EDAS (EGNOS Data Access Service): Differential GPS corrections performance test with state-of-the-art precision agriculture system

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BIOGRAPHIES

Juan Vázquez holds an MSc. in Telecommunication Engineering from the University of Oviedo. He has worked in the GNSS industry since 2008, when he joined GMV. There, he participated in several R&D projects related to GNSS system architecture, applications and integrity concepts. In 2010, he started working within the Service Provision Unit of ESSP SAS, as a consultant from GMV. He joined ESSP in 2012, where he is leading the team in charge of the EDAS service provision.

Elisabet Lacarra received her master degree in Telecommunication Engineering in 2005. Later she was collaborating in different projects related to GNSS systems in GMV. Since 2009 she has been working inside the ESSP, firstly as performance expert for the analysis and assessment of EGNOS performance and later as EDAS Service expert for the management of all activities related to the EGNOS Data Access Service provision.

Miguel A. Sánchez holds an MSc. in Telecommunication Engineering from the Technical University of Madrid (UPM). During 10 years in GMV AD he was deeply involved in GNSS projects related to EGNOS and GBAS development and operational implementation, and worked also as consultant for AENA and EUROCONTROL. He joined ESSP SAS from its early stages and, after more than 8 years in the company, is currently acting as Service Adoption and Support manager responsible for user support, user data services activities and any activity aimed at facilitating the adoption of EGNOS services in all market segments.

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ABSTRACT

EDAS (EGNOS Data Access Service) is the EGNOS internet broadcast service, which provides free of charge access to the data generated and collected by the EGNOS infrastructure. EDAS gathers all the raw data coming from the GPS, GLONASS and EGNOS GEO satellites collected by all the receivers located at the EGNOS reference stations, which are mainly distributed over Europe and North Africa. Once the data are received and processed, EDAS disseminates them over the Internet in real time and also through an FTP archive. The EDAS services portfolio is the result of various protocols and formats supported, along with several types of information made available to users by each service. This paper investigates the potential use of EDAS Differential GNSS corrections to support precision agriculture applications, by analysing the achieved performance during a dedicated in-field test campaign that has been conducted by ESSP and Topcon Agriculture.

EDAS service provision is performed by ESSP, as EGNOS Service Provider, under contract with the European GNSS Agency (GSA), the EGNOS program manager. The European Commission (EC) is the owner of EGNOS system (including EDAS) and has delegated the exploitation of EGNOS to the GSA. ESSP also manages the EGNOS Helpdesk, which provides technical support to users by answering to any potential question or by providing clarifications about EGNOS services, thus including EDAS.

In 2016, ESSP presented at the ION GNSS+ conference [21] the EDAS DGPS corrections performance achieved by applying EDAS DGPS corrections to the GNSS measurements from public reference GNSS stations (EUREF) at selected European locations in real-time during a 5-week period [21]. That study showed that horizontal accuracies below 1 meter (95th percentile) can

be achieved using EDAS DGPS corrections up to a distance of 250 km from the designated EGNOS station and that, within that range, pass-to-pass accuracies (15 minutes, 95%) were expected to remain below 20 cm. However, those pass-to-pass results were considered preliminary since they were based on post-processed static data (according to ISO 12188-1) and needed to be confirmed by in-field tests, i.e. considering the environmental and dynamic conditions of farming operations. This year, ESSP complements the study presented last year by conducting in-field tests aiming at measuring the pass-to-pass accuracy that can be supported by EDAS DGPS corrections in a dynamic and real-life environment.

In order to assess and validate the in-field tests, Topcon Agriculture joined ESSP for the activity. Topcon receivers, vehicles and guidance systems were used in order to confirm the suitability of the EDAS DGPS corrections for precision agriculture.

Firstly, this paper introduces the EDAS system and its architecture, presenting the main types of data disseminated through its services and the online information available to the users. As part of this introduction, special attention is put on the description of the EDAS Ntrip service. This service has been the main enabler for the performance tests presented in the scope of this paper, since it provides differential corrections to the GPS and GLONASS satellites in RTCM format, taking the EGNOS stations as reference stations.

Then, the paper describes the test scenarios and setups at the selected farm in Europe. Two different Topcon guidance systems on board tractors were running simultaneously to assess the EDAS DGPS positioning performance with respect to a reference, which was provided by an RTK-based Topcon solution. In each test, multiple runs with the rover tractor were performed over the reference patterns previously defined in the Topcon guidance systems. This paper presents a detailed analysis of the data recorded during the tests, especially in terms of the key performance indicators of the EDAS DGPS solution with respect to the RTK one.

The in-field tests results show that the DGNSS corrections broadcast by EDAS could be a suitable solution for cereal farms (in particular for spraying/spreading of any crop type and tilling and harvesting of cereal), when located within a reasonable distance (below 250 km approximately) to the target EGNOS reference station. It is to be noted that cereal farms represent around 80% of the farms in Southern Europe.

I. INTRODUCTION TO EDAS

EDAS Overview

EGNOS, the European Satellite Based Augmentation System (SBAS), currently provides corrections and integrity information to GPS signals over a broad area over Europe and is fully interoperable with other existing SBAS systems (e.g. WAAS, the North American SBAS).

ESSP (European Satellite Services Provider) is the EGNOS system operator and EGNOS Service provider, under contract with the European GNSS Agency (GSA), for the following three services:

- **EGNOS Open Service (OS)**, freely available to any user [2].
- **EGNOS Safety of Life (SoL)** Service, that provides the most stringent level of signal-in-space performance for safety critical applications [3].
- **EGNOS Data Access Service (EDAS)**, which is the EGNOS terrestrial data service offering free of charge access to GNSS data to authorised users [1].

As it can be observed in Figure 1, EDAS gathers all the raw data coming from the GPS, GLONASS and EGNOS GEO satellites collected by all the receivers located at the EGNOS stations. The EGNOS operational system comprises 38 ground stations (Ranging and Integrity Monitoring Station - RIMS) and 4 uplink stations (Navigation Land Earth Stations - NLES), mainly distributed over Europe and North Africa. EDAS disseminates this GNSS data in real time and through an FTP archive to EDAS users and/or Service Providers.

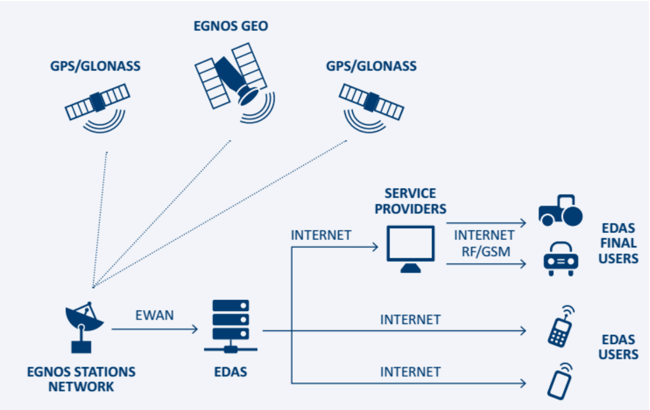

Figure 1: EDAS High-Level Architecture [1]

EDAS provides an opportunity to deliver EGNOS correction data to users who cannot always view the EGNOS satellites (such as in urban canyons), or GNSS data to support a variety of other services, applications and research projects.

Nowadays, EDAS offers the following services (please refer to the EDAS Service Definition Document [1] - for a detailed description, http://egnos-user-support.essp-sas.eu/new_egnos_ops/content/egnos-sdds):

- **Main Data Streams** [4]: GNSS data is provided through the Internet in real time in ASN.1 format [8] (Service Level 0) and RTCM 3.1 [9] format (Service Level 2).
- **Data Filtering** [4]: GNSS data can be received from pre-defined (according to RIMS location) subsets of RIMS stations when connecting to EDAS Service Level 0 and Service Level 2. Users can choose among 6 pre-defined groups of RIMS.
- **SISNeT Service** [6]: EGNOS messages are provided in real time using the ESA's SISNet protocol [10] .
- **FTP Service** [5]: Historical GNSS data are available through an FTP site including:
  - EDAS SL0, SL2 raw data.
  - GPS/GLONASS navigation and observations (RINEX [12] format)
  - EGNOS messages (EMS [13] + RINEX-B formats)
  - Ionosphere information in IONEX [14] format.
- **Ntrip service** [7]: GNSS measurements and corrections are delivered in real time using Ntrip protocol, in RTCM 2.1 [15], 2.3 [16] and 3.1 [9] formats. In particular, EDAS Ntrip service provides differential GNSS corrections (RTCM 2.1, 2.3) and phase measurements as well as additional messages for RTK (Real-time kinematic) positioning (RTCM 3.1).

The following table summarizes the types of data that can be retrieved via the different EDAS services.

Table 1: EDAS Services

Mode	EDAS Service	Type of Data				Protocol	Formats
		Observation & navigation	EGNOS messages	RTK messages	DGNSS corrections		
Real Time	SL/DF 0	X	X			EDAS	ASN.1
Real Time	SL/DF 2	X	X			EDAS	RTCM 3.1
Real Time	SISNeT		X			SISNeT	RTCA DO-229D
Real Time	Ntrip	X		X	X	Ntrip v2.0	RTCM 2.1, 2.3, 3.1
Archive	FTP	X	X			FTP	RINEX 2.11, RINEX B 2.10, EMS, IONEX, SL0 and SL2 raw binary data

EGNOS data coming from the EDAS Services can be used for the development of applications based on GNSS data streams, or for the provision of added-value services based on EDAS.

EDAS registration

In order to request an EDAS account, users should follow the steps detailed below:

1. Register in the EGNOS User Support Website: http://egnos-user-support.essp-sas.eu
2. Fill and submit the EDAS registration form (only accessible upon registration in the web)

EDAS online information

The following means of information are made available by ESSP regarding EDAS through the EGNOS User Support Website (http://egnos-user-support.essp-sas.eu):

- **EDAS Service Definition Document** [1]: The EDAS SDD provides information on the EDAS services and their conditions of use. The EDAS SDD describes the EDAS system architecture and the current EDAS services (data type, formats, protocols and committed performance).
- **EGNOS User Support Website**: Up-to-date information about the EDAS services, the real-time status of the services, the access to the EGNOS helpdesk and the process to register to EDAS can be found in the EGNOS User Support Website [22].

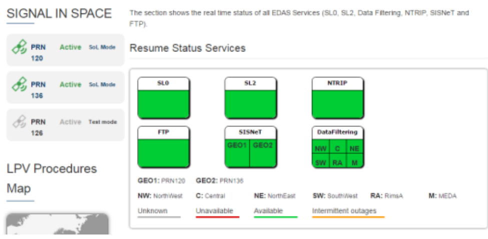

Figure 2: Real-time EDAS services status

- **EGNOS Monthly performance report:** Monthly reports contain the EDAS performance in terms of availability and latency for all services.

EDAS Services Performances

The EDAS SDD [1] defines the committed performance levels for EDAS (levels that should always be met in a nominal situation) in terms of availability and latency:

- **Availability**: percentage of time in which EDAS is providing its services according to specifications. The availability is measured at the EDAS system output (excluding user access network performance).
- **Latency**: time elapsed since the transmission of the last bit of the navigation message from the space segment until the data leaves the EDAS system (formatted according to the corresponding service specification). EDAS latency is a one-way parameter defined for real-time services.

Based on the above definitions, the table below provides EDAS services' minimum availability and maximum latency:

Table 2: EDAS services min availability and max latency

Performance	SL0	SL2	SISNet	FTP	Ntrip	Data Filtering	
						SL0	SL2
Availability	98.5%	98.5%	98%	98%	98%	98%	98%
Latency (sec)	1.30	1.45	1.15	N/A	1.75	1.60	1.75

The availability and latency performance achieved from July 2016 to June 2017 are shown in Figure 3 and Figure 4 respectively.

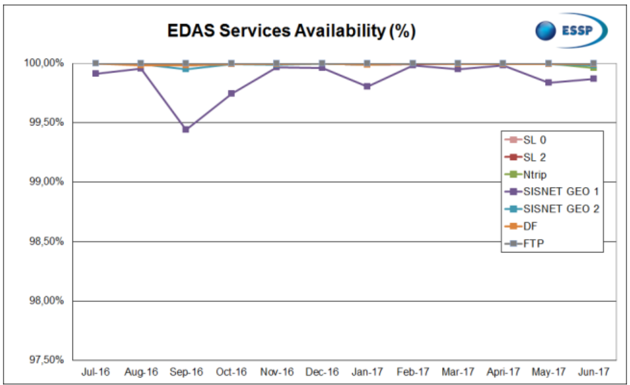

Figure 3: EDAS services availability

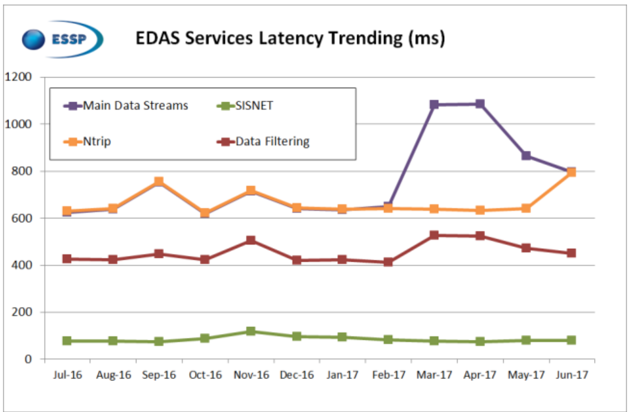

Figure 4: EDAS services latency

EDAS availability has been consistently above 99.5% (normally above 99.9%) and the latency has been typically below 1 second for all services. Hence, the commitment performance of the EDAS SDD [1] has been met for all the services throughout the whole period by a comfortable margin.

II. EDAS FOR DGNSS POSITIONING

Differential GNSS (DGNSS) corrections are sent through the EDAS Ntrip Service via Internet in order to support differential operation, obtaining accuracies of sub-meter level for navigation applications.

EDAS disseminates this information in real time through the Ntrip (version 2.0) protocol [11], which uses RTSP (Real Time Streaming Protocol) for stream control in addition to TCP (Transmission Control Protocol) and RTP (Real Time Transport Protocol) for data transport on top of the connectionless UDP (User Datagram Protocol).

The EGNOS Stations (RIMS and NLES) are considered as static reference receivers, which are placed at fixed and known surveyed locations. Then, since the satellite positions and the reference antenna location are known, the ranges can be determined precisely. By comparing these ranges to those obtained from the satellite observation measurements, the pseudorange errors can be accurately estimated (i.e. ionospheric delays, tropospheric delays, ephemeris errors and satellite clock errors), and corrections determined. These DGNSS corrections can then be broadcast to nearby users, who apply them to improve their position solutions.

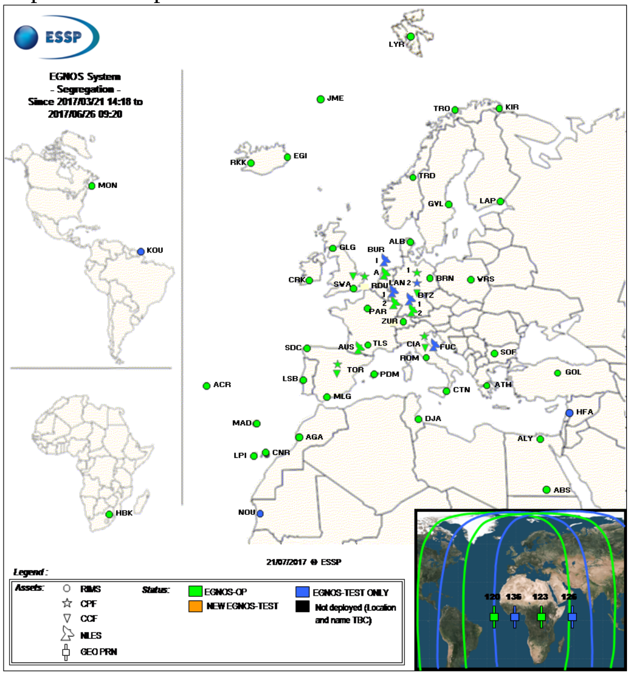

Figure 5: EGNOS RIMS stations

The DGNSS corrections are sent through the EDAS Ntrip Service in RTCM 2.1 and RTCM 2.3 formats, using the messages shown in table below:

Table 3: EDAS DGNSS Message Types

EDAS DGNSS Messages	Message Types	
	RTCM 2.1	RTCM 2.3
Differential GPS Corrections	1	1
GPS Reference Station Parameters	3	3
Reference Station Datum	N/A	4
Extended Reference Station Parameters	N/A	22
Antenna Type Definition Record	N/A	23
Antenna Reference Point (ARP)	N/A	24
Differential GLONASS Corrections	N/A	31
GLONASS Reference Station Parameters	N/A	32

For detailed information about the connection and usage of the EDAS Ntrip service, the EDAS Ntrip User Information Package [7] is available for registered users. EDAS Ntrip supports internet access including wireless internet access through mobile IP networks, and allows simultaneous PC, laptop, PDA, or receiver connections to a broadcasting host. Using this service, GNSS receivers can improve the accuracy of satellite-based positioning systems up to sub-meter level applying DGNSS techniques.

As already mentioned, EDAS DGNSS corrections are provided for the EGNOS stations and the user performance is driven by the physical distance to the closest site. Also, Internet coverage is required to access the EDAS Ntrip service.

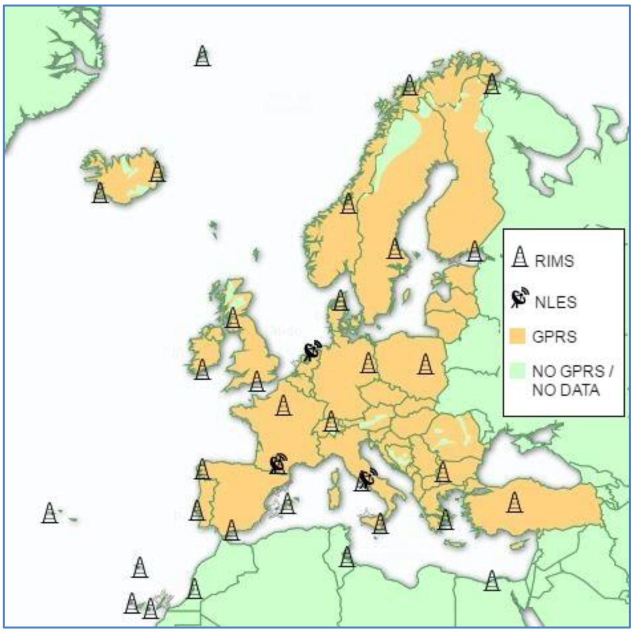

Figure 6: Estimated GPRS coverage (Europe) and EGNOS stations

The GPRS coverage information available from the European states is shown in orange taking into account the coverage maps of several telecommunications providers (it should be noted that the GPRS coverage information is qualitative, and has been obtained from the public information provided by the main telecomm providers in Europe). Those land masses not analysed or in which no GPRS Coverage is identified, are plotted as light green in Figure 6.

Previous work and motivation

In the related article presented at the ION GNSS 2016 [21], the EDAS DGPS corrections performance was analysed by applying EDAS DGPS corrections to the GNSS measurements from multiple public reference stations (static data) at selected European locations in real-time during a 5-week period. That study showed that horizontal accuracies below 1 meter (95th percentile) can be achieved using EDAS DGPS corrections up to a distance of 250 km from the designated EGNOS reference station and that, within that range, pass-to-pass accuracies (15 minutes, 95%) were expected to remain in the order of 20 cm (see Figure 7 and Figure 8). For that assessment, the pass-to-pass accuracy was computed based on static receivers following the process described in ISO 12188-1 [20] .

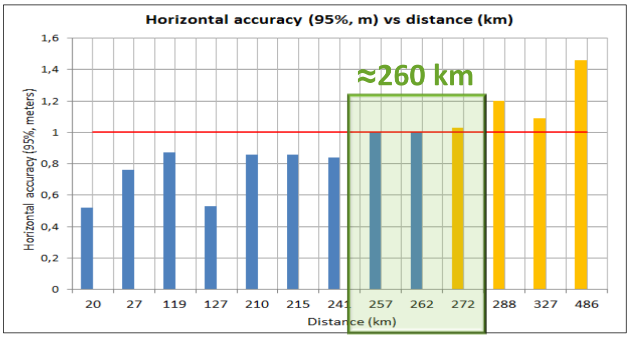

Figure 7: EDAS based DGPS solutions horizontal accuracy vs baseline (02/07/2016-06/08/2016) [21]

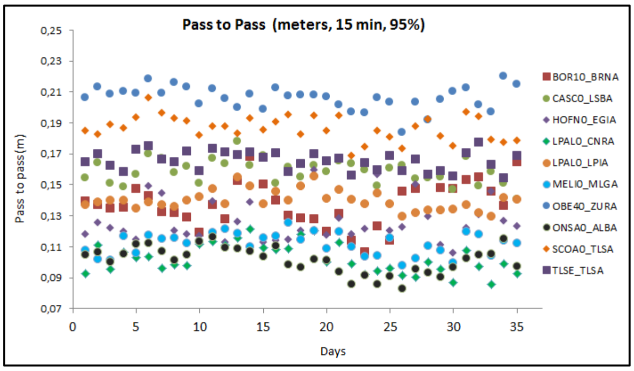

Figure 8: EDAS based DGPS: daily pass to pass accuracy[21]

In the agriculture domain, the pass-to-pass accuracy is the key performance indicator to assess the precision of guidance systems, characterizing the short-term dynamic performance determined from off-track errors along the straight segment passes (error with respect to the desired path in the direction perpendicular to the tractor trajectory). In addition to a sufficient absolute horizontal accuracy (at least 1 meter -95th percentile- is required for cereal and dry soil cultivation), the repeatability of the position solutions is critical (underperformance above the allowed margins can have serious economic impacts). In order to cover a given field, farmers typically (other types of patterns –identical curve, centre pivot- are used for specific cases) define a pattern which is composed by a set of parallel lines separated by the implement distance. In this manner, if the guidance system allows precisely following the reference pattern, the efficiency and productivity of operations is maximized ensuring that the same soil is not covered twice and avoiding that a certain part of the field is not treated.

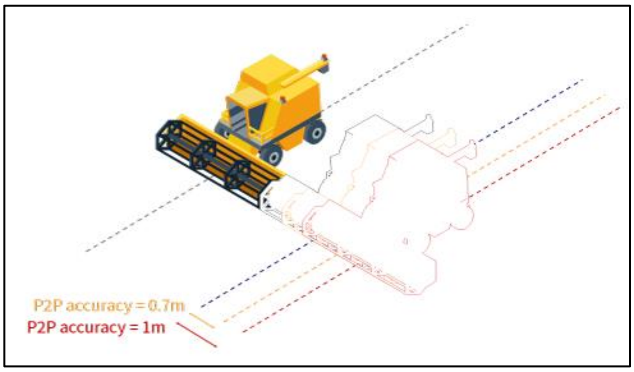

Figure 9: Pass-to-pass concept [23]

Looking at the results obtained in [21], from the point of view of precision agriculture applications, last year's article concluded that "*If these results obtained from static data were confirmed by in-field tests, EDAS DGPS corrections could be used in a wide range of agriculture applications, such as seeding, planting, spreading and spraying for cereals and dry soil cultivation.*"

Hence, the objective of the study presented in the current paper was to confirm if the pass-to-pass performance results obtained last year (based on static data and post-processed according to [20]) would also be observed in a real-life scenario, considering the environmental and dynamic conditions of farming operations.

In order to achieve that goal, Topcon Agriculture, joined ESSP for the activity. Topcon receivers, vehicles and guidance systems have been used for the test campaign that is presented in the following sections.

III. EDAS DGPS FOR PRECISION AGRICULTURE: TEST CAMPAIGN

Test set-up

The test campaign that is presented in this section was performed at a farm in Marchena (Seville, Spain) on June 13th, 2017.
For the test, a tractor was equipped with two different Topcon guidance systems running simultaneously in order to be able to assess the EDAS DGPS positioning performance with respect to the reference, which was provided by a top-performing RTK-based Topcon solution (HiperV RTK base).

Hence, two independent positioning outputs were continuously available (placed along the same longitudinal axis on the roof of the tractor):

- **RTK position**: provided by the AGI-4 receiver fed by *Topcon's HiperV* RTK base.
- **DGPS position**: provided by the AGI-4 receiver fed by the EDAS Ntrip service.

With regards to the EDAS Ntrip input, it should be noted that, due to the geographical location of the farm that was selected for the tests, the DGPS corrections used for the test came from the EGNOS RIMS station in Malaga, 110 km away from the test location.

Figure 10: Topcon AGI-4 receivers used for the test (left: receiver fed by EDAS DGPS, right: receiver fed by Topcon's HiperV RTK base).

On board the tractor, 2 *Topcon X35* consoles were installed, each one connected to one of the receivers shown in Figure 10. Additionally, a *Topcon AES-25 electric steering system* was installed on the tractor so that the selected navigation input (either the RTK or the EDAS DGPS input) could be used to automatically guide the tractor along the defined reference pattern.

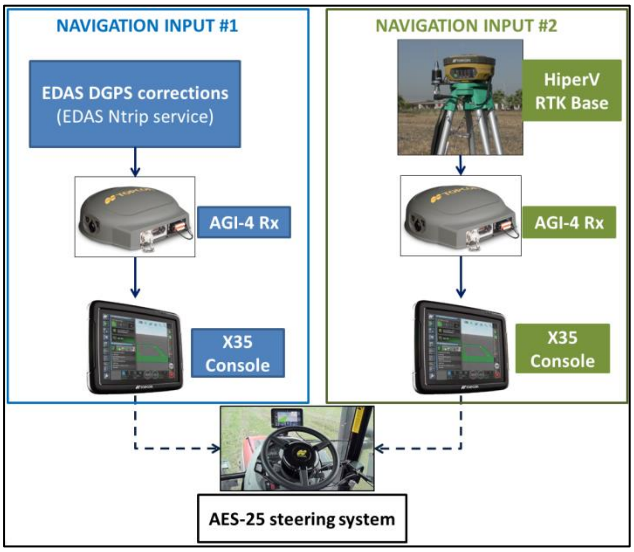

Figure 11: Navigation inputs used for the tests.

During the whole test duration, the logging function of the *X35 Consoles* was active so that, on top of the measurements taken in-field, an exhaustive data analysis could be performed after the tests.

Another relevant parameter in terms of configuration is the target separation between the parallel lines that compose the pattern defined for the trials (Figure 12). Although no implement was attached to the tractor for the tests, a theoretical implement with a width of 3 meters was configured in the *X35 consoles.* This means that, in the best case and as the different lines are covered with the tractor, the actual lateral separation between consecutive lines should match that implement width.

Tests Execution

Once the set-up was ready and the required calibration of the steering system was complete, the first action was the pattern definition in the two *X35 Consoles.* Considering the shape of the farm (rectangular), it was decided to work with parallel AB lines.

In order to define the reference pattern, the tractor was placed on one side of the farm (Point A in Figure 12). After marking that point in both *X35 consoles* simultaneously, the tractor followed (manually guided) a straight line parallel to the edge of the farm. At a distance of approximately 200 metres from Point A, the second reference point was defined (Point B in Figure 12). The imaginary straight line from Point A to Point B became our line #0. Then, the parallel lines automatically defined by the *X35 Console* with a lateral separation equal to the configured implement width (3 metres in our case) completed the definition of the pattern to be used for the tests. Due to the dimensions of the field and the configured implement width, 8 A-B lines (#0 to #7) composed our working pattern (see Figure 12).

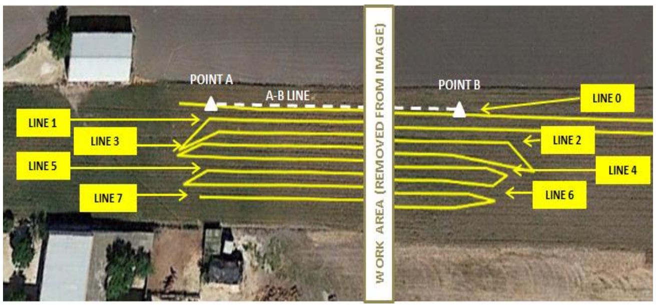

Figure 12: Farm field and pattern lines.

Based on the above pattern, three different complete runs covering the defined A-B lines were performed. Two key aspects characterise those runs:

- **Navigation system** connected to the **steering system**: depending on the run, the AGI-4 fed by *Topcon's HiperV* RTK Base or the one fed by EDAS was connected to the automatic steering system.
- **Main procedure for** pass-to-pass **performance assessment**: on top of the information provided by the *X35 Consoles*, which provide an estimated deviation with respect to the reference pattern in real-time (see deviation indication inside red circle in Figure 13), two different approaches have been used to measure the pass-to-pass accuracy:
  - Post-processing: the data logged by the *X35 Consoles* was post-processed to compute the cross track error of the EDAS DGPS solution with respect to the RTK one (reference) along the pattern.
  - In field measurements: when the *AGI-4* receiver fed by the EDAS DGPS corrections was connected to the steering system, the lateral separation between consecutive lines was manually measured in field.

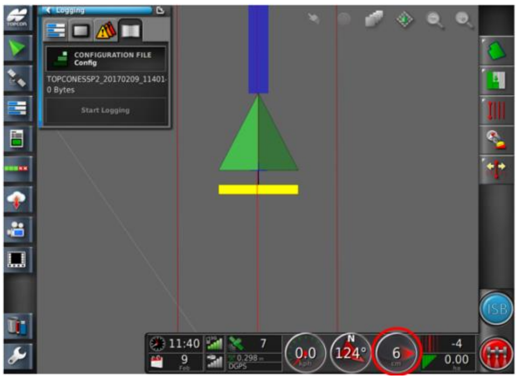

Figure 13: Topcon X35 Console interface.

The following table summarises the key features characterising the three test runs that were performed:

Table 4: Test runs - definition

Test Run #	Navigation input-auto-steering	Performance assessment	Duration
Run #1	RTK (Topcon's HiperV base)	Post-processing	20 min
Run #2	RTK (Topcon's HiperV base)	Post-processing	18 min
Run #3	DGPS (EDAS Ntrip – Malaga)	In-field measurement	40 min

The following paragraphs provide a detailed review of the tests results for the runs introduced by Table 4.

Test Results: Run #1

As described in Table 4, for this run, the RTK system (Topcon's HiperV base station) was feeding the tractor's automatic steering system. The onboard *X35 consoles* allowed monitoring the estimated deviations reported by EDAS DGPS positioning solution and the RTK one along the different A-B lines in real-time. At this point, it is important to recall that identical Topcon AGI-4 receivers (see Figure 10) were in charge of the computation of both navigation solutions.

Regarding the trajectory followed by the tractor in order to cover the defined pattern during this run, the following A-B lines were covered consecutively: line #0, #1, #2, #3, #4, #5, #6.

The main inputs used for the pass-to-pass performance assessment corresponding to this run were the log files generated by the onboard *X35 Consoles* which included, with 1 Hz logging frequency: *time, latitude, position, speed, heading, number of satellites used in the position computation, correction source, HRMS and engage status.*

Among the above parameters, and apart from the time stamp of each recorded data set, the following parameters were the key ones for the performance assessment of the results:

- *Position* reported by each *X35 Console* (comparison of the computed position provided by the RTK fed receiver and the EDAS DGPS fed receiver). The position output provided by the RTK fed receiver has been taken as the reference/truth, considering that the typical error of the RTK solution is negligible for the current study (RTK errors at centimetre level versus decimetre level errors to be studied).
- *Engage status and heading*: these two parameters were key since they allowed identifying the straight trajectory segments matching each A-B line (i.e. excluding turns or transitions between lines).
  - The engage status indicates that the auto steering function is activated (situation along the different lines but not during turns which are manually performed).
  - The heading was also used in order to exclude the manoeuvres performed by steering system when entering a given A-B line and retain only the straight part of the trajectory guided by the steering system.

Once the data set corresponding to each straight line within the test run was identified for the two console outputs, the positions reported by both *X35 Consoles* (each fed by one *AGI-4* receiver) were post-processed to compute the instantaneous cross track error of the EDAS DGPS solution with respect to the RTK one (i.e. difference between sensor outputs in transversal direction to the corresponding A-B line). After that, the instantaneous pass-to-pass error along the corresponding A-B line for any given couple of consecutive lines is obtained by subtracting the instantaneous cross track errors of the current line and the previous one. Figure 14 illustrates this process.

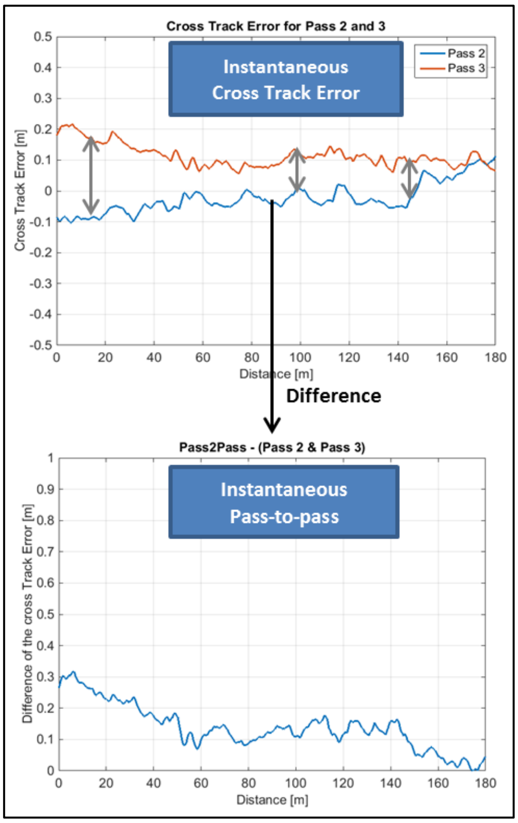

Figure 14: Instantaneous pass-to-pass performance computation (post-processing).

Following the procedure described above, Figure 15 depicts the instantaneous pass-to-pass error obtained during run#1 for the different couples of A-B lines.

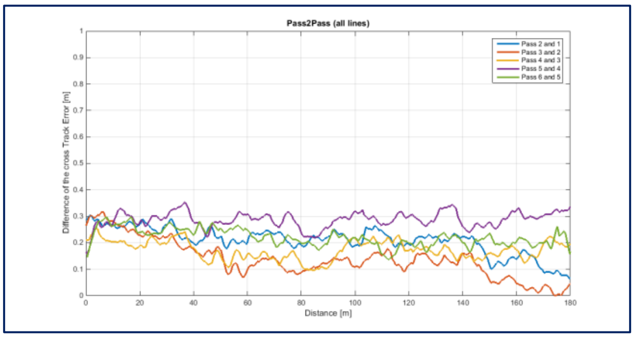

Figure 15: Instantaneous pass-to-pass accuracy – Run#1.

As shown in Figure 15, the instantaneous pass-to-pass accuracy for the first test run, considering all the A-B lines and taking the RTK position as the reference, was typically in the 15-25 cm range.
Table 5 shows the average of the instantaneous pass-to-pass accuracy for each couple of consecutive passes and also the average of the complete run.

Table 5: Average EDAS DGPS pass-to-pass accuracy– Run#1

Passes	1 &2	2&3	3&4	4&5	5&6	Full Run
Pass-to-pass accuracy (average)	20 cm	14 cm	16 cm	28 cm	22 cm	**21 cm**

Test Results: Run #2

For the second test run (Run#2), as for run#1 (see Table 4), the RTK system (*Topcon's HiperV* RTK base station) was feeding the tractor's steering system.

The main difference with respect to run#1 was linked to the way to connect the different A-B lines in order to cover the reference pattern. In this case, wider turns without reversing were used, resulting in the following A-B lines sequence: line #0, #2, #4, #6, #7, #5, #3, #1 (refer to Figure 12).

Figure 16 depicts the instantaneous pass-to-pass accuracy performance achieved during run#2. The results are quite similar to those from run#1 (pass-to-pass accuracy in the 15-25 cm range) although the repeatability seems to be slightly better in this case.

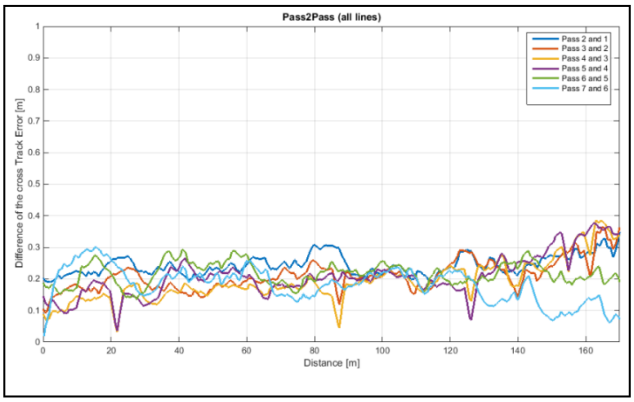

Figure 16: Instantaneous pass-to-pass accuracy – Run#2.

The average instantaneous pass-to-pass accuracy for each couple of lines and the overall average of the run (see Table 5) confirm that the observed pass-to-pass accuracy remains in the order of 20 cm, showing quite consistent values along the complete run.

Table 6: Average EDAS DGPS pass-to-pass accuracy– Run#2

Passes	1 &2	2&3	3&4	4&5	5&6	6&7	Full Run
Pass-to-pass accuracy (average)	23 cm	20 cm	18 cm	19 cm	22 cm	19 cm	**22 cm**

Test Results: Run #3

For run#3 (see Table 4), the *AGI-4* receiver fed by the EDAS DGPS corrections provided by the EDAS Ntrip service for Malaga RIMS station was connected to the Topcon *AES-25 electric steering system*. Hence, during run#3, the auto-guidance function was based on EDAS input. In this case, the main procedure used for the pass-to-pass accuracy performance assessment was based on in-field measurements of the achieved lateral separation between consecutive lines. It should be noted that this is the procedure that farmers typically follow to check the pass to pass performance.

At this point, it is important to recall that the configured implement width was 3 meters. Hence, for each couple of consecutive lines, the actual lateral separation was determined in-field (the error with respect to the 3 meters target being the measured pass-to-pass accuracy).

The process for the in-field measurement of the pass-to-pass accuracy for a given couple of A-B lines is depicted in Figure 17, and consists on the following steps:

1) The tractor, having the steering system engaged to the EDAS DGPS navigation input, is stopped at a designated area (***Measurement Area*** in Figure 17) within a given A-B line. Using a physical point of the tractor's external body work, a first mark is done on the ground (***Orange X*** in Figure 17).
2) With the steering function engaged to the EDAS navigation system output, the designed A-B line length is covered by the tractor (***Line 0*** in Figure 17).
3) At the end of the line, the tractor is manually turned to the next line (***Line 1*** in Figure 17) and the steering system is engaged again to the EDAS navigation system input.
4) Once the tractor has covered the full line in the opposite direction as the previous one, the tractor is stopped at the ***Measurement area***. Then, using the same physical reference of the tractor's external body work as in step 1, a second mark is done (***Blue X*** in Figure 17); this second mark needs to be aligned with the first mark (***Orange X*** in Figure 17) perpendicularly to the subject A-B lines.
5) The distance in the transversal direction to concerned A-B lines is measured (target distance is 3 metres in this case –implement width-). The deviation of this measurement from the 3 metres target is the pass-to-pass accuracy for the concerned lines – ***Line 0*** and ***Line 1*** in Figure 17).
6) Then, the process is restarted (Step 1) for the next couple of A-B lines.

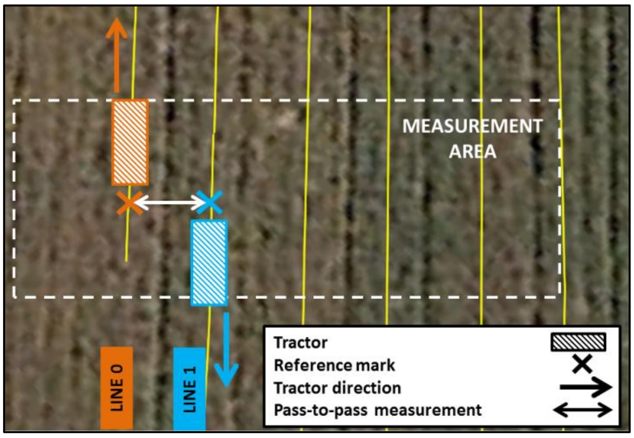

Figure 17: In-field pass-to-pass measurement (procedure).

Table 7 summarises the pass-to-pass measurements that were obtained for the available couples of A-B lines (see Figure 12) using the procedure described above.

Table 7: EDAS DGPS Pass-to-pass accuracy– Run#3

Passes (In-field)	0 &1	2&3	4&5	6&7
Pass-to-pass accuracy	3-4 cm	10-12 cm	1-3 cm	7-8 cm

As one can easily see, the achieved results obtained through this process exceeded the expectations, being 12 cm the maximum measured pass-to-pass accuracy.

Figure 18: EDAS DGPS Pass-to-pass (lines 0 & 1).

IV. CONCLUSIONS AND FUTURE WORK

The current paper is focused on the EDAS Ntrip Service, which can be used for DGNSS positioning since it provides DGNSS corrections for the EGNOS stations, located mainly over Europe and North of Africa, in real-time over the internet.

In the related article presented at the ION GNSS 2016 [21], the EDAS DGPS corrections performance was analysed by applying EDAS DGPS corrections to the GNSS measurements from multiple public reference stations (static data) at selected European locations in real-time during a 5-week period. That study showed that horizontal accuracies below 1 meter (95th percentile) can be achieved using EDAS DGPS corrections up to a distance of 250 km from the designated EGNOS station and that, within that range, pass-to-pass accuracies (15 minutes, 95%) were expected to remain in the order of 20 cm. However, those pass-to-pass results were considered preliminary since they were based on post-processed static data (according to ISO 12188-1).

As a natural continuation of the work presented last year, the present article reports on the results of 1 day in-field test session, conducted by Topcon Agriculture and ESSP, which aimed at analysing the pass-to-pass accuracy performance that could be achieved with EDAS DGPS corrections considering the environmental and dynamic conditions of farming operations. Topcon Agriculture supported ESSP by providing the required receivers, vehicles and guidance systems that have enabled the test executions.

For the test executions and considering the designated farm for the tests, the EDAS DGPS corrections provided for the Malaga RIMS station have been used. That translates into an EDAS based DGPS solution analysed with an estimated baseline distance of 110 km. For the whole test duration, a *Topcon* RTK solution has always been running in parallel to the EDAS DGPS solution to provide the required reference for the post-processing of the recorded data.

As part of the tests, three different runs over the defined reference pattern were done. For two of them, the pass-to-pass accuracy performance was obtained by post-processing the data logged during the tests. Average pass-to-pass accuracies of 21 and 22 cm were supported by the EDAS based DGPS position solution during those runs. Finally, during the third run, after connecting the receiver using EDAS DGPS corrections to the tractor's steering system, in-field measurements of the supported pass-to-accuracy were taken. During this run, the measured pass-to-pass accuracy supported by EDAS DGPS corrections remained below 12 cm for the analysed couples of lines.

In summary, the observed EDAS DGPS pass-to-pass accuracy performance during the test execution shows that EDAS DGPS corrections can support pass-to-pass accuracies in the order of 20 cm in a consistent manner and with a high degree of repeatability. Such performance level is considered to be appropriate for most cereal farm operations. In particular, the observed performance is sufficient to support the following precision agriculture applications:

- Spraying/Spreading of any crop type.
- Tilling of cereal.
- Harvesting of cereal.

Additionally, although more in-field tests are required to conclude on this point, EDAS DGPS could also be a suitable solution for seeding of cereal.

Hence, the test campaign that is reported in this article, jointly performed by Topcon Agriculture and ESSP, indicates that EDAS DGPS corrections could support a wide range of precision agriculture applications and become an attractive alternative for cereal farms, when located in the vicinity of an EGNOS RIMS station.

In order to improve the current understanding of the actual performance delivered by EDAS DGPS corrections from the point of view of precision agriculture applications, Topcon Agriculture and ESSP will engage in further testing activities. As part of those tests, it is foreseen to verify the observed EDAS DGPS pass-to-pass accuracy performance in different geographical locations (different baselines for the EDAS based DGPS solution) and performing actual agriculture operations (with a real implement attached to the tractor).

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