GPS-aflukning på sprøjter. Gratissignal kontra RTK.

Samt anvendelse af sektionsafluk på dyse niveau.

Sagsnr.: 2021 - 3915

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Sagsnr.: 2021 - 3915

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1. Objectives and summary of the project

The objective of this project is to provide an overview over the latest technologies in terms of section-control that are present on the market.
To achieve this objective, the project has been divided into two phases:

- In the first phase, Teknologisk Institut, in collaboration with Brøns Maskinforretning, ran a test to compare the accuracy between a free GPS-correction signal (EGNOS) and a subscription-based RTK-signal.
- In the second phase, Teknologisk Institut and VELAS created and forwarded to Danish growers a survey intended to gather information regarding the level of spraying-technologies adopted by farmers in terms of both GPS accuracy and section control set-ups.

2. Equipment tested

The sprayer used in the accuracy test was an Amazone UX 6201 Super, trailed by a JCB Fastrac 4220 equipped with an RTK-GPS antenna.

The Amazone UX 6201 Super[1] is a high-end trailed field sprayer. The model used in the test was configured with a 6.200-liter tank and a 36m wide boom divided into 50 cm sections. The section control technology [2] consists in a series of nozzle-groups formed by a 4-fold nozzle body. Depending on the application map and the driving direction (e.g. when turning) each nozzle is automatically activated and deactivated, as well as it is automatic the switch-over of the nozzle type and adjustment of the flow rate, depending on the application rate and turning radius. For what regards the boom stability, the UX 6201 Super is equipped with a fully automatic boom swing-control which include vertical and horizontal tilt adjustment based on a technology involving two acceleration sensors and six ultrasound sensors placed along the boom.
For what regards the navigation system, the UX6201 Super is equipped with an antenna able to link to EGNOS GPS-correction signal. This allows farmers to spray with geolocalized section control without the need of equipping their tractor with an RTK antenna and to pay the subscription to the correction signal. The sprayer can steer actively thanks to a turning axle placed below the chemical tank.

[1] UX 4201 og UX 5201 og UX 6201 Super - Amazone (bronsgroup.com)
[2] https://amazone.net/en/plan-learn/learn/perfection-for-precision-plant-protection-amaselect


Figure 1 The Amazone 6201 Super, trailed by a JCB Fastrac 4220


Figure 2 A quick visual comparison of the height range at which the boom can be set on this sprayer

3. Field test

The test had the purpose of comparing how accurate are the following two differential correction signal:

- EGNOS stands for *European Geostationary Navigation Overlay Service*. It is Europe's regional satellite-based system for differential corrections of GPS receivers. This system uses GNSS measurements taken by reference stations located across Europe which are sent to a central computing unit before being broadcasted over the covered area. EGNOS accuracy is claimed to be <1m. European Union stated that more than 75% of European GNSS enabled tractors are equipped with EGNOS[3]. In this test, the EGNOS signal was acquired by the sprayer antenna.

- Subscription-based RTK: GPSnet.dk. The correction signal is delivered via a GSM modem installed above the tractor's cabin. GPSnet.dk works with all tractor's brands and autosteering devices.

The test runs were conducted at Stauning Airport (Lufthavnsvej 6, 6900 Skjern).

3.1. Test set-up

Teknologisk Institut prepared an application map containing a series of identical 3x10 m rectangles, placed diagonally in respect to the driving directions (Figure 3) in which the sprayer had to spray water. Each treatment is made by two rectangles, the first is sprayed with the tractor driving from West to East, while the second application area is sprayed with the tractor driving in the opposite direction, as shown in Figure 3. Each of the 3 replicates consisted in 4 application areas ordered as following: EGNOS-RTK-RTK-EGNOS. (Figure 4).
During all the application, the tractor drove along the runway's centerline.

The purpose of the specific shape and orientation of the application areas is meant to simulate the tractor reaching an area which is not straight, such as, for example, the headland of a field. This decision was taken because, thanks to our experience, we identified the headlands as one of the areas in agricultural fields where there is the highest overlap, due to irregularity of most of the fields' borders. Therefore, in our opinion, this is a first step to optimize the chemical inputs in the fields.

[3] " EGNOS extension to Eastern European Neighbourhood partner countries", PowerPoint presentation, https://www.euspa.europa.eu/simplecount_pdf/tracker?file=uploads/egnos_for_enp_east.pdf

Figure 3 Application map: first replica including driving directions. Blue stands for EGNOS, red for proprietary RTK

Figure 4 The whole application map. Blue stands for EGNOS, red for proprietary RTK

To measure the accuracy of each RTK-GPS signal, Teknologisk Institut measured the GPS coordinates of each of the four corners of the sprayed area with a survey-grade RTK-GPS receiver[4] (Figure 8).
The whole test was run twice and a total of 24 areas were sprayed and measured per each RTK signal.

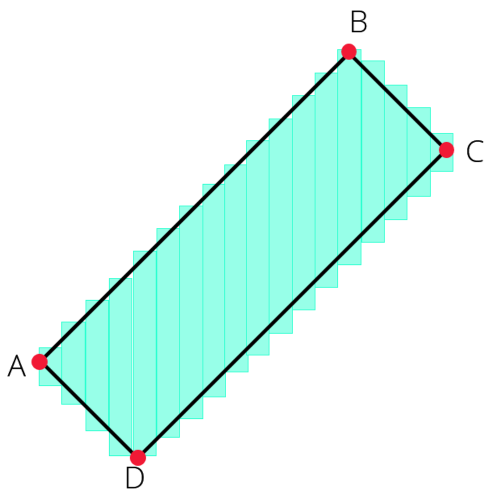

Figure 5 Graphic example of where we measured the GPS position (red dots) of the sprayed area.

[4] Topcon HiPer SR, horizontal accuracy of 10 mm + 0,8 ppm
https://www.topconpositioning.com/gnss/integrated-gnss-receivers/hiper-sr#panel-product-specifications;

Figure 6 The UX 6201 Super spraying during the test.

Figure 7 Fresh application

Figure 8 Measurement of the GPS coordinates of the sprayed area with a survey-grade RKT-GPS receiver

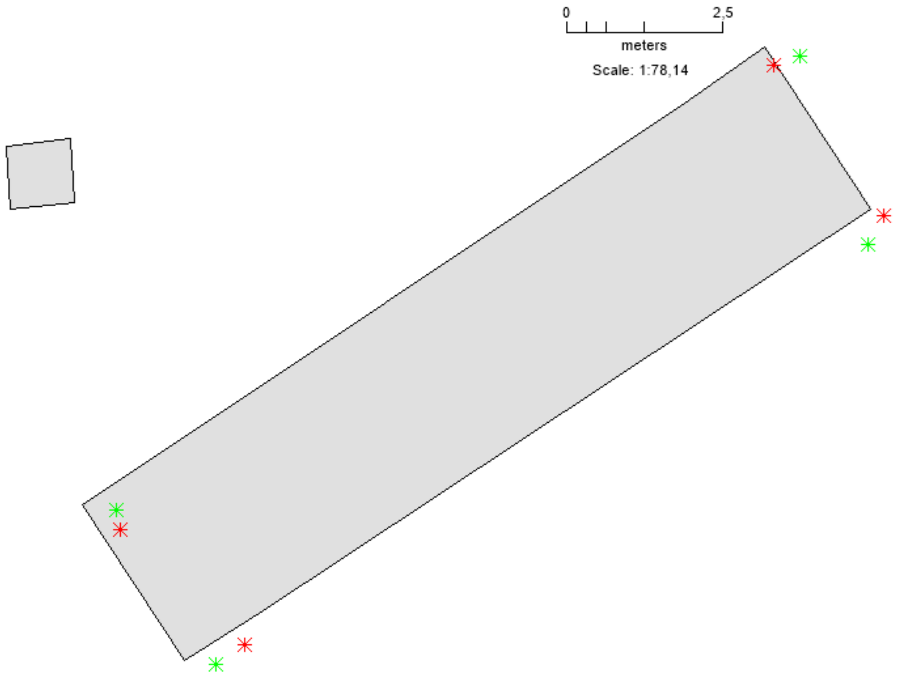

Figure 9 GPS measurements displayed in GIS (Gray: target area; Red stars: GPS position in the first run; Green stars: position in the second run

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3.2. GPS receivers' settings

The tractor was equipped with an AmaPad 2[5] ISOBUS terminal. When using third-party manufacturer GPS-system, such as RTK in this specific case, Amazone suggest setting the transfer rate to 57,600 bps.

We used the following parameters:

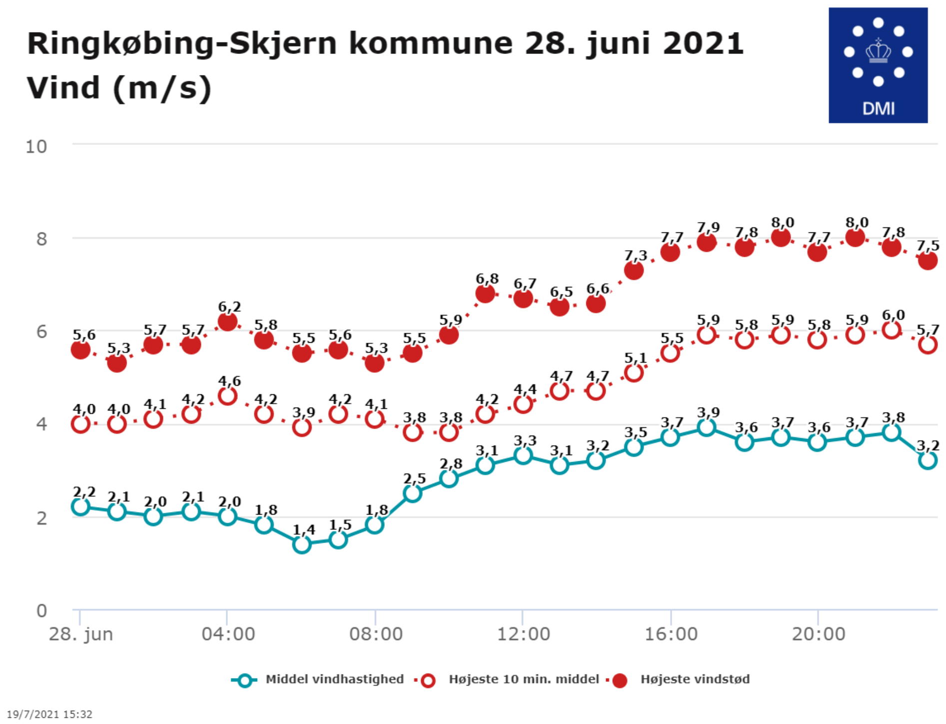
	Baud rate (bps)	Frequency (Hz)
RTK	57600	10
EGNOS	19200	1-5

Figure 10 Screenshot of the spray computer interface: the application areas are represented by two gray rectangles, the green arrow represent the tractor and its driving direction. At last, the white line is the position of the boom.

[5] https://amazone.net/en/products-digital-solutions/digital-solutions/terminals-hardware/isobus-terminals/amapad-2-isobus-terminal-59044

3.3. Weather data

The test was run the first time between 09:00-10:00 while the second time between 11:00-12:00. The wind data are reported in Graph 1. The wind never reached speeds which would exceed the common farmers' practices. Moreover, the boom was leveled at 50 cm above the ground level. For these reasons, the wind-drift effect can be neglected.



Graph 1 Recorded wind speed during the test day (source DMI)

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4. Data analysis and results

Application precision consists of the following aspects: Coverage of the targeted area (hit%), area sprayed outside the targeted area (miss%), systematic displacement between applied and targeted area, and, finally, difference between applied and targeted area. Thus, the following application precision measurement parameters were calculated for each observation, the first two being coverage parameters:

1. Hit (%) = fraction of application area inside of target area / target area × 100
   Hit% describes how well the target was covered, ignoring how much application occurred outside the target area, hence, describing how target-sensitive application occurred (Sensitivity).

2. Waste (%) = fraction of application area outside of target area / application area × 100
   Miss% describes how much of the applied area missed the target, ignoring how much application occurred inside the target area, hence, describing how specific application occurred (Specificity). Under the assumption of homogeneous application, the Miss% describes the sprayed amount waisted.

3. Applied area (m^2)
   The area covered by the application, regardless of coverage or displacement with target.

4. Displacement (m) = centroid displacement of application area from target area
   Displacement describes how much the applied area is shifted or displaced with respect to the target area, ignoring coverage and applied area.

Outliers: A priori outliers were detected using graphical tools (Graph 2 and Graph 3). Run 1 RTK partial block 2 observations were removed due to a deviating displacement. This was expected, as the displacement settings in the tractor were adjusted after the first six observations. EGNOS is unaffected by these settings. Run 2 EGNOS partial block 1 observations were removed due to a clearly deviating application area. Although no external information is available, these observations were regarded to be error-prone and, hence, removed.

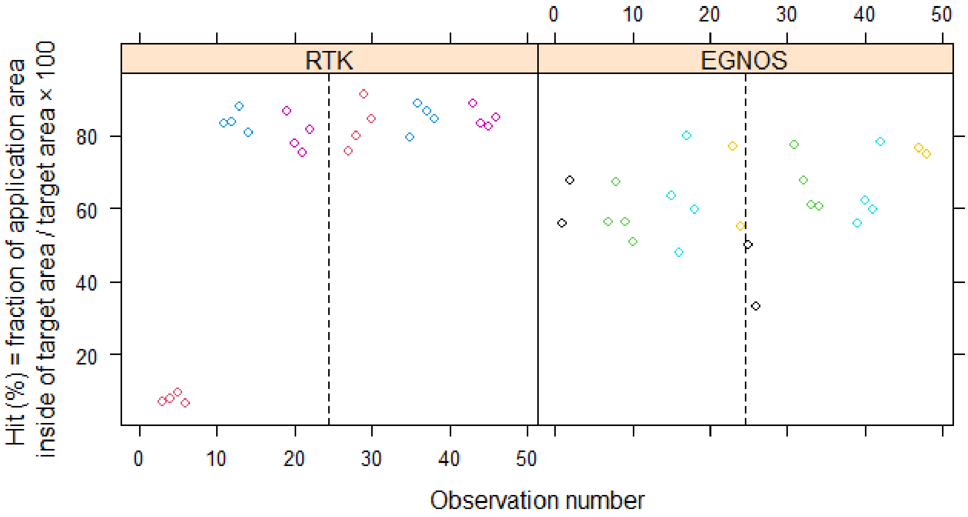
Displacement settings: Both the EGNOS and RTK technology suffers from the fact that GPS-unit and application nozzles are positionally not fully coinciding. The distance between GPS-unit and nozzles can, at least theoretically, be added to the sprayer settings, thereby reducing the displacement between target and application area. In this trial, however, it was only possible to manipulate the RTK displacement setting. The RTK displacement setting was adjusted after the first two RTK applications (Run 1 RTK partial block 2 observations, removed as outliers) in order to improve RTK-based application precision. The EGNOS treatments were not adjusted throughout the runs.

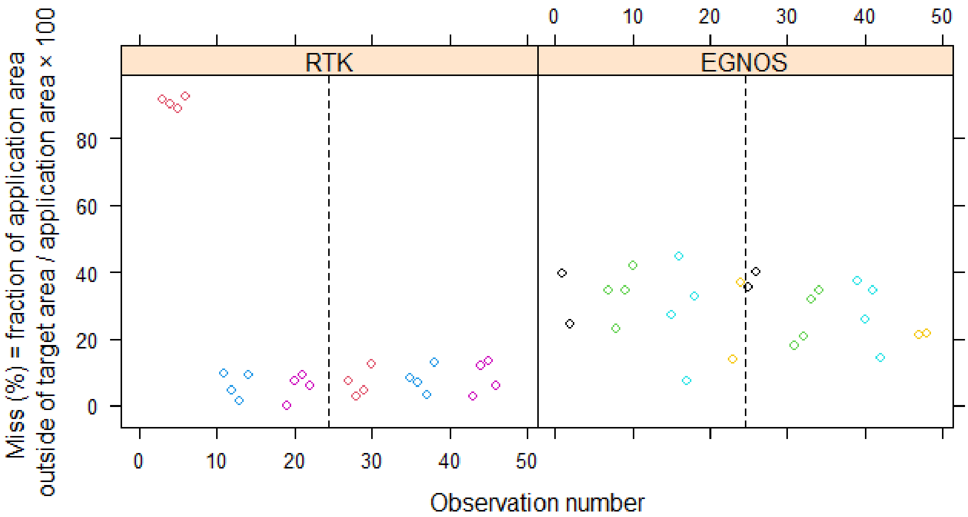
Graph 3 clearly indicates that the EGNOS technology showed increased displacement in comparison to the RTK technology, after outliers were removed. Estimated displacement for the RTK and EGNOS were 0.50±0.06 and 1.3±0.06 m, respectively.
However, as displacement is a setting-constrained and not technology-constrained parameter, application precision in RTK and EGNOS should be considered after correcting for differences in displacement settings between the two technologies. We therefore modelled the contrast between RTK and EGNOS for all measurement parameters corrected for the technology-wise average displacement. All estimates were than scaled to the average displacement of the RTK technology, as the estimated RTK displacement of 0.50±0.06 m may be considered realistic in practical settings.

Statistical analyses: We used the following mixed effects models to estimate mean values and contrasts between the two treatments (*Trt*) RTK and EGNOS for all measurement parameters *y*:

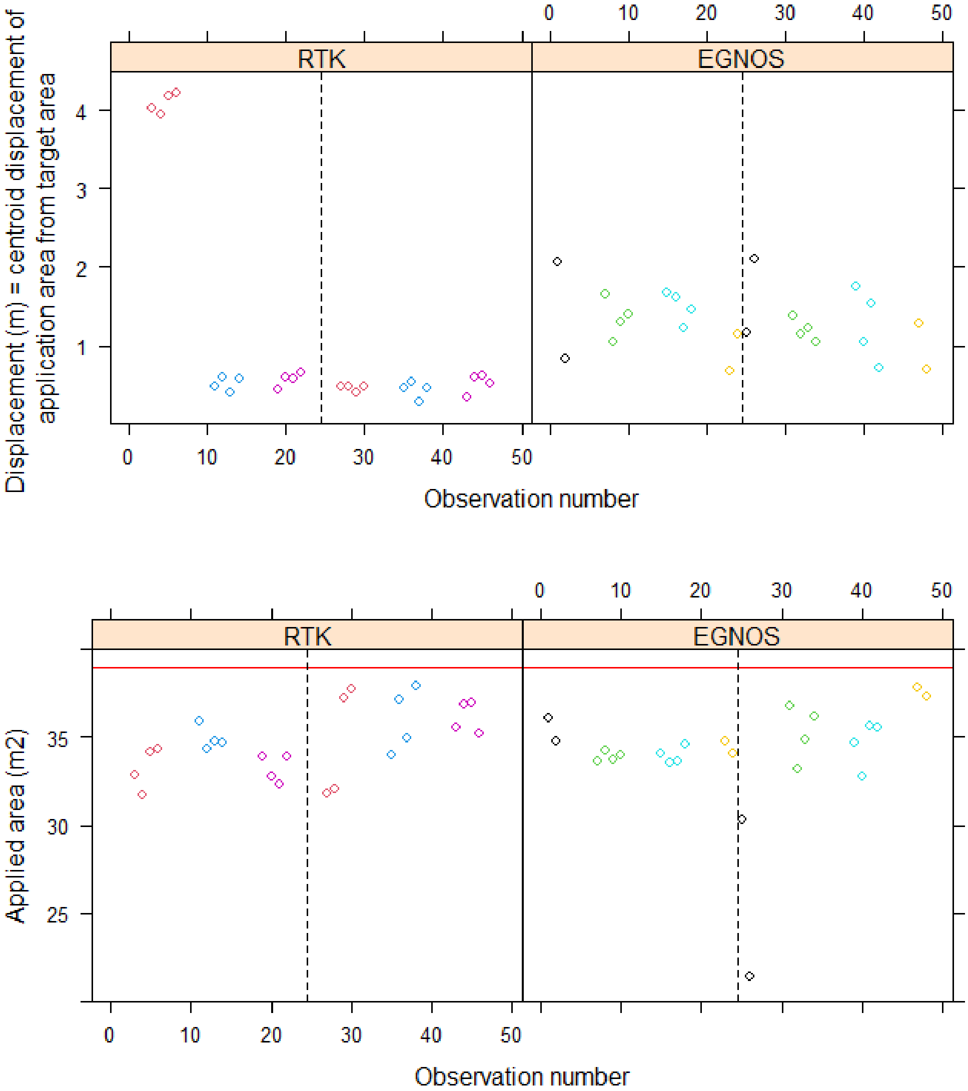
$$y^t = \beta_0 + \beta_1 Displacement + \beta_2 Direction + \beta_3 Trt + \beta_4 Direction \times Trt + block + partial\ block + e$$

Here, *block*, *partial block* and residuals *e* were all modelled as independent and normally distributed. y^t indicates the transformed measurement parameter; Hit% and Miss% were logit-transformed, while Area was square-root-transformed, and the corrected Displacement was untransformed. All estimates are reported on the back-transformed scale. The model for the corrected Displacement did not include the observed Displacement as explanatory variable. In order to investigate whether the GPS-types RTK and EGNOS displayed significantly different variances in the measurement parameters, we also employed heteroscedasticity models with different variances for the two GPS-types. All analyses were carried out using R (R Core Team 2021).





Graph 2 Observed Hit% and Miss%. Stippled lines indicate transition from run 1 to run 2. Colors indicate partial blocks



Graph 3 Observed Displacement and Applied area. Stipules indicate transition from run 1 to run 2. Colors indicate partial blocks. The red line indicates the 39 m2 target area

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5. Results

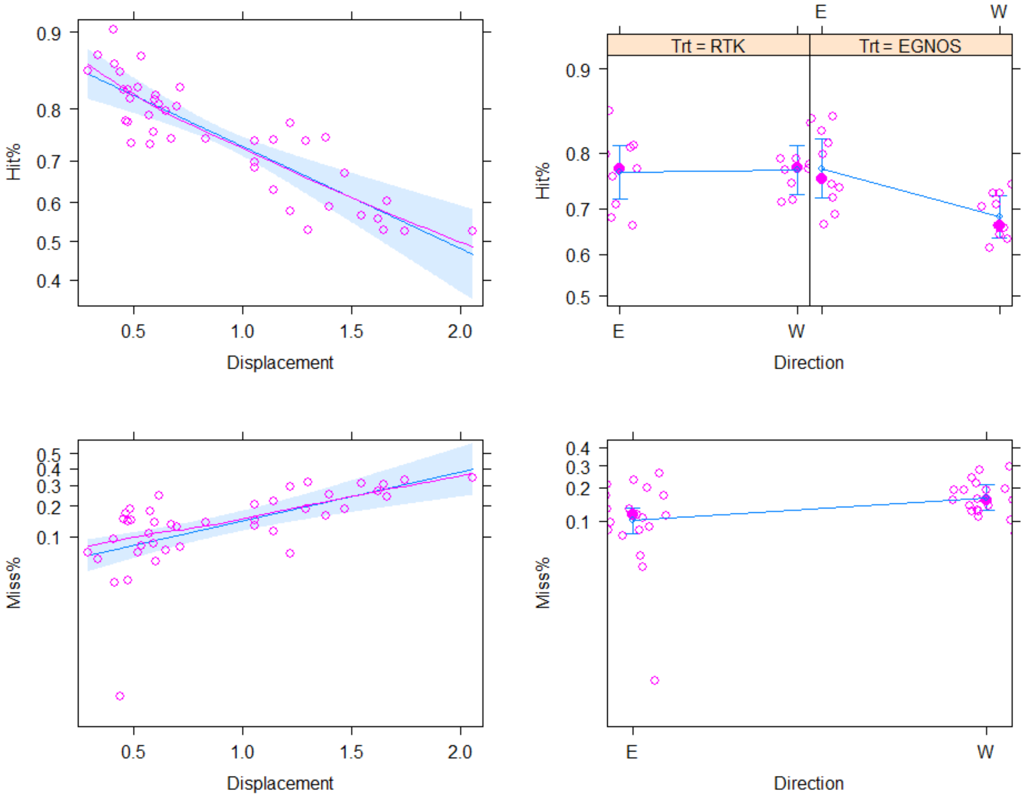
Overall, EGNOS performed significantly less precise than RTK. Although EGNOS showed a comparable precision (i.e., non-significant difference between RTK and EGNOS) concerning applied area ($p = 0.85$) and concerning Hit% ($p = 0.27$), EGNOS was outperformed by RTK concerning Miss%, with 6.8% less application occurring outside the target area ($p = 0.02$). Thus, EGNOS provides a less target-specific application technology in comparison with RTK.
Both RTK and EGNOS delivered a 10% smaller application area than the target area, and both RTK's and EGNOS' precision was influenced by displacement, i.e., systematic shift of applied area with respect to target area. This indicates that tuning of the spraying technology by setting an appropriate distance between GPS-unit and nozzles is crucial for both RTK and EGNOS technologies. EGNOS was found to show a 4.2 times larger variation in displacement, even after correcting for differences in displacement settings between RTK and EGNOS in the current trial, indicating that EGNOS is more disturbed by displacement problems.
Both technologies showed a significant effect of driving direction (E or W) concerning Miss% ($p < 0.001$). Hit% was affected by driving direction only when using the EGNOS technology ($p = 0.02$).

Results are shown in Table 1 and Graph 4.

Table 1 Estimated Application precision parameters for RTK and EGNOS

Application precision parameter	GPS-type	Estimated mean and 95%-CI	Difference	p-value	Relative variance	p-value
Hit-%	RTK	83.8 (69.6, 92.1) %	-3.1%	0.27	0.95	0.82
	EGNOS	80.8 (33.7, 97.2) %			Ref.	
Waste-%	RTK	5.1 (0.2, 56,5) %	6.8 %	0.023*	2.70	<0.001*
	EGNOS	11.9 (0.7, 70.9) %			Ref.	
Applied area (m^2)	RTK	34.9 (25.6, 45.6) m^2	0.1 m^2	0.85	1.67	0.05
	EGNOS	35.0 (26.6, 44.6) m^2			Ref.	
Corr. displacement	RTK	-	-	-	0.24	<0.001*
	EGNOS				Ref.	

CI: confidence interval



Graph 4 Estimated significant effects. Hit% and Miss% are significantly affected by observed displacement ($p < 0.05$) and driving direction ($p < 0.05$). The effect of driving direction was GPS-type-specific for Hit%, with EGNOS being negatively affected by driving westward. Miss% is negatively affected by driving westward regardless of GSP-type.

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Table 2 Observations

Observation number	TRIAL DESIGN					MEASUREMENTS				Outlier
	Run	GPS-type	Driving direction	Block	Partial block	Area (m^2)	Hit%	Miss%	Displacement (m)	
1	1	EGNOS	E	1	1	36,1	56,0	39,4	2,1	
2	1	EGNOS	W	1	1	34,8	67,6	24,2	0,8	
3	1	RTK	E	1	2	32,8	7,1	91,6	4,0	×
4	1	RTK	W	1	2	31,7	7,9	90,3	3,9	×
5	1	RTK	E	2	2	34,2	9,7	88,9	4,2	×
6	1	RTK	W	2	2	34,3	6,7	92,4	4,2	×
7	1	EGNOS	E	2	3	33,7	56,4	34,6	1,6	
8	1	EGNOS	W	2	3	34,2	67,4	23,1	1,1	
9	1	EGNOS	E	3	3	33,7	56,5	34,7	1,3	
10	1	EGNOS	W	3	3	34,0	50,7	41,7	1,4	
11	1	RTK	E	3	4	35,9	83,2	9,5	0,5	
12	1	RTK	W	3	4	34,4	83,9	4,7	0,6	
13	1	RTK	E	4	4	34,7	87,7	1,5	0,4	
14	1	RTK	W	4	4	34,7	80,9	9,0	0,6	
15	1	EGNOS	E	4	5	34,1	63,5	27,3	1,7	
16	1	EGNOS	W	4	5	33,6	47,7	44,5	1,6	
17	1	EGNOS	E	5	5	33,7	79,8	7,5	1,2	
18	1	EGNOS	W	5	5	34,6	59,6	32,9	1,5	
19	1	RTK	E	5	6	33,9	86,7	0,1	0,4	
20	1	RTK	W	5	6	32,8	78,0	7,2	0,6	
21	1	RTK	E	6	6	32,3	75,3	9,1	0,6	
22	1	RTK	W	6	6	33,9	81,6	6,1	0,7	
23	1	EGNOS	E	6	7	34,8	76,7	13,9	0,7	
24	1	EGNOS	W	6	7	34,1	55,1	36,9	1,1	
25	2	EGNOS	E	1	1	30,3	50,2	35,4	1,2	×
26	2	EGNOS	W	1	1	21,4	32,9	39,9	2,1	×
27	2	RTK	E	1	2	31,8	75,6	7,3	0,5	
28	2	RTK	W	1	2	32,1	79,8	2,9	0,5	
29	2	RTK	E	2	2	37,2	91,1	4,4	0,4	
30	2	RTK	W	2	2	37,7	84,7	12,3	0,5	
31	2	EGNOS	E	2	3	36,8	77,2	18,0	1,4	
32	2	EGNOS	W	2	3	33,2	67,5	20,8	1,1	
33	2	EGNOS	E	3	3	34,9	61,0	31,8	1,2	
34	2	EGNOS	W	3	3	36,2	60,7	34,4	1,1	

35	2	RTK	E	3	4	34,0	79,6	8,5	0,5	
36	2	RTK	W	3	4	37,2	88,7	6,8	0,5	
37	2	RTK	E	4	4	35,0	86,8	3,1	0,3	
38	2	RTK	W	4	4	38,0	84,6	13,0	0,5	
39	2	EGNOS	E	4	5	34,7	55,7	37,3	1,7	
40	2	EGNOS	W	4	5	32,8	62,2	25,9	1,1	
41	2	EGNOS	E	5	5	35,7	59,8	34,6	1,5	
42	2	EGNOS	W	5	5	35,5	78,2	14,1	0,7	
43	2	RTK	E	5	6	35,6	88,7	2,6	0,3	
44	2	RTK	W	5	6	36,9	83,2	11,9	0,6	
45	2	RTK	E	6	6	37,0	82,3	13,1	0,6	
46	2	RTK	W	6	6	35,2	85,0	5,8	0,5	
47	2	EGNOS	E	6	7	37,8	76,5	21,1	1,3	
48	2	EGNOS	W	6	7	37,3	74,8	21,8	0,7	

References

R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/

To provide an overall estimation of the accuracy of RTK and EGNOS in this trial, we aggregated the displacement values per each of the two treatments.

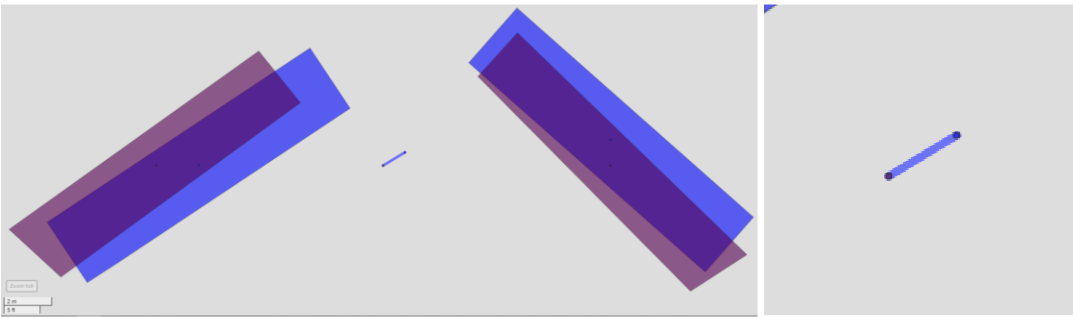
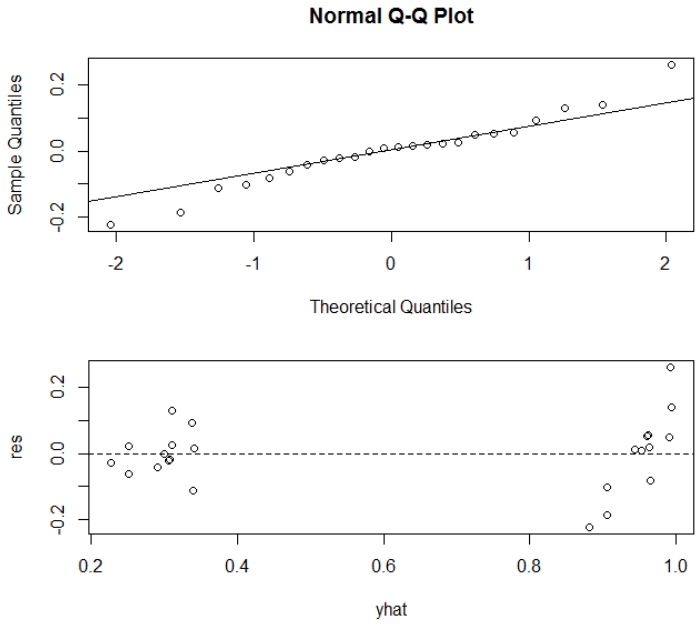


Figure 11 Graphic representation of displacement in a single plot (Target area: blue; EGNOS, sprayed area: purple). Displacement describes how much the applied area is shifted or displaced with respect to the target area, ignoring coverage and applied area.

Looking at the results in Table 3, RTK perform significantly better than EGNOS, with an average-aggregated displacement of 9 cm, compared to 90 cm achieved by EGNOS.

Table 3 Additional data analysis

Application precision parameter	GPS-type	Estimated mean and 95%-CI	Difference	F-value	Group
Displacement, aggregated at repetition-level	RTK	0.09 (0.01, 0.23) m	0.81 m	190.416	a
	EGNOS	0.9 (0.6, 1.27) m			b



Graph 5 Distribution of displacement data

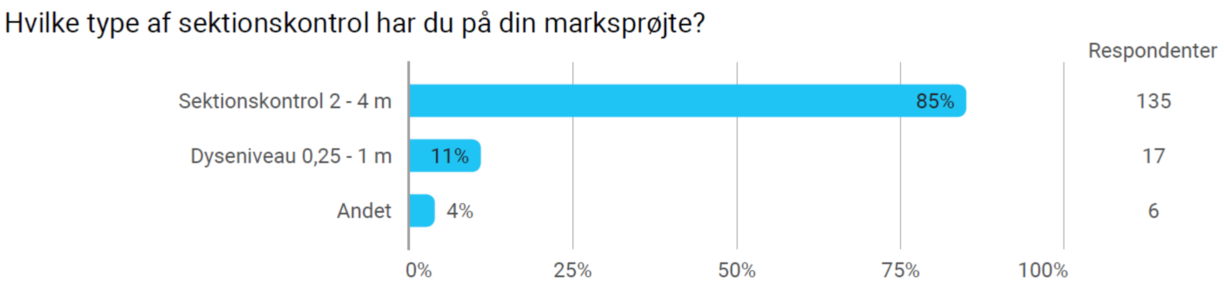
6. Conclusions

From the results of the test, we can state that RTK has showed higher performances than EGNOS, when it comes to precision-spraying. For a correct distribution of chemicals in the field, we estimate that RTK-applications would need a buffer of up to 0.23 m. Conversely, EGNOS-application would need a buffer up 1.27 m and, for this reason, this technology does not seem suitable for sub-meter accurate application.

In addition, this test also shows that a correct set up of the sprayer and parameters such as the distance between the D-GPS antenna and the nozzles, regardless of whether this antenna receives RTK or EGNOS signal, are crucial for a correct application of chemicals in the field.

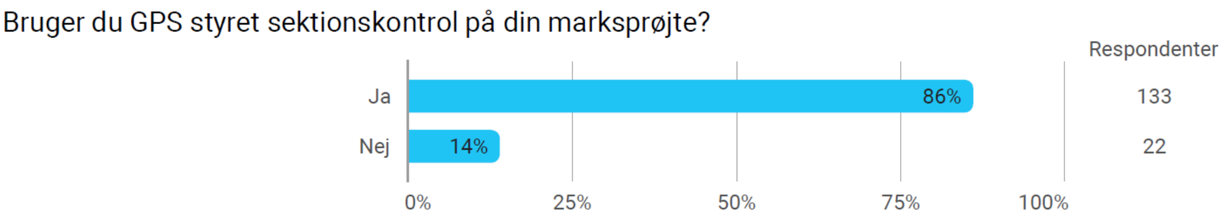
7. Survey

Below here are reported questions, answers and farmer's comments:

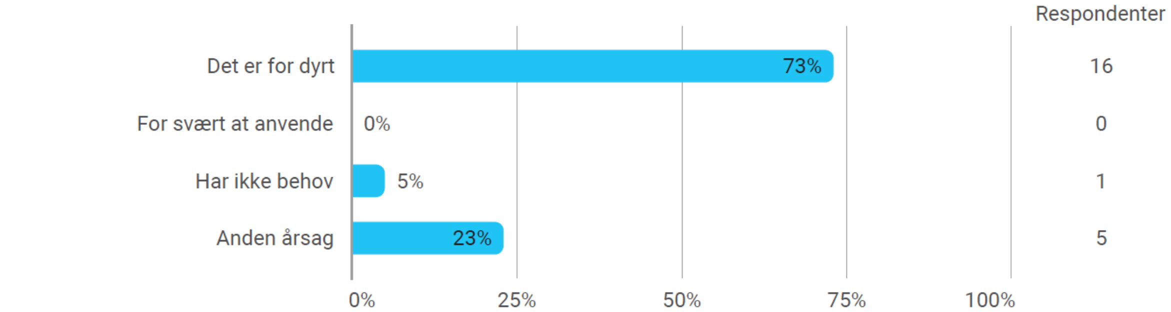


Hvilke typer af sektionskontrol har du på din marksprøjte? – Andet

- 1,5 m
- Horsch leeb 36 meter. Dyseluk fra 0,5 m - 2 m
- 8k
- Manuel sektionskontrol



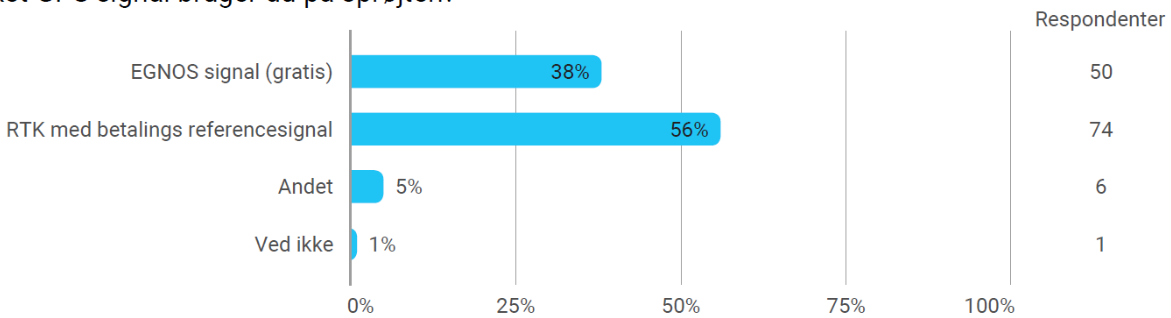
Hvorfor ikke?



Hvorfor ikke? - Anden årsag:

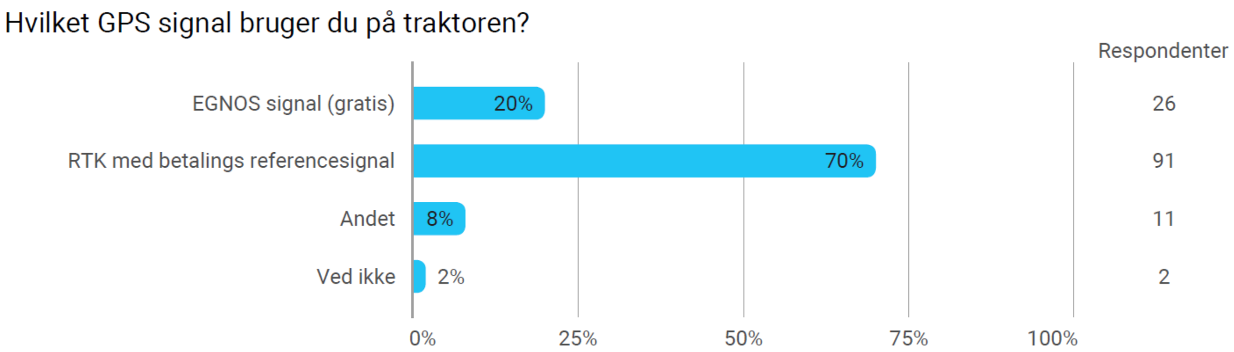
- sprøjten er ikke udstyret til det
- Chefen har ikke villet betale for det, til trods for at vi driver 700 ha
- Ikke kommet der til endnu. Men kommer
- Det er nok ikke prisrentabel for en fritidsbonde med 40 ha planteavl

Hvilket GPS signal bruger du på sprøjten?



Hvilket GPS signal bruger du på sprøjten? - Andet

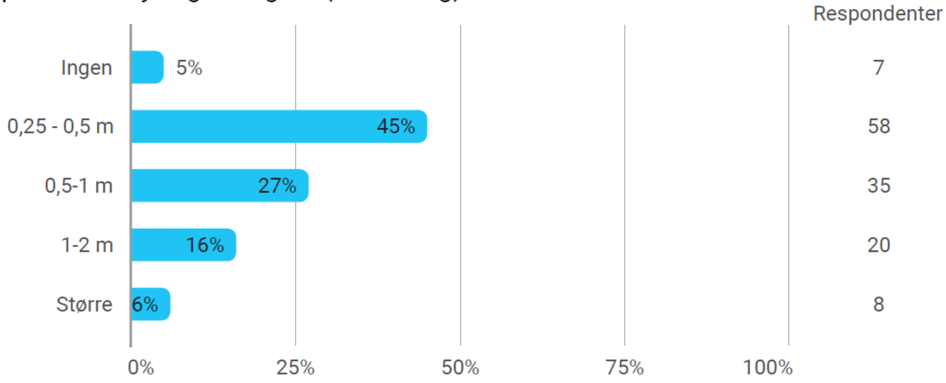
- Det gratis RTK2GO korektionssignal
- John Deere sf 1 gratis signal
- Rtk med eget rtk signal
- Agopengps
- Begge dele både rtk og egnos kommer an på traktoren som er foran



Hvilket GPS signal bruger du på traktoren? - Andet

- Ardusimpel rtk modtager og ntrip server RTK2GO
- Ikk noget
- Ikke noget
- Intet
- John deere sf1 eller rtk, afhængig af om mit rtk anlæg bliver brugt til såning når vi sprøjter.
- Rtk med gratis rtk signal
- Intet
- Rtk gratis
- Bruger ikke gps på traktoren til sprøjtning. Dog RTK til såning
- Begge 2

Hvor stort er dit overlap ved kilestyring/forager? (indstilling)



Hvor stort er dit overlap ved kilestyring/forager? (indstilling) - Større

- 4m sektioner
- Der er 4m. i en sektion. Men overlap styres I %
- Bestemt af kemi type 0-2m
- ?

Here below the final comments from the farmers:

1. *Synes ikke gratis signal er godtnok til sektionsafluk*
2. *Altid rtk*
3. *Det kan være utrolig upræcis i visse marker hvilket medføre at selv om der køres med rtk med backup er man nød til at køre nogle marker i hånden.*
4. *Kverneland kan ikke finde en løsning på den pågældende model, derfor bliver det for dyrt selv at udvikle en løsning*
5. *Egnos signal, har med med at "drive" over længere tid, efter man har kørt ydreomgang på marken*
6. *Syntes det er svært og få præcis nok. Kører kun med det sjældent*
7. *Det vi mangler er en måde så det var nemt at kontrollere om der ikke bleve mister. Det er ikke alle som har en flyveplads at gøre det på. Vi har lige fået ny sprøjte og brug rigtig meget tid på at justere åben/luk men vi tør ikke gå længere ned end 1-2 m. Vi kunne helt sikkert gå en på 0-1 m men det er svært at tjekke. Det er også dumt at have små trekanter med græs ukrudt til foråret. Fint på noget som er nemt at justere det efter så vil der kunne spares noget kemi*
8. *Har kørt med både gratis signal og kører med rtk nu og mærker ikke nogen forskel.. jeg kører vel og mærket med alm*
9. *sektionskontrol kan godt være at det er noget andet på dyse niveau*
10. *RTK tages fra eksisterende anlæg på traktor*
11. *Det sidste svar var bedste bud men spøjten viser stort set samme areal som er i marken*

12. *Egnos er alt for upræcis, det glider i både længde og bredde retning. Startede med det for 10 år siden. Hvis man forlod marken for st køre hjem og fylde sprøjten, skulle man markere op igen. Min erfaring siger at man mindst skal have RTK, men har man RTK kan man også lade traktoren køre automatisk i sprøjtesporene, det giver sådan en dejlig rolig sprøjtebom i længderetningen =mere ensartet afsætning.*
13. *Den store forskel på egnos og rtk til sektionskontrol er drift mere end præcision. Jeg har sået med sektionskontrol på gratissignal i mange år, og afvigelserne kommer pga drift af signalet når det tager for lang tid at behandle en mark. Hvis der ikke var drift på gratissignal, ville jeg ikke betale for rtk i dag.*
14. *If visse afgrøder er det vigtigt at kunne sikre at der ikke-rygning bliver sprøjtet mere end 100 %. Start / stop ved forager kan tåle lidt overlap, men det kan gøre skade at lave en dobbeltsprøjtning I markens fulde længde, der kan det være en fordel at have små sektioner 0.5-1 meter, så overlapper bliver minimeret*
15. *Hvis du skal have noget ud af det skal aflukket være på dysenevu*
16. *Automatisk Sektionskontrol fra Fendt vario guide der styrer en horsch sprøjte via isobus er virkelig virkelig godt. Ift overlap, så er det noget man vælger hvor meget der skal være afhængigt af midlerne og opgaven*
17. *Overlap i kiler bliver sektions bredde ved luk stillet til 90%*
18. *Man kan sagtens lave et GPS anlæg til under 10000 kr*
19. *Sætter vi overlap ned til 0, så kommer der lidt striber ved åben og luk, derfor har vi 0,25-0,5m*
20. *Det er super godt at køre med*
21. *Selvkørende hardi sprøjte*
22. *Hvis det var billigere at få på gamle sprøjter ville det hjælpe meget*
23. *Jeg er meget tilfreds med sprøjten, en Kverneland. Det handler også en del om hvordan man indstiller systemet ved kiler mm. for at den laver et tilfredsstillende arbejde. Skal nu til vinter have den opgraderet til gradueret tildeling for at kunne gøde med den i forbindelse med præcisionslandbrug.*

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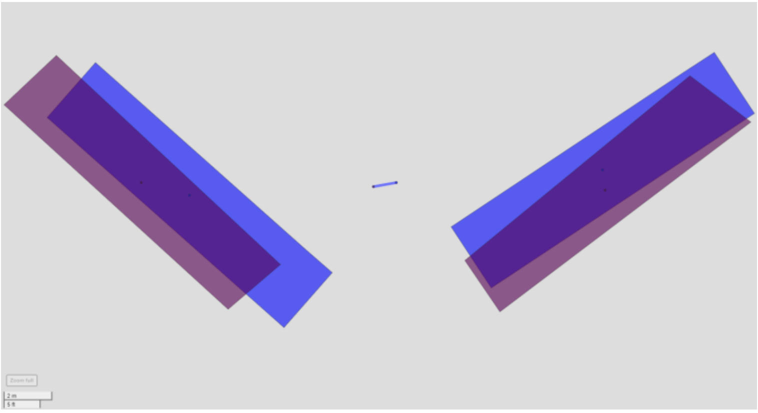
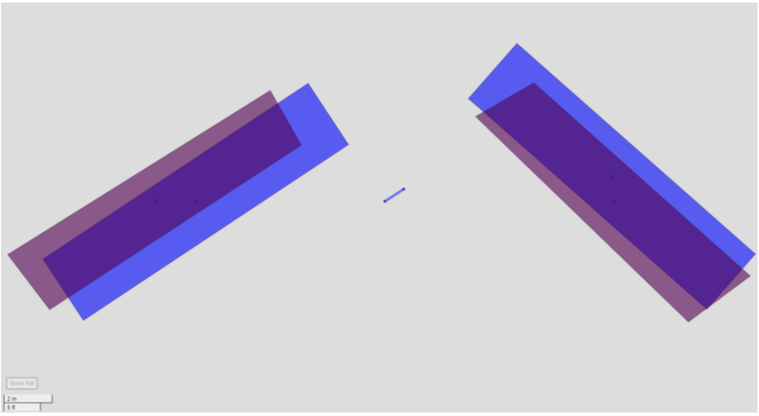
8. APPENDIX

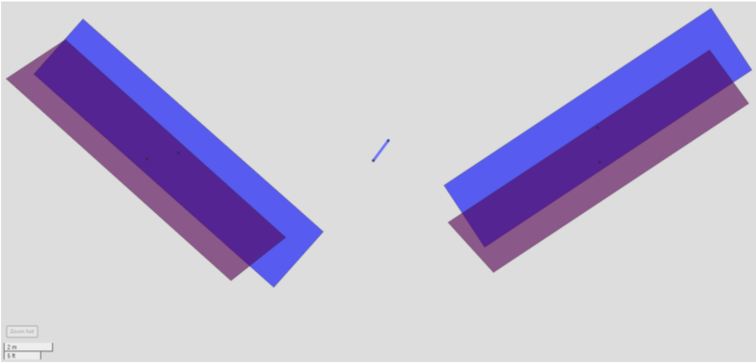
In the appendix is reported a visual overview of each single plot.
Legenda:

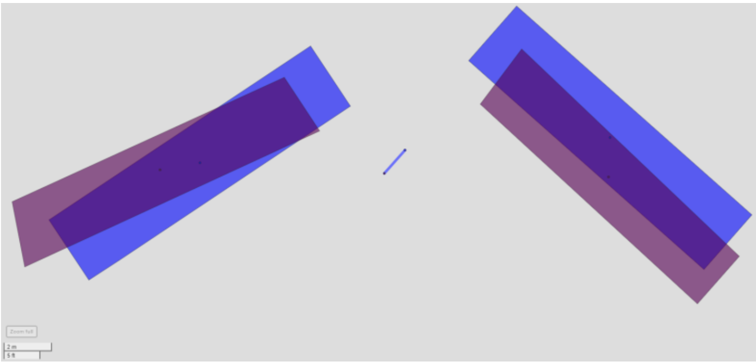
- Target area: blue
- EGNOS, sprayed area: purple
- RTK, sprayed area: yellow

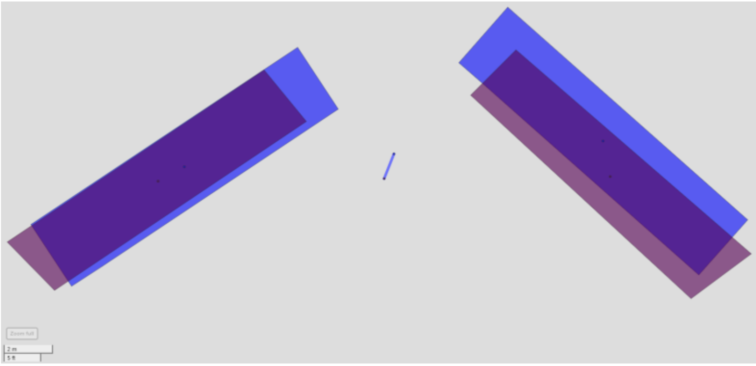
8.1. EGNOS, first run

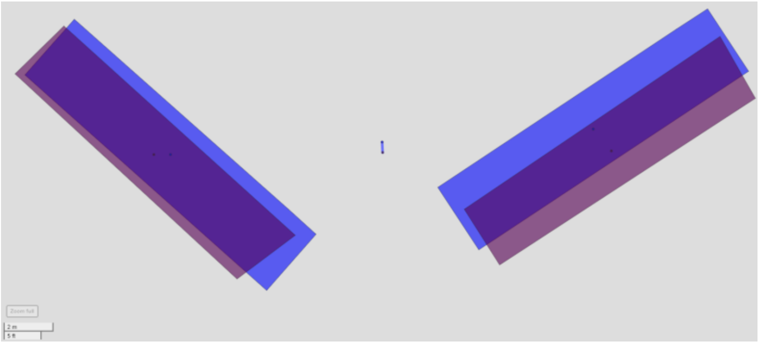




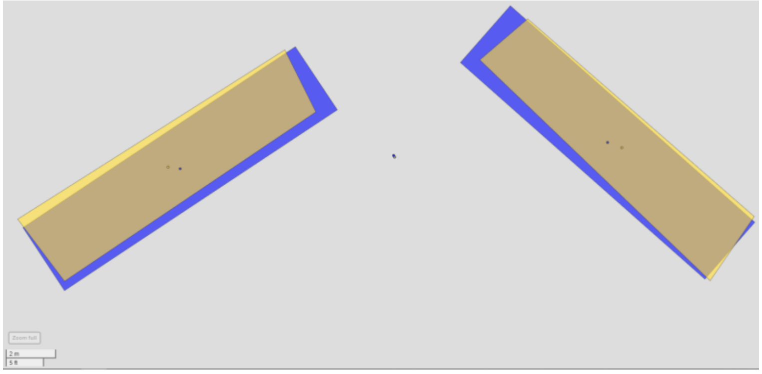


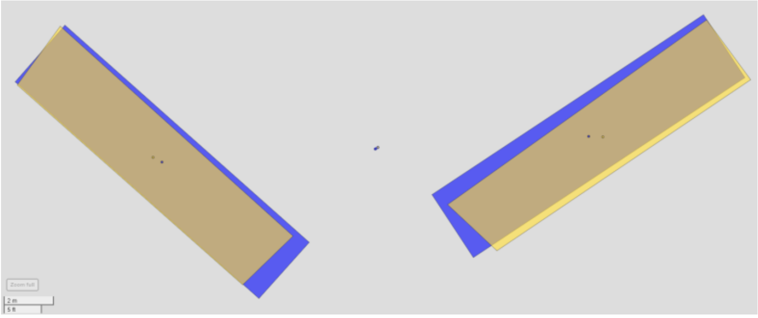


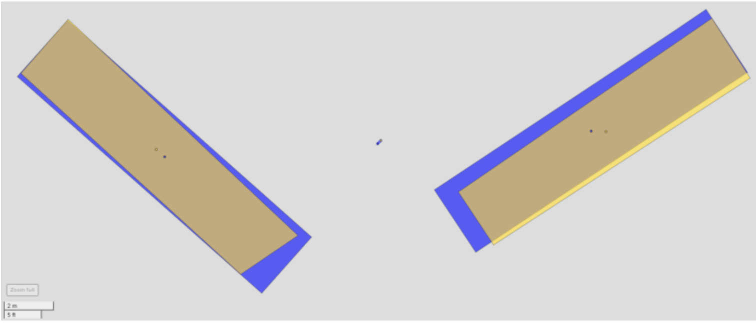


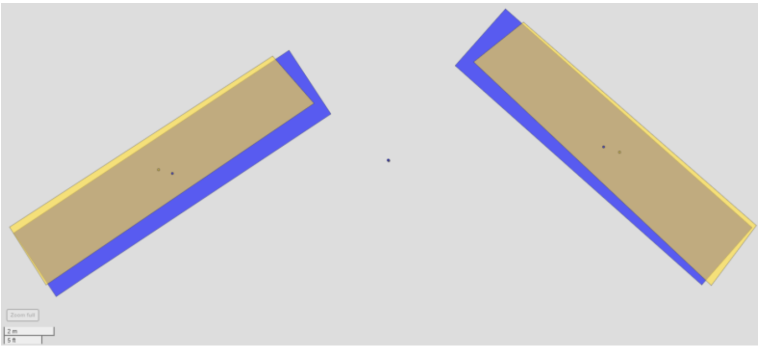


8.2. RTK, first run

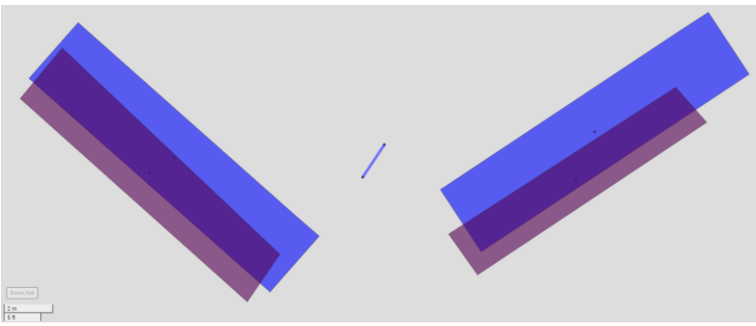








8.3. EGNOS, second run



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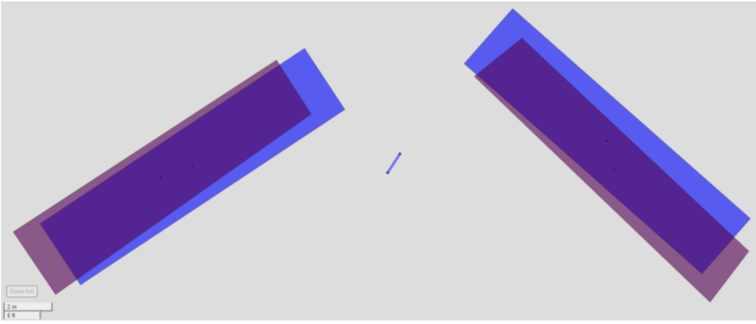
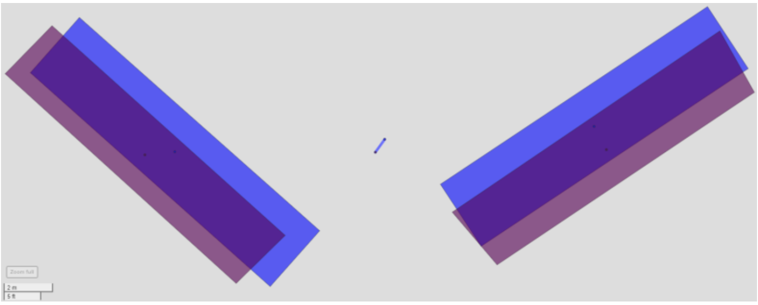
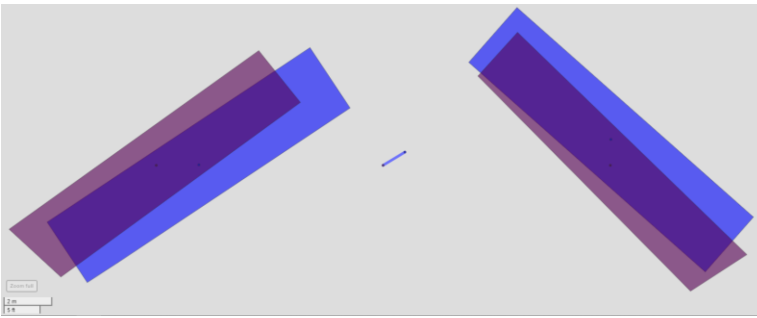
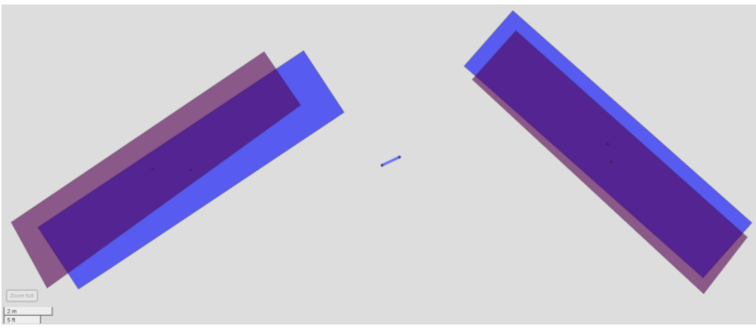
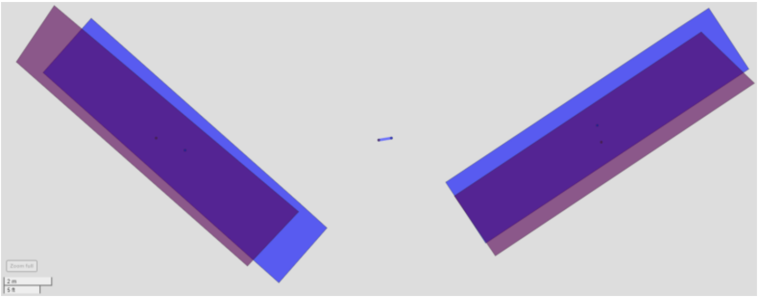


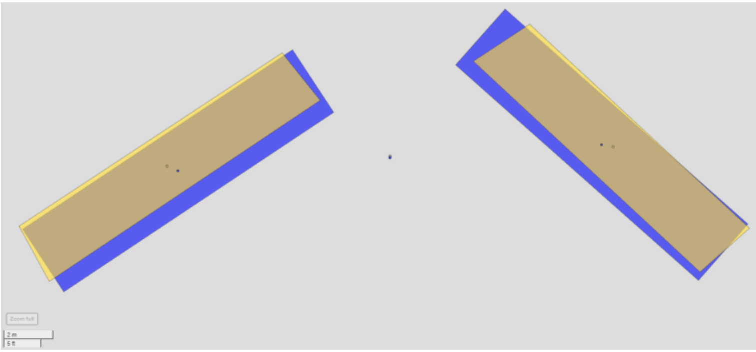


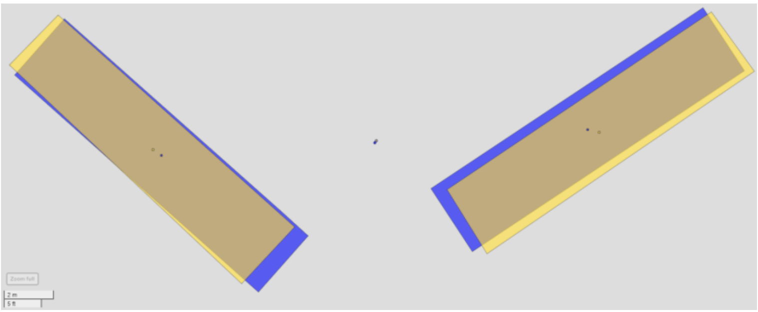


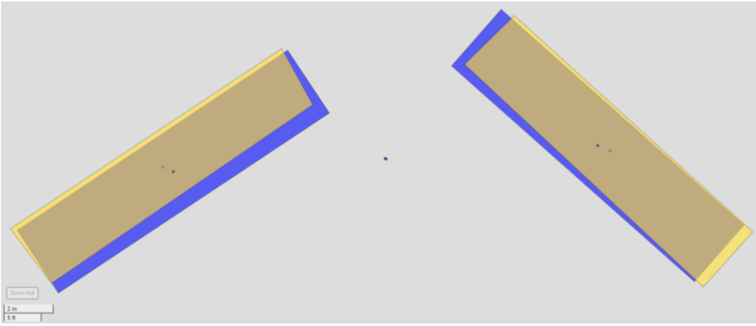


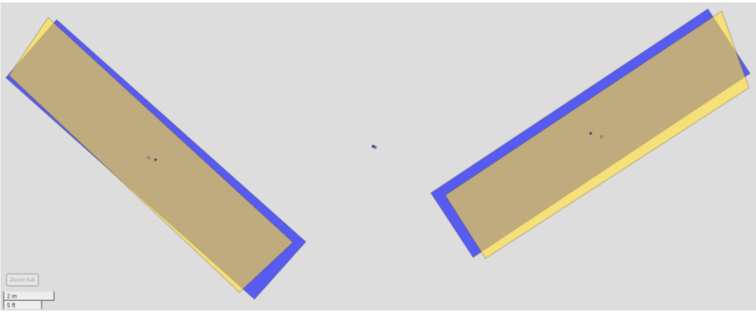


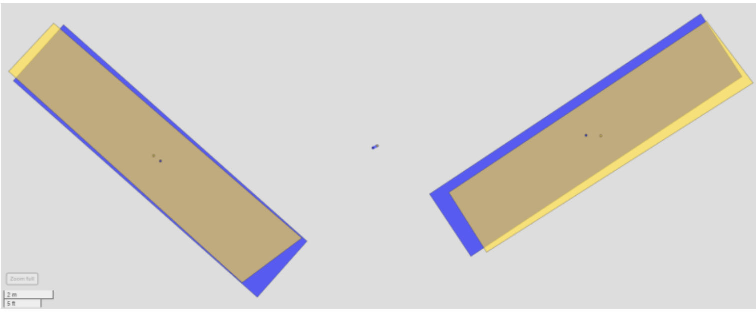
8.4. RTK, second run

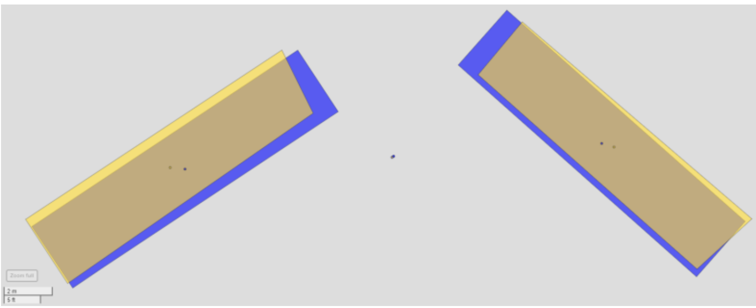












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