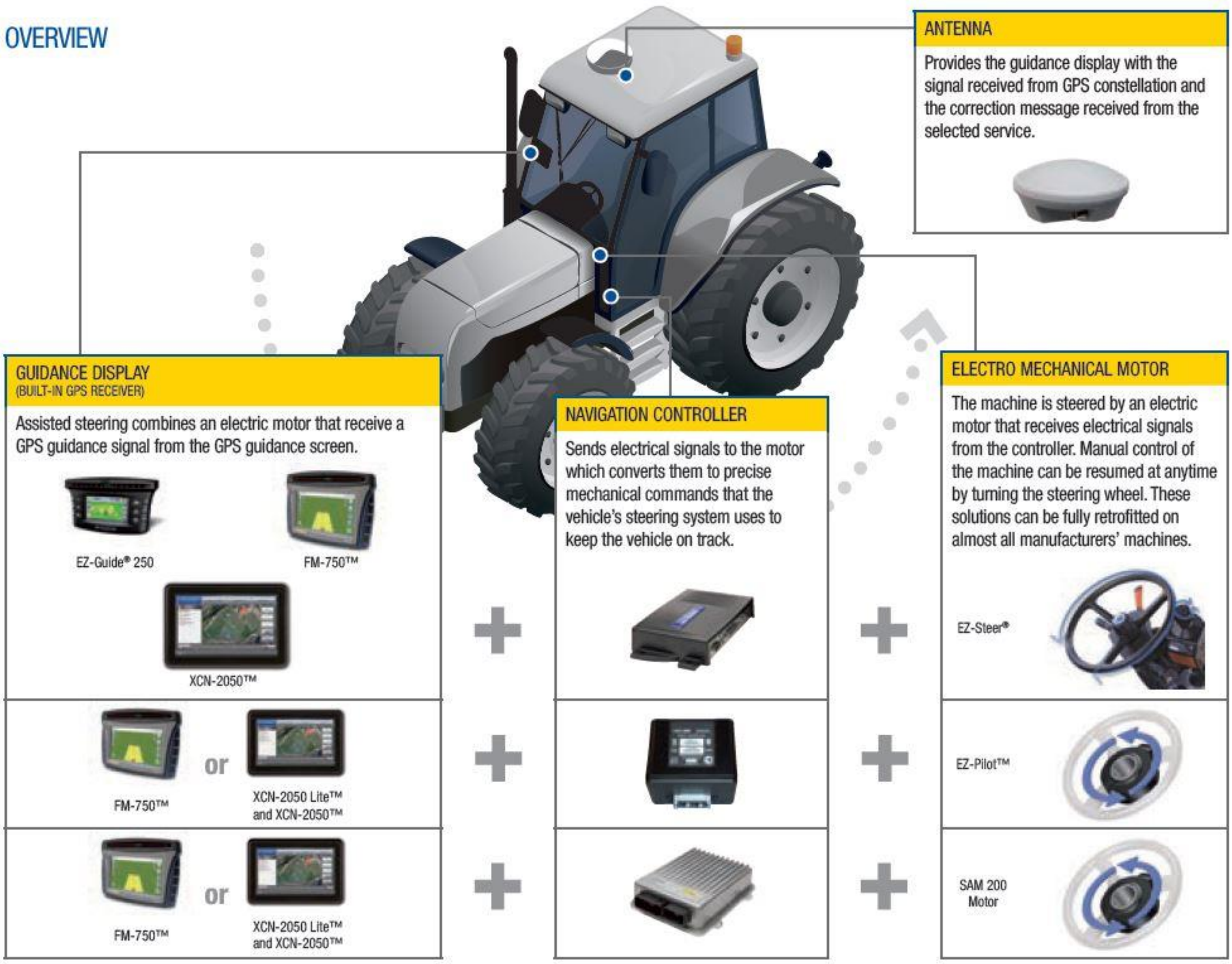


Figure 5. Example of auto-guidance system overview (https://murphysmotors.ie/gps-precision-farming/)

The electromechanical motor required depends on the specific solution to be adopted. There are some models that perform the movements directly in the steering wheel with a motor coupled to it, while others do it incorporating a friction wheel, as it can be seen in above Figure 5.

This middle autonomous level, as mentioned before, still requires the on-board driver's supervision (for example for big direction turns, etc.), but allows him to pay attention to other activities such pesticide sprinkle, seed dissemination, etc. while the autonomous driving is being performed.

At last, it is important to note that accuracy is a must in an autonomously guided machine. To measure it, a new term called "pass-to-pass accuracy/error" is used. This term is defined as the accuracy which can be achieved over a 15-minute window, being 15 minutes the approximate time to make a pass in a typical field[1]. Once a pass in the field with the tractor has been done, when a new pass is done and the tractor arrives to the same point according to GNSS equipment, this position is not exactly the same, there is a bias. That bias is the pass-to-pass accuracy.

According to the above explained pass-to-pass accuracy, three categories can be established:

- Sub-meter accuracy: It usually means approximately 2-4 feet (0,5-1,2 m) year-to-year and less than 1 foot (0,3 m) pass-to-pass errors. This accuracy can be achieved by using differential GPS corrections, obtained from satellite or radio sources like the OmniSTAR[2], or John Deere StarFire1[3] signals. These corrections are relatively inexpensive, but some of them require an annual subscription. This sub-meter system accuracy may be required for example when performing tillage, or when using some types of fertilizer or chemical applications when seeding and harvesting. These devices can be easily transferred between vehicles, so the same steering system can be used on different vehicles.

- Decimeter accuracy approximately 4-8 inches (10-20 cm) year-to-year and 3-5 inches (7-12 cm) pass-to-pass errors are feasible with decimeter accuracy systems. This can be achieved using either a local base station or dual frequency receivers with private satellite differential correction services, such as Omni STAR High Performance (HP) or John Deere Star Fire 2 (SF2). With the increased performance, operators can use auto-guidance during most of the conventional field practices that do not require very high accuracy, such as intra-row weed control automation. It is important to note that the new GALILEO High Accuracy Service (HAS) allows (PPP – see below) correction signal transmission through its E6-B channel and provides users to get positioning error below 20 cm. Being a new service, receptors will be growing in the market as from now.

- Centimetre accuracy can be obtained with additional signal corrections. There are two classical approaches to get the signal corrected: real time kinematic (RTK) and precise point positioning (PPP).
  - RTK differential correction consists of the usage of radio communications to propagate the accurate position of a reference point in which a base

[1] https://egnos-user-support.essp-sas.eu/new_egnos_ops/pass_to_pass#:~:text=Pass-to-pass%20accuracy%20is,pass%20in%20a%20typical%20field.&text=This%20bias%20is%20the%20so,-to-pass"%20accuracy.

[2] Omnistar is a trademark of Trimble Navigation Limited. https://www.omnistar.com/Applications/Agriculture.aspx

[3] John Deere StarFire 3000 or 6000 Receiver is a trademark of John Deere and it is latest in Global Navigation Satellite System (GNSS) signal processing technology, and a differential correction signal. https://www.deere.com/en/technology-products/precision-ag-technology/guidance/starfire-6000-receiver/

station is based, so that to apply the corrections according to the RTK base station location, as shown in Figure 6.

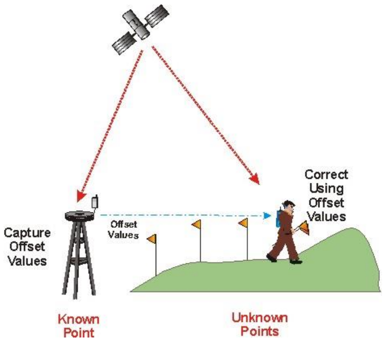


Figure 6. Graphical explanation of RTK technique (Source: https://traversesurvey.com/products/)

- PPP instead relies on current and coming GNSS signals. It uses processed measurements from a single user receiver, using detailed physical models and corrections, and precise GNSS orbit and clock products computed beforehand. The advantages of this approach are that it allows high accuracy without using local base stations in the vicinity of the user and that, as GNSS orbit and clock are by nature global, the PPP solutions are also global. The main disadvantage is that, due to the delay in satellite communications, corrections do not arrive in real time, making it difficult to be used for real-time applications. There are several SW products implementing PPP processing strategy[4], some of them are SW programs, like gLAB (a GNSS tool suit created by ESA and UPC) and magicGNSS (developed in Spain by GMV); other are PPP online services, such as magicPPP (GMW) Navcast (from Spaceopal) and TerraStar Corrections (Hexagon).

- In addition to the ability to precisely determine geographic location, auto-guidance systems usually measures the vehicle orientation in space, and compensates for unusual attitude, including roll, pitch and yaw.

- Centimetre pass-to-pass accuracy is used in tasks such as conducting a strip-till operation, followed by the seeding process in a new pass. It is necessary to assure seeds are placed at the center of the tilled strip. Operations near the edge of the tilled strip or even out of it can have a negative impact in the crop yield.

The assisted guidance level allows to switch from autonomous to manual guidance whenever is required, (for example for big direction turns, etc.) and it is compatible with a significant number of vehicles that do not have these systems incorporated

[4] https://gssc.esa.int/navipedia/index.php/PPP_Systems

from the manufacturer. It is an affordable option to those who does not want to spend a big amount of money in a new tractor.

1.5 Integrated auto-guidance

This application is very similar to the previous one, but it requires the highest of the accuracy levels explained above, to allow the driver not being in the vehicle, having a fully autonomous vehicle.

Tractors or similar vehicles can be used autonomously linked with another vehicle with assisted guidance or even manual guidance. This needs a connection between them in order to “follow the path” with no risks. Figure below shows the main components required in a vehicle tandem of this type.

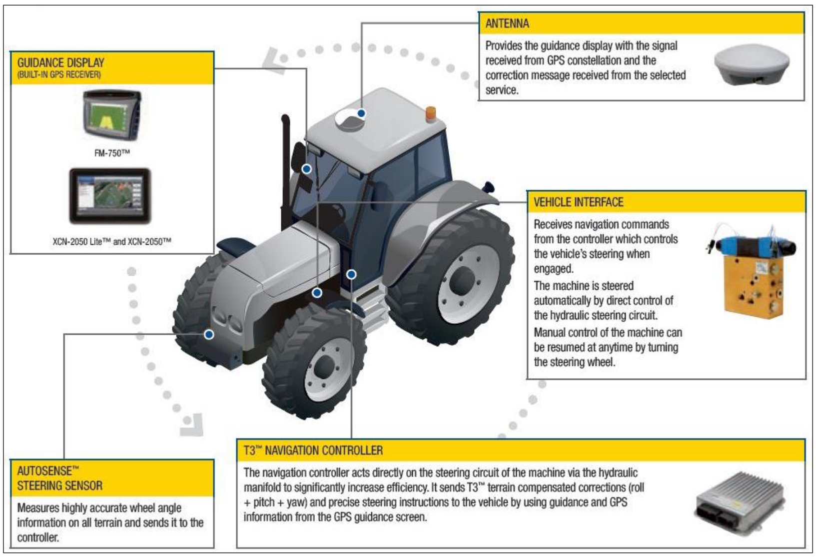


Figure 7. Example of integrated auto-guidance system overview (https://murphysmotors.ie/gps-precision-farming/)

There are two main differences with the previous assisted guidance level technology needs:

- Navigation controller: It acts directly on the steering circuit sending the commands to the hydraulic manifold. It increases the efficiency and makes it possible not only to control the direction in a precise way, but also to cope with terrain irregularities.

- Vehicle interface: It substitutes the electro mechanical motor of the assisted guidance applications. It links the navigation controller with the hydraulic manifold and makes the commands needed to control the last one. It also automatically changes the steering mode to manual when the steering wheel is turned.

1.6 Drones

Even though drones are not considered as agricultural vehicles, their usage in precision agriculture is notably increasing in the last years due to their versatility and autonomy to efficiently accomplish determined task, such as fumigation among others introduced below.

One of the most important tasks in which drones as to be used for precision agriculture is in defining the field limits. In order to use machine guidance, the field must be limited so that the path can be optimized and the vehicles can follow it without problems. With GNSS, drones can obtain those data. For bigger land field areas, satellite Earth Observation applications can be also used, together with other possible cadastre data to delimitate the borders of each field.

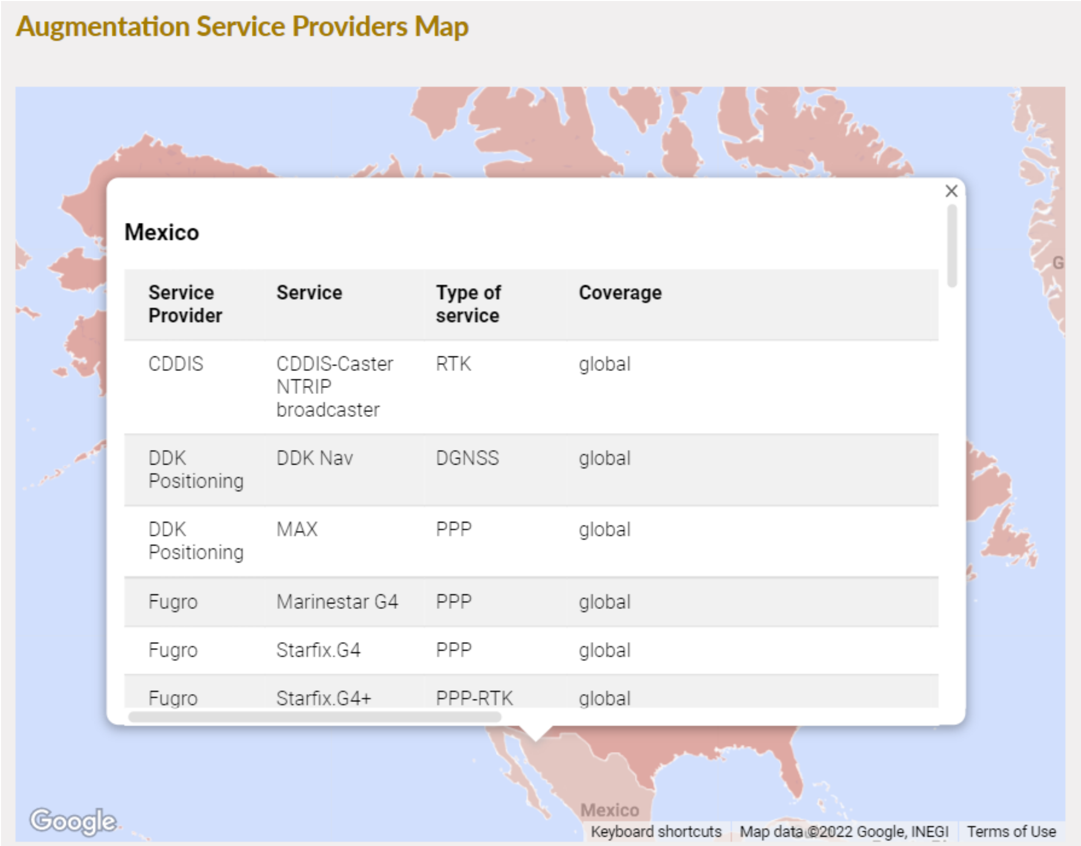
Drones are possible systems that can be also used to obtain images to determine the quality of the field and the crop in a much reduced period of time.

In addition, it is increasing the usage of the unmanned aviation systems for fumigation and crop treatments, allowing to accomplish these usually long and burdensome tasks in an easy way and with not so many human resources.

These applications will be analysed deeply in another technical reports.

1.7 Current technology status and next steps (Commercial opportunities)

Above mentioned applications already exist in Mexico, Central America and the Caribbean implemented and provided by companies like Fugro, Hemisphere, or Hexagon. There are different types of services appropriate to all needs and budgets, offering different levels of accuracy from centimetres to decimetres.



Service Provider	Service	Type of service	Coverage
CDDIS	CDDIS-Caster NTRIP broadcaster	RTK	global
DDK Positioning	DDK Nav	DGNSS	global
DDK Positioning	MAX	PPP	global
Fugro	Marinestar G4	PPP	global
Fugro	Starfix.G4	PPP	global
Fugro	Starfix.G4+	PPP-RTK	global

Figure 8. Augmentation service providers that support Galileo in Mexico (https://www.gsc-europa.eu/gnss-market-applications/augmentation-providers-map)

Nowadays, multiconstellation is already present in their systems and these companies have implemented their solutions using Galileo.

Finally, it is important to remark that this technology is not deemed affordable for small fields due to the high invest needed at the beginning to acquire the vehicles or to adapt the ones already in use. On the other hand, it shall be taken into account that GNSS signal is not accurate when there are obstacles (e.g.: trees), so in these situation RTK is a must (with it corresponding price increase).

Due to the current usage of GNSS for machine guidance, the question about the advantage of why using **Galileo** could arise. Both GPS and GLONASS services have military and civil purposes, stablishing different levels of accuracy for each of them (more accurate in the first one). In their open frequencies (not for military purposes) this accuracy can be augmented through augmentation systems, but they depend on the manufacture companies and they usually require the payment of a subscription to have the access to this service. The basic resolution offered by both GPS and

GLONASS (2-3 meters[5]) is not always enough for the tasks to achieve in these types of applications.

On the other hand, **Galileo** offers a fully civil service with no extra payment for higher accuracy. Although it is not granted it serves for all the application (when very high accuracy is needed, augmentation systems are still required), it still covers more applications requiring mid-high accuracy than the other constellations. The civil purpose of the service (free usage without any fee or tax) with a sub-meter accuracy (theoretically reached with the Galileo new generation satellites) makes possible to have the same service provided by other constellations with augmented resolution systems, but at a lower cost. Considering the (sometimes high) price of the different solutions in the market, the possibility to get the same performance in a cheaper way could move the customer towards based-on Galileo solutions. It will also reduce the cost to get high accuracy, because a bigger part of the market would not need augmentation service systems. All these points make **Galileo** constellation a competitor to be considered in the Mexican market to fulfil the precision agriculture requirements.

[5] See https://gssc.esa.int/navipedia/index.php/GLONASS_Performances for further information

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