Analysis of the visibility of GPS satellites in the urban environment using point cloud representation

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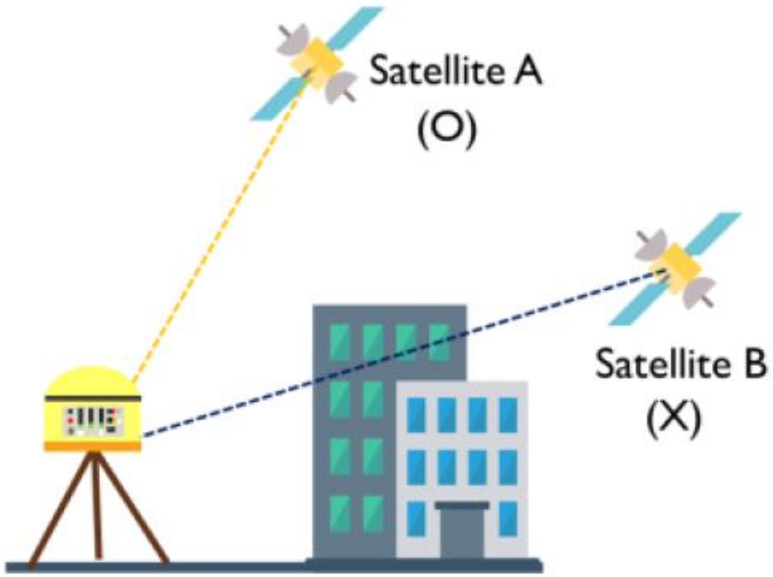
Delegate: Bastiaan van Loenen

Table of contents

Line of Sight

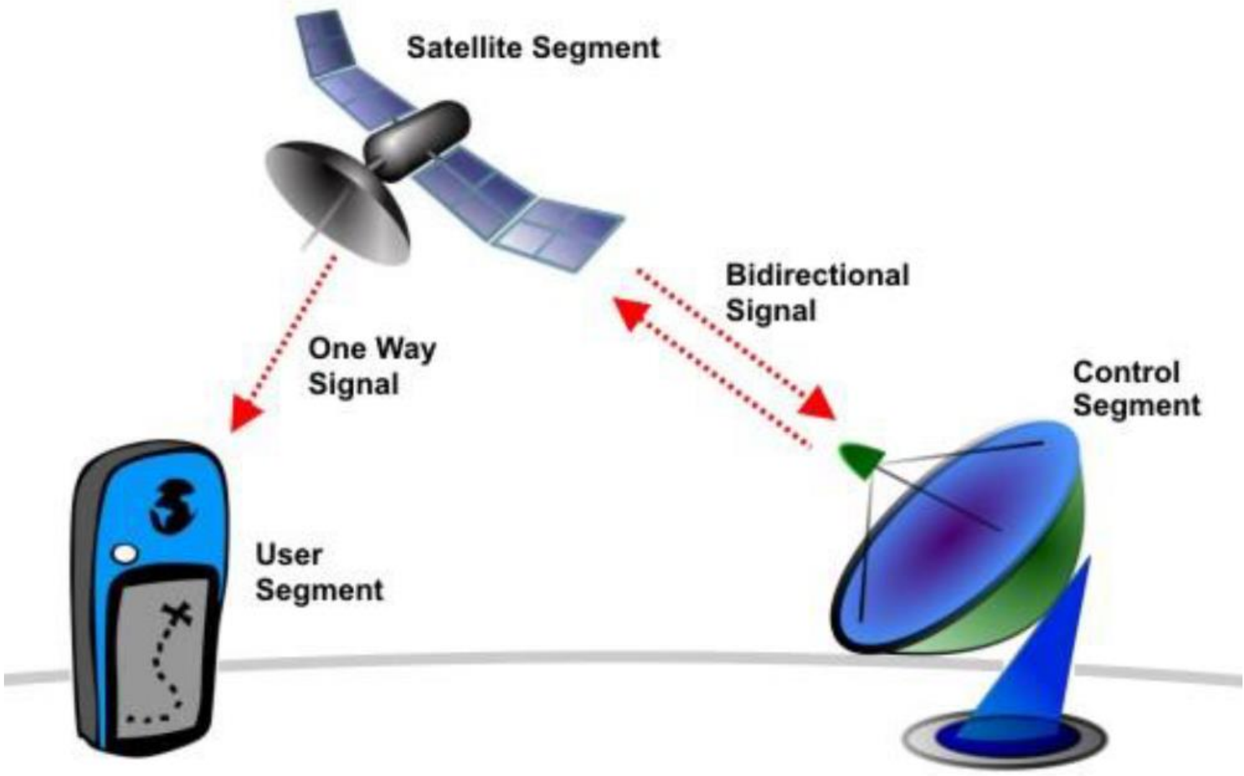
- Satellite visibility is defined as the connecting “line” established between the satellite and the ground receiver (Line of Sight - LoS)



Lu and Han (2020)

GPS

- Has three segments



- Minimum four satellites are needed to determine the coordinates of the receiver (x, y, z coordinates and the clock error)

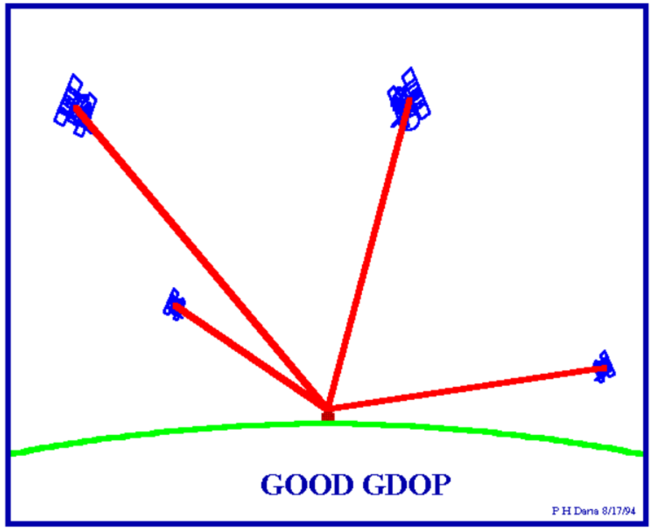
DoP values

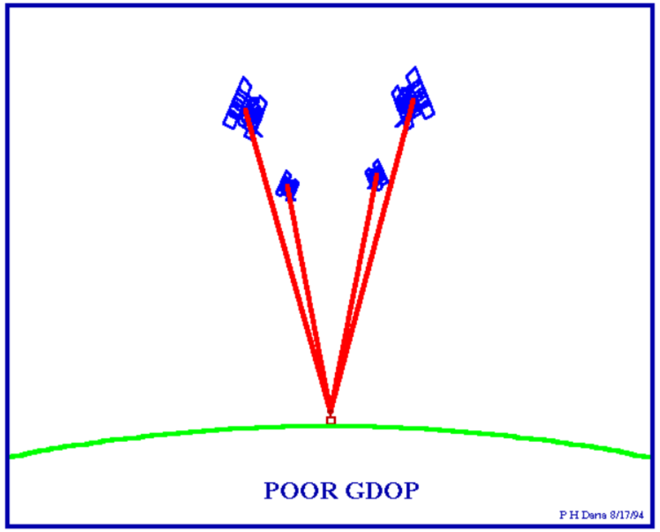
- Dilution of precision = numerical representations of the geometry of the satellites
- Dependent on the positions of satellites that are visible to the receiver.

- Volume of the shape of the vectors between the satellite segment and the user segment

- The components of the Geometrical DoP are: Positional DoP, Vertical DoP, Horizontal DoP and Time DoP

- The smaller the GDOP value is, the better the geometrical configuration of the satellites above the receiver is

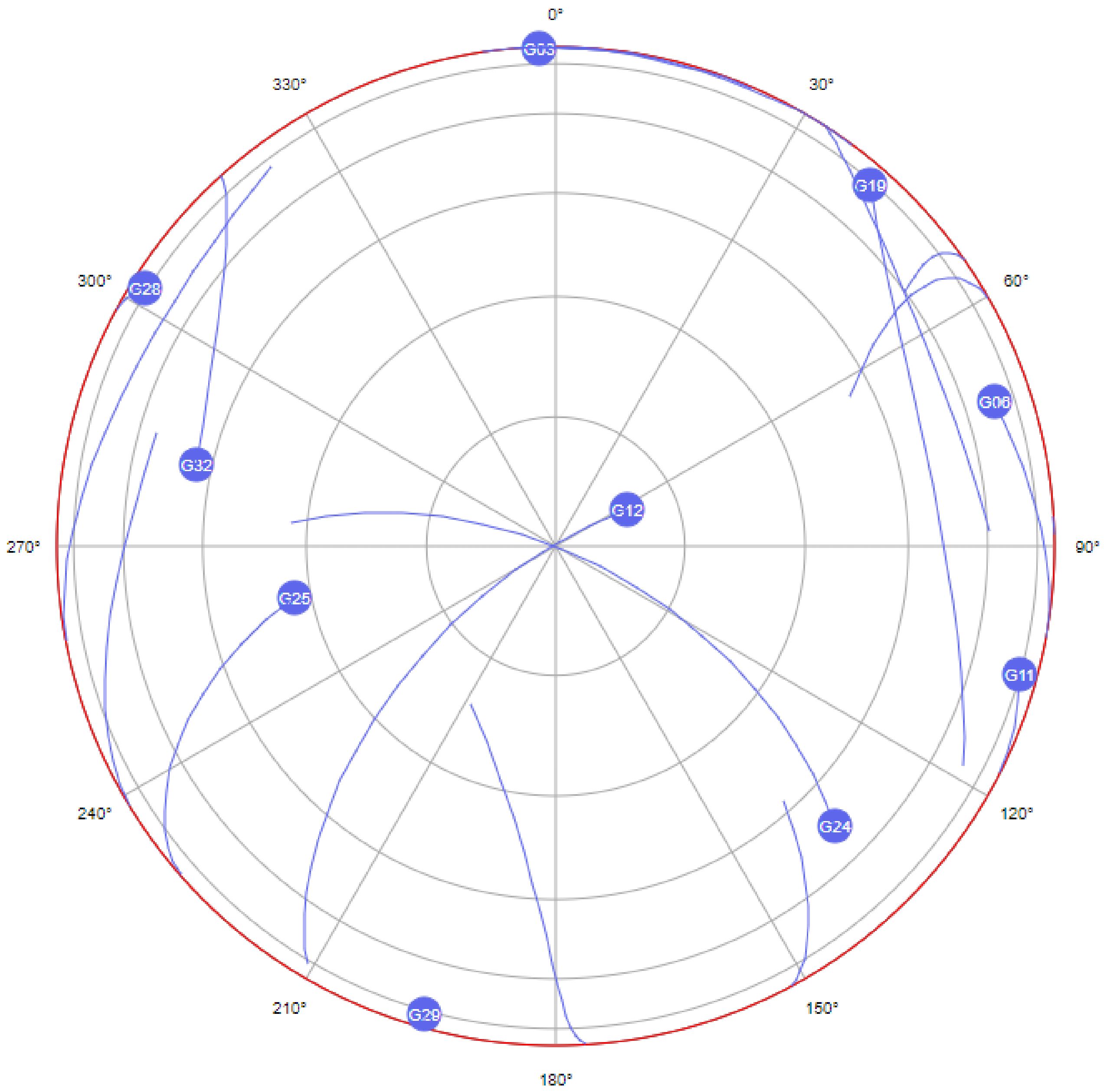




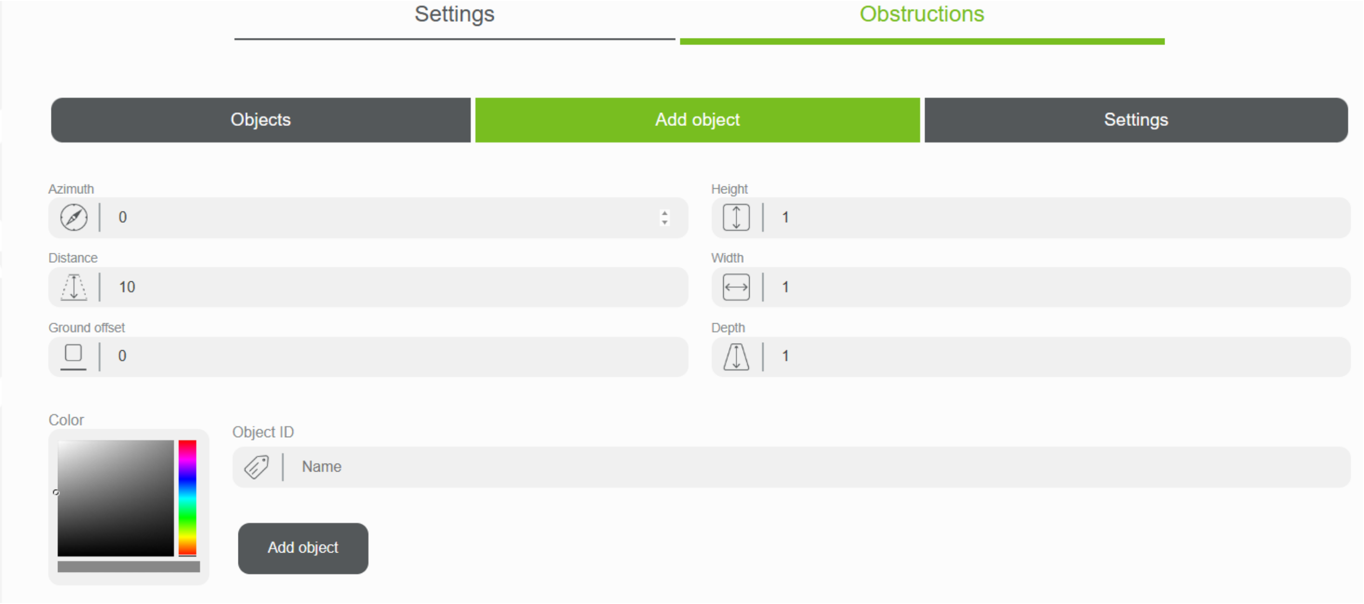
P.H Dana (1994)

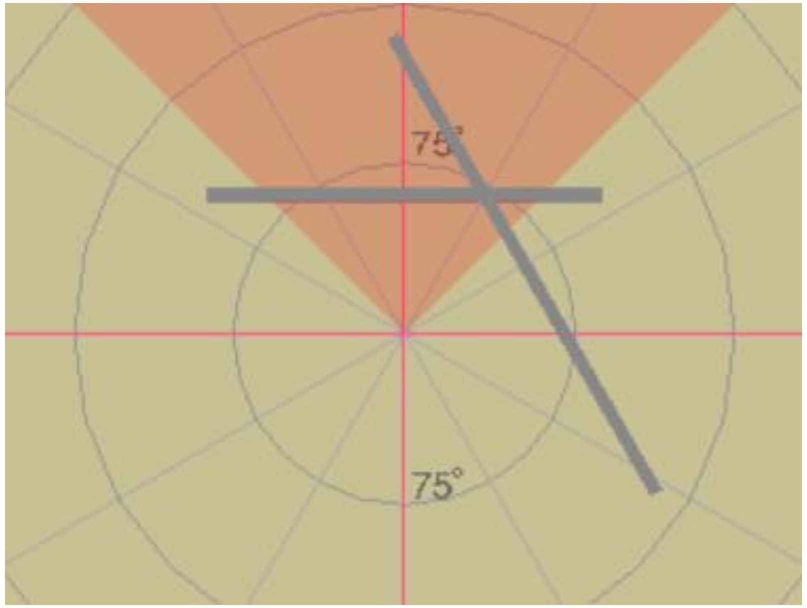
GNSS planning tools

- Software tools used to predict the quality of the GNSS survey based on the geometry configuration of the satellites above the location of the receiver at a given moment of time


0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
G03
G19
G06
G11
G24
G12
G25
G28
G32
G29

- Actual GNSS mission planning tools do not offer the user the possibility to insert the environment of the receiver properly

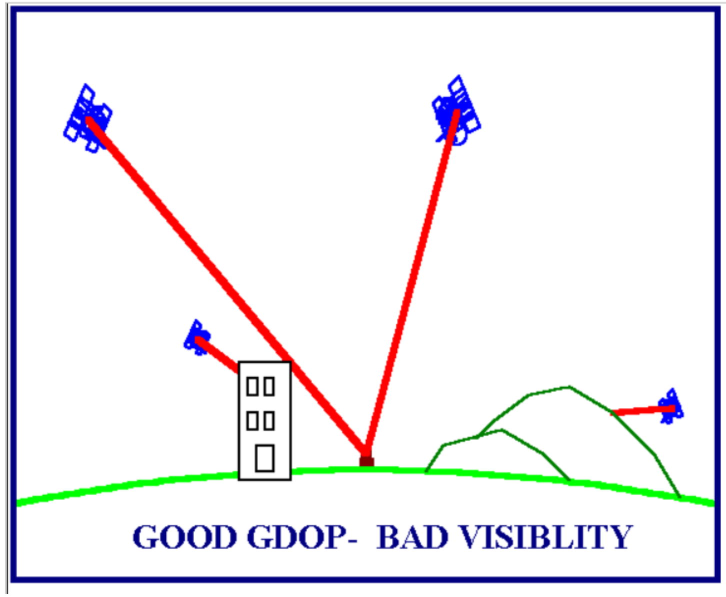




Research question:

- Main research question: *To what extent can point cloud data be integrated in the behaviour of the satellite LoS and how does this relate to and influence the DoP values?*

- How are obstructions represented in calculation of DoP?
- How good is the carried analysis compared with the given result by simulation tools/ GNSS equipment?
- How can such a simulation of a GNSS mission be helpful?
- What determines the threshold that decides if a line of sight is visible or not?



Why point clouds?

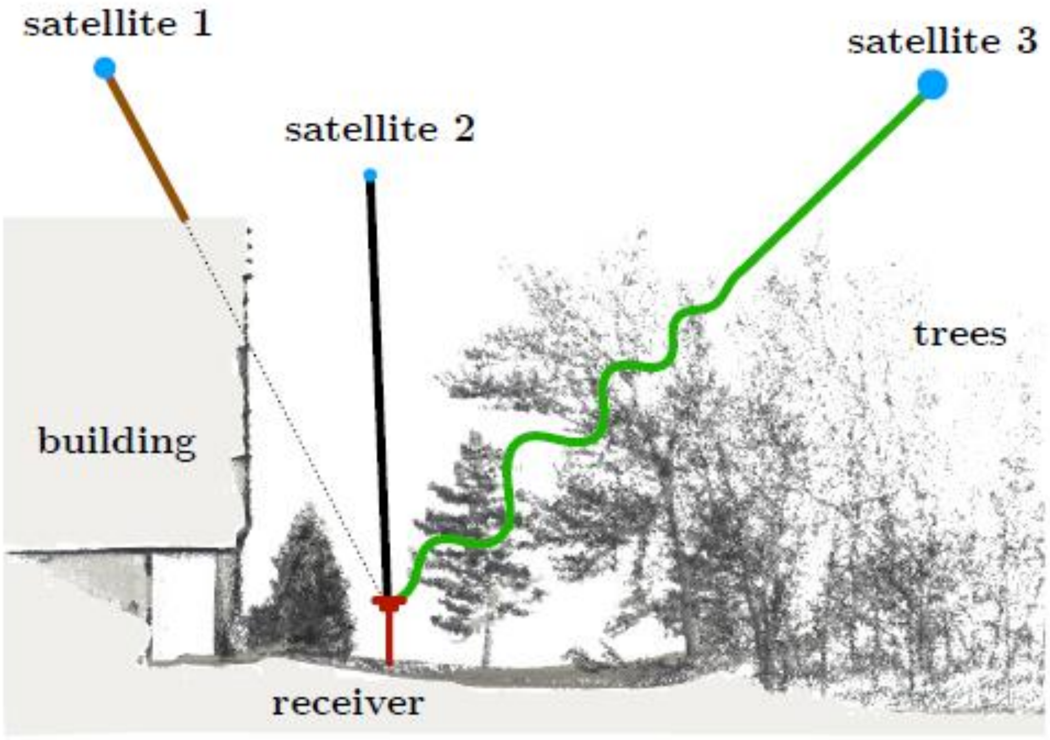
- Good 3D representation of the environment
- They represent vegetation
- Disadvantage: they do not represent a continuous surface compared to the 3D model

Why an analysis of DoP values?

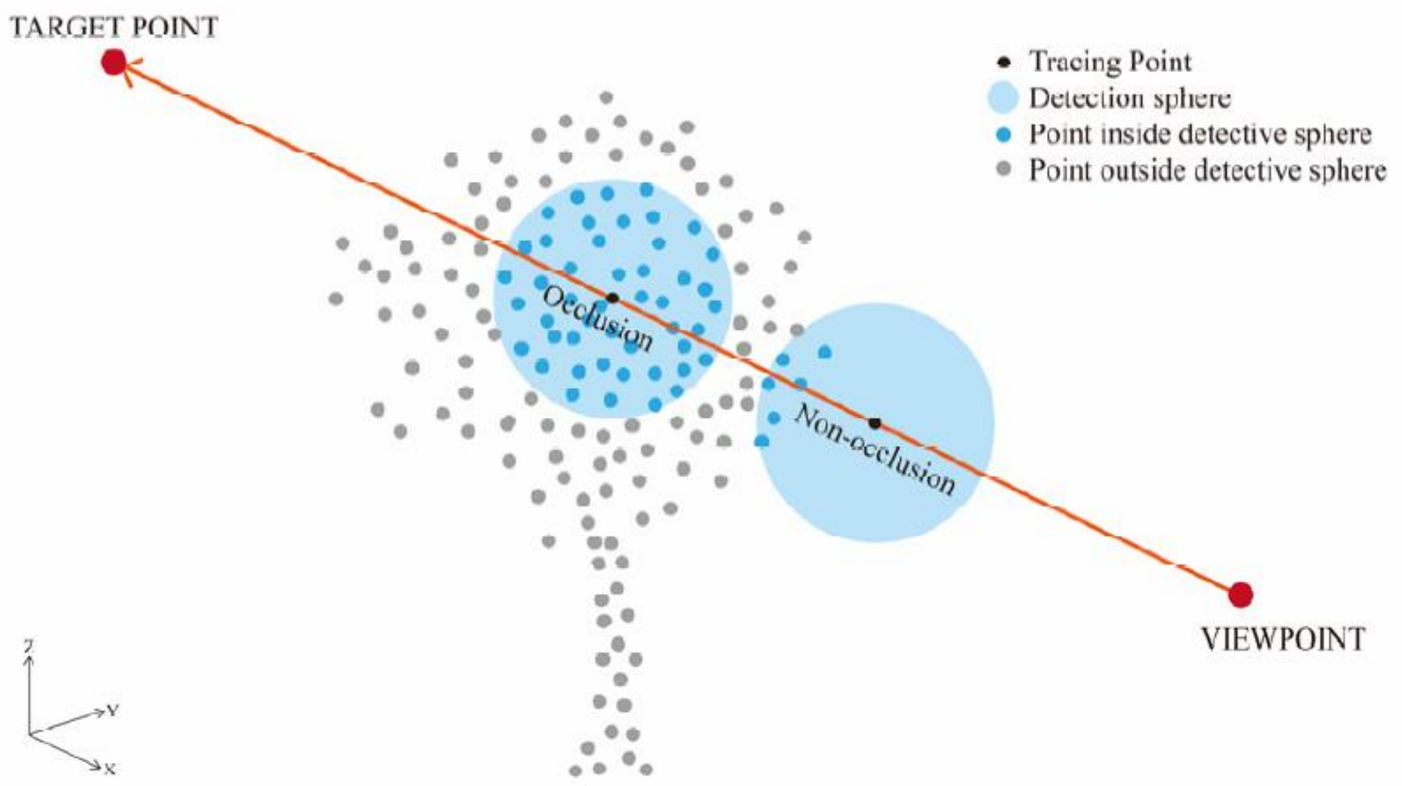
- DoP values can be used for the selection of the satellites which give the position solution (Novatel, 2015)

Related Work

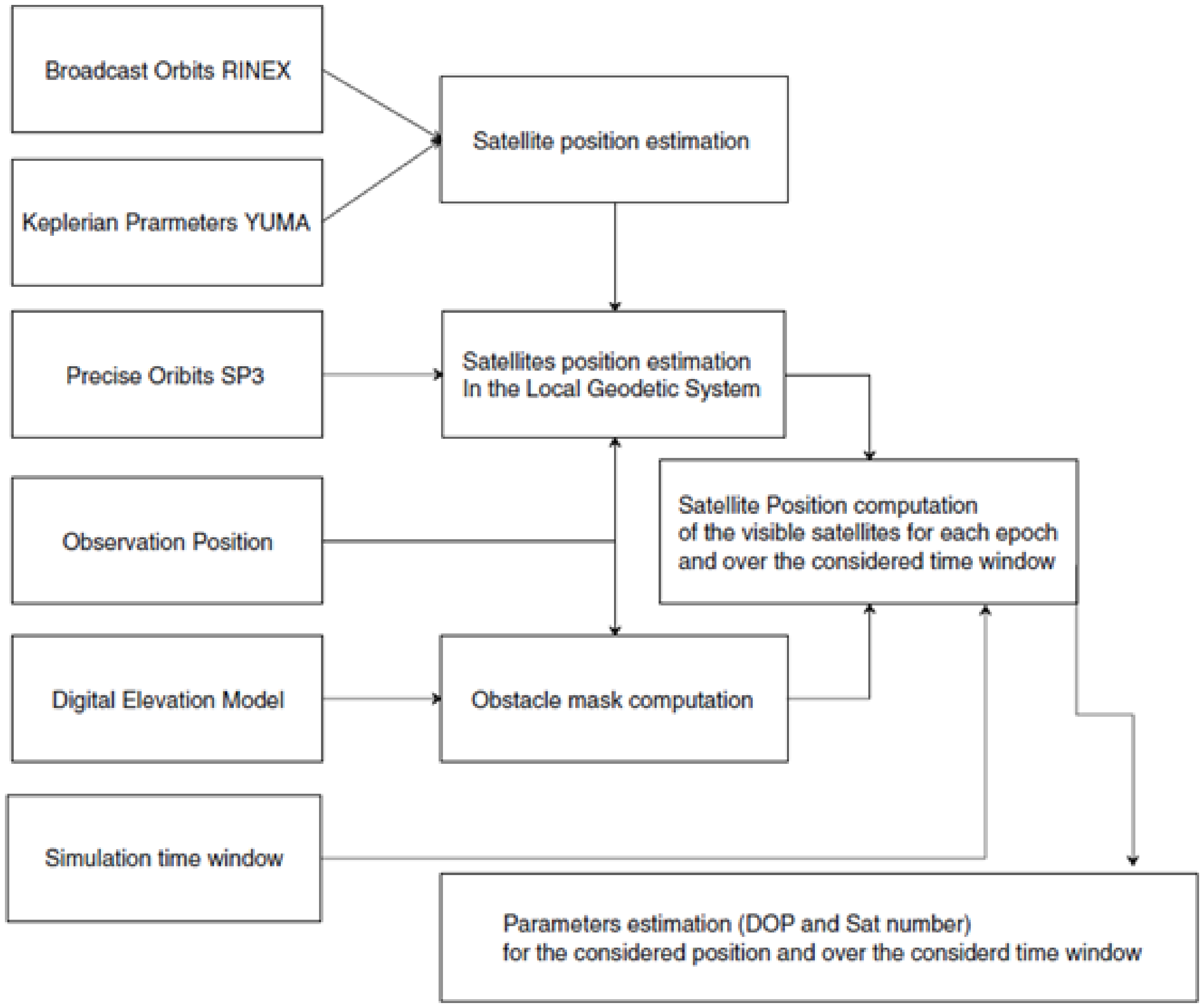
- Dandurand et al. (2019) – created a prediction model based on both the satellite constellation and the shape of the of the point cloud which represents the environment of the receiver



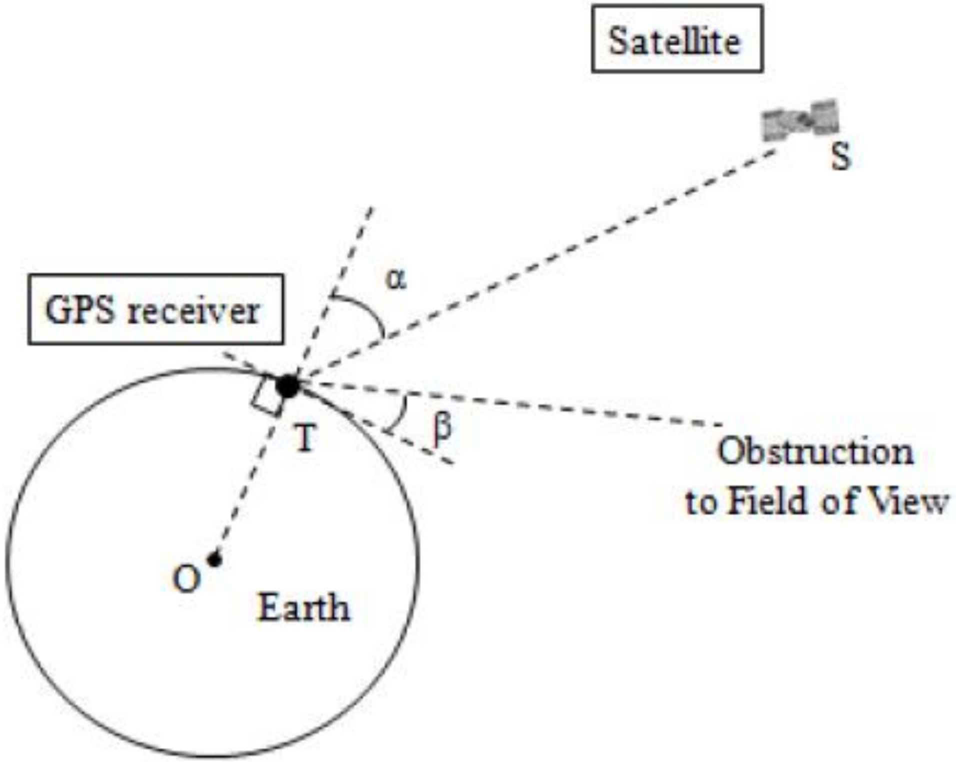
- Zhang et al. (2021) – two methods for assessing visibility between a viewpoint and a target point: one method for tall vegetation and the other method for buildings – both methods involve choosing a threshold to conclude if the LoS is blocked or not



- Gandolfi et al. (2011) – presented a GNSS planning tool software written in C++ and using DEM as 3D data



- Yuen (2009) presented in his master thesis the computation of DoP values of satellites above a given cut-off angle as well as the satellite coordinates in ECEF coordinate system (Earth – Centered Earth-Fixed)

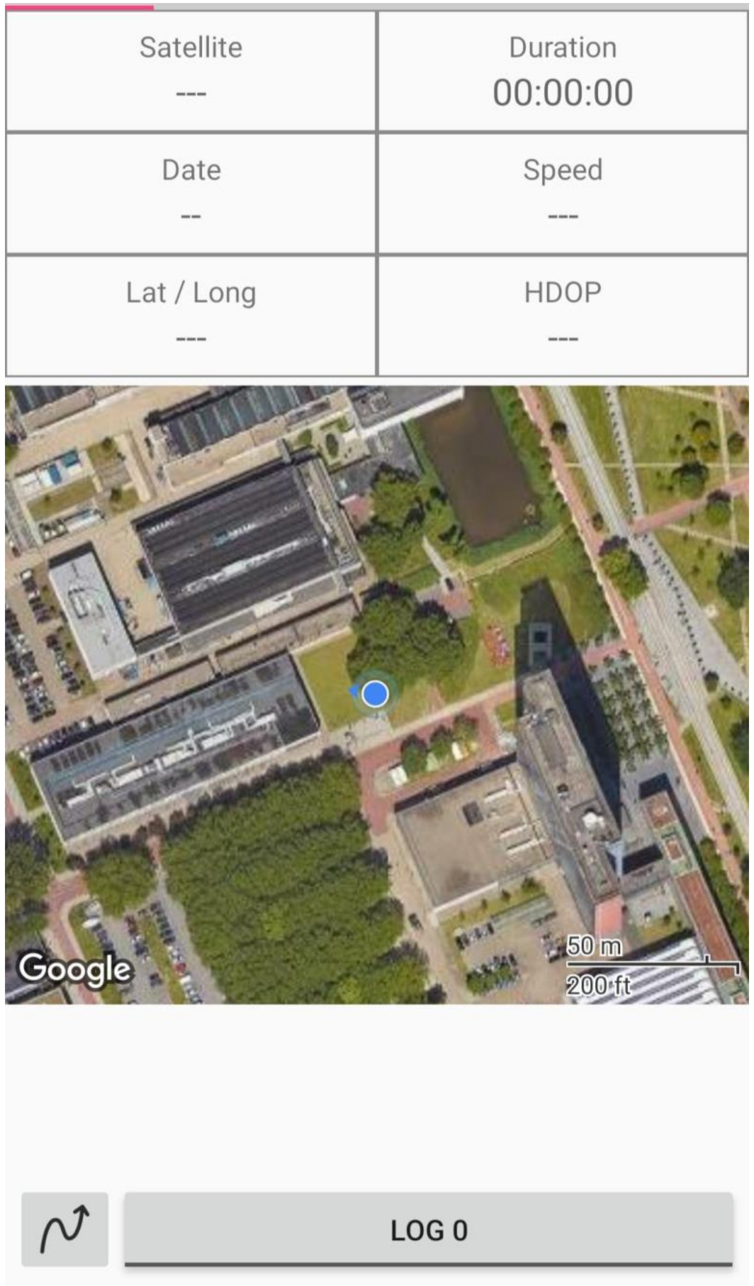


My method

- Instead of approximating the LoS with a mathematical line in 3D space
- I approximate it with a cylinder to filter point cloud objects

Resources

- AHN4 point cloud set
- Correct GPS SEM almanac for the week
- LASTools
- NMEA Tools on a Samsung Galaxy S20 FE

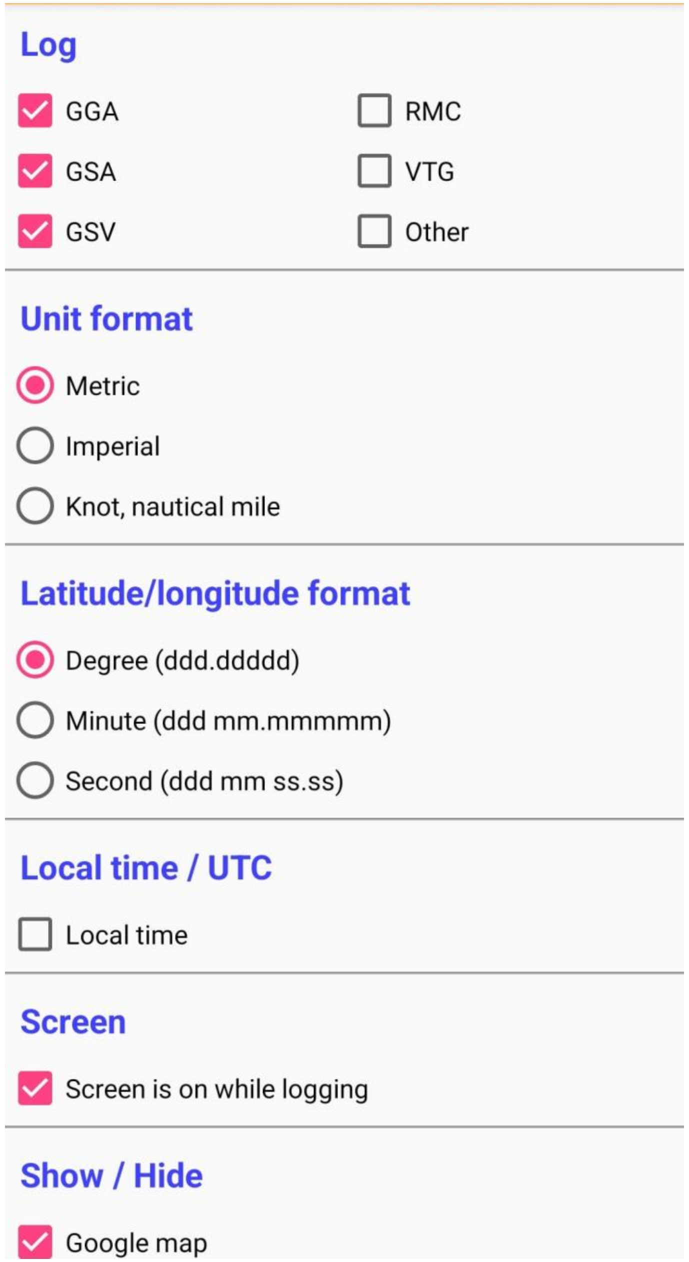

Satellite

Duration
00:00:00
Date
--
Speed

Lat / Long

HDOP

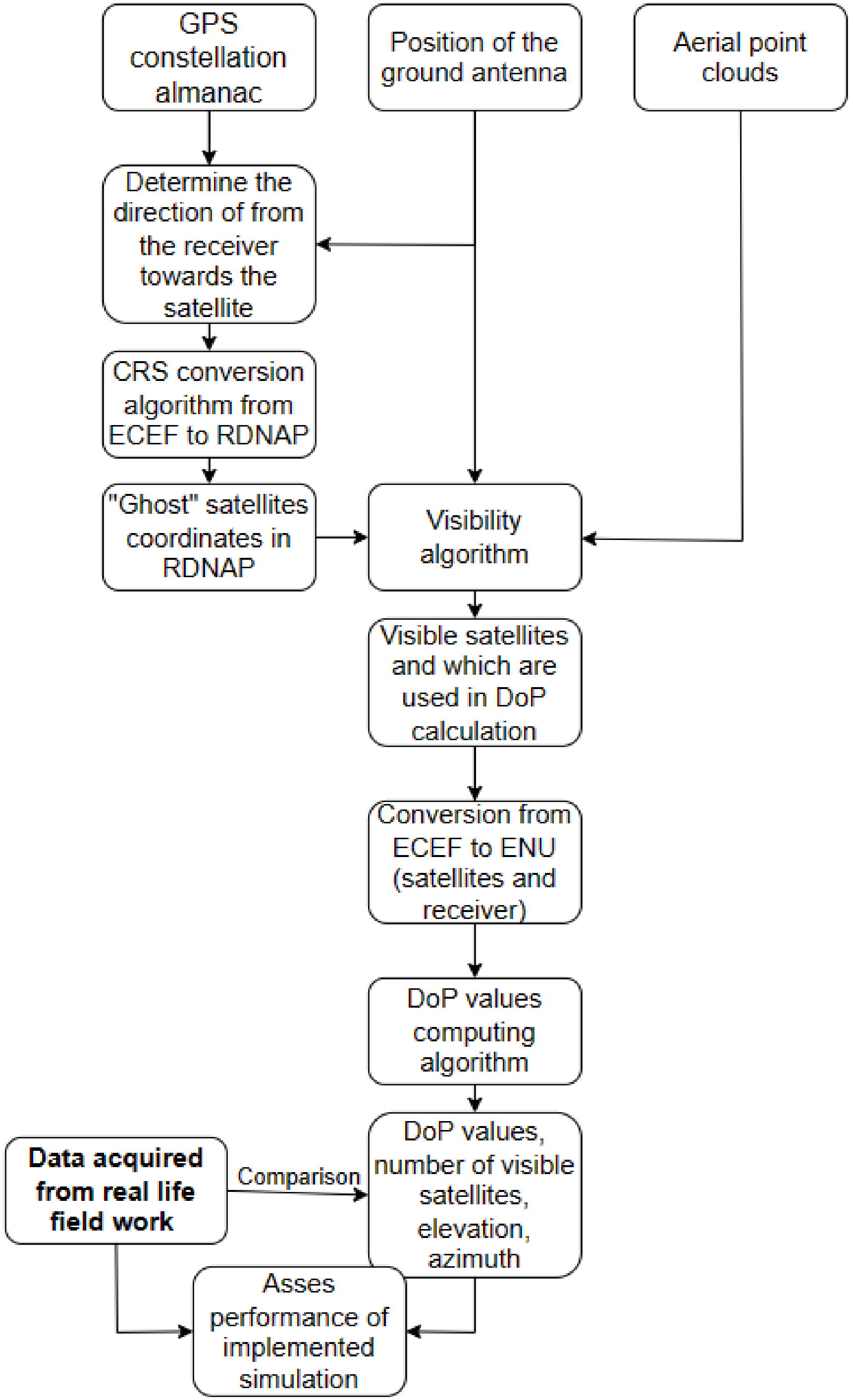
Google
50 m
200 ft
LOG 0


Log
GGA
RMC
GSA
VTG
GSV
Other
Unit format
Metric
Imperial
Knot, nautical mile
Latitude/longitude format
Degree (ddd.ddddd)
Minute (ddd mm.mmmmm)
Second (ddd mm ss.ss)
Local time / UTC
Local time
Screen
Screen is on while logging
Show / Hide
Google map

NMEA strings

```
$GPGSV,3,1,11,05,30,303,41,06,18,199,41,07,68,116,42,09,38,080,43,1*6A
$GPGSV,3,2,11,11,38,232,40,13,14,255,36,20,63,278,43,29,05,313,28,1*61
$GPGSV,3,3,11,30,52,184,49,04,06,078,,16,10,028,,1*51
$GNGSA,A,3,05,06,07,09,11,13,20,29,30,,,,0.9,0.6,0.8,1*33
$GNGGA,093341.55,5159.870061,N,00422.641143,E,1,12,0.6,1.7,M,47.0,M,,*7F
```

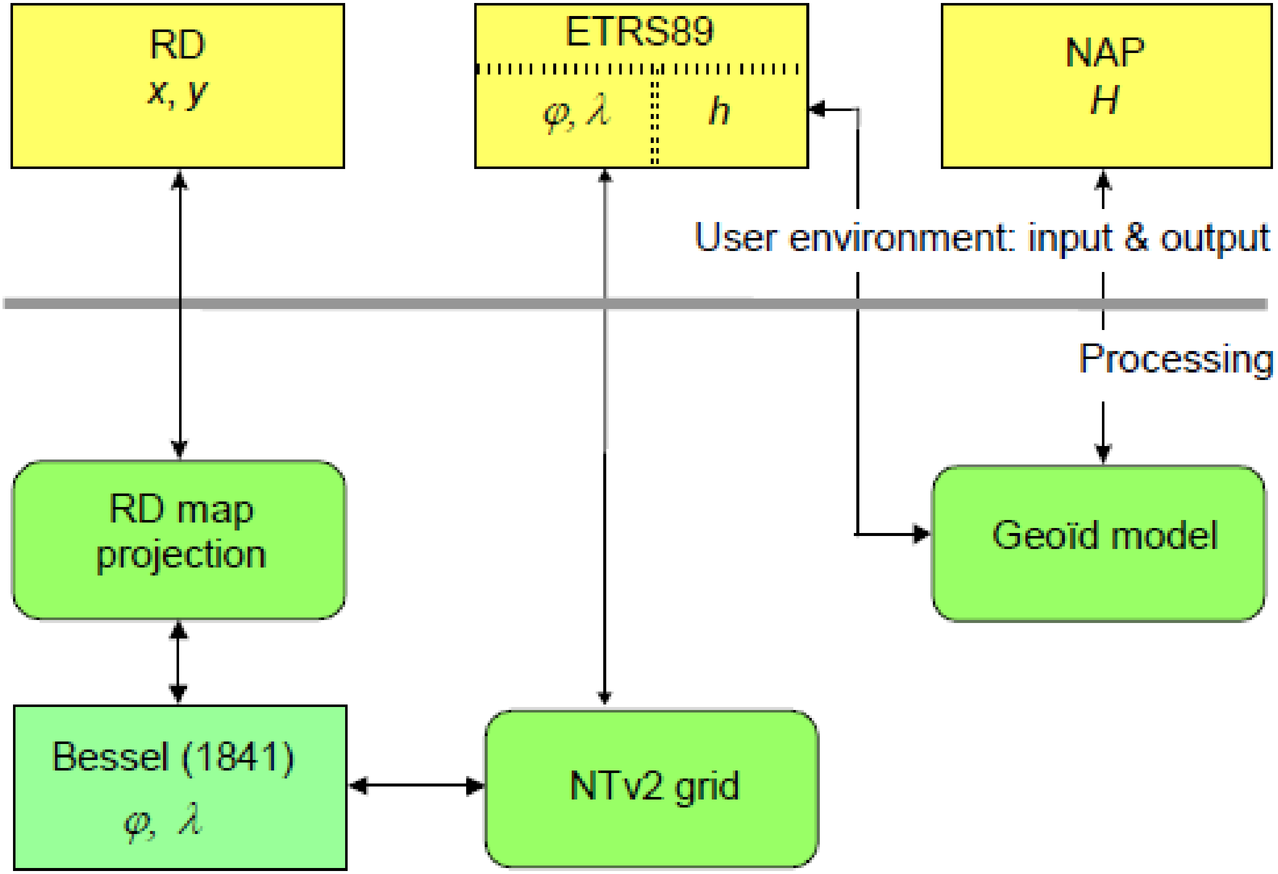
Methodology



Creation of “ghost” satellites

- Additional point positions on the LoS between the satellite and the receiver
- Why?
- To minimize the distance to fit in the boundary of the 3D data (Netherlands)
- For the coordinate transformation to work

Coordinate conversion from ECEF to RDNAP



Implementation – PROJ commands

From RD and NAP to ETRS89

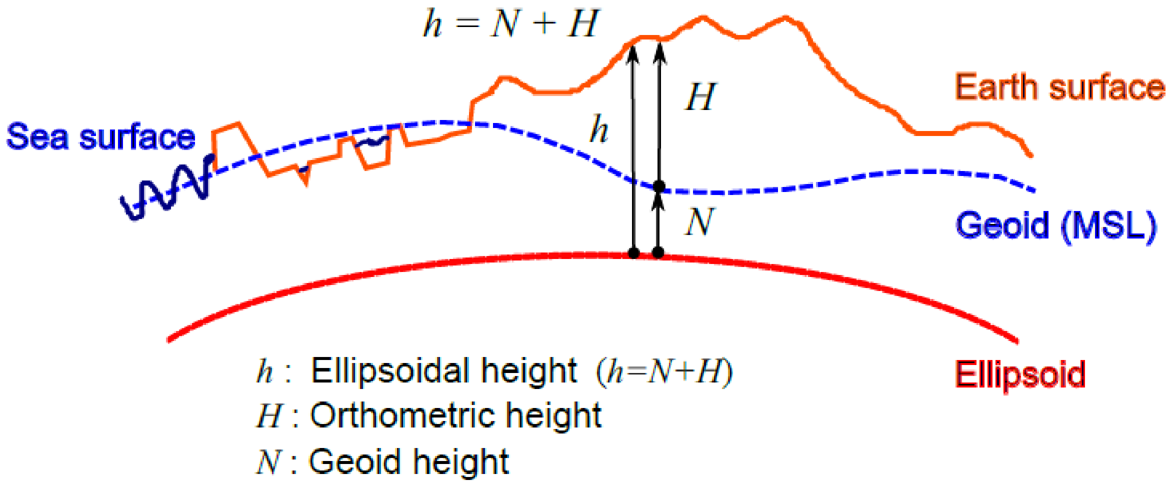
Command	Comments
`cct -I -o output.txt +proj=pipeline`	*Set optional output file;*
`+step +proj=unitconvert +xy_in=deg +xy_out=rad`	*Convert units (Section 2.1 / 3.4);*
`+step +proj=axisswap +order=2,1`	*Swap for PROJ order longitude, latitude;*
`+step +proj=vgridshift +grids=nlgeo2018.tif`	*Transformation (Section 2.5 / 3.5);*
`+step +proj=hgridshift +inv +grids=rdtrans2018.tif`	*Correction (Section 2.3 / 3.2);*
`+step +proj=sterea +lat_0=52.156160556 +lon_0=5.387638889 +k=0.9999079 +x_0=155000 +y_0=463000 +ellps=bessel`	*Projection (Section 2.4 / 3.1);*
`input.txt`	*Set optional input file*

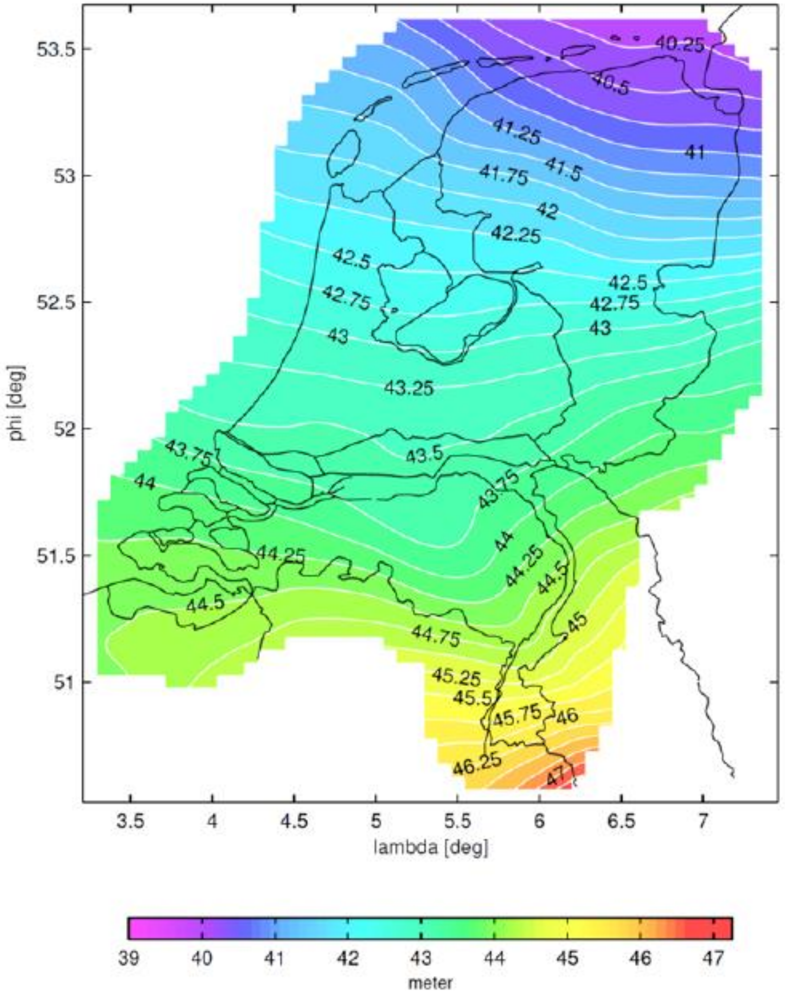
Lesparre et al. (2018)

Coordinate transformation of the receiver

- The receiver’s coordinates are given in WGS84
- To be converted to both ECEF and RDNAP
- However, the given height is the orthometric height

About the height…



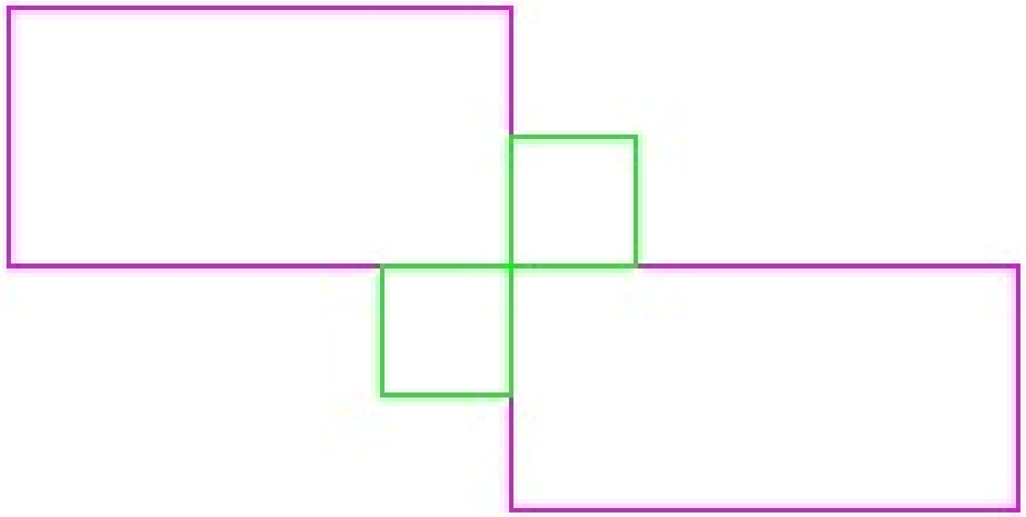


Methodology – Visibility algorithm

- Filtering operations
- Why? – To discover which satellites are visible
- Contains two parts: a 2D algorithm and a 3D algorithm

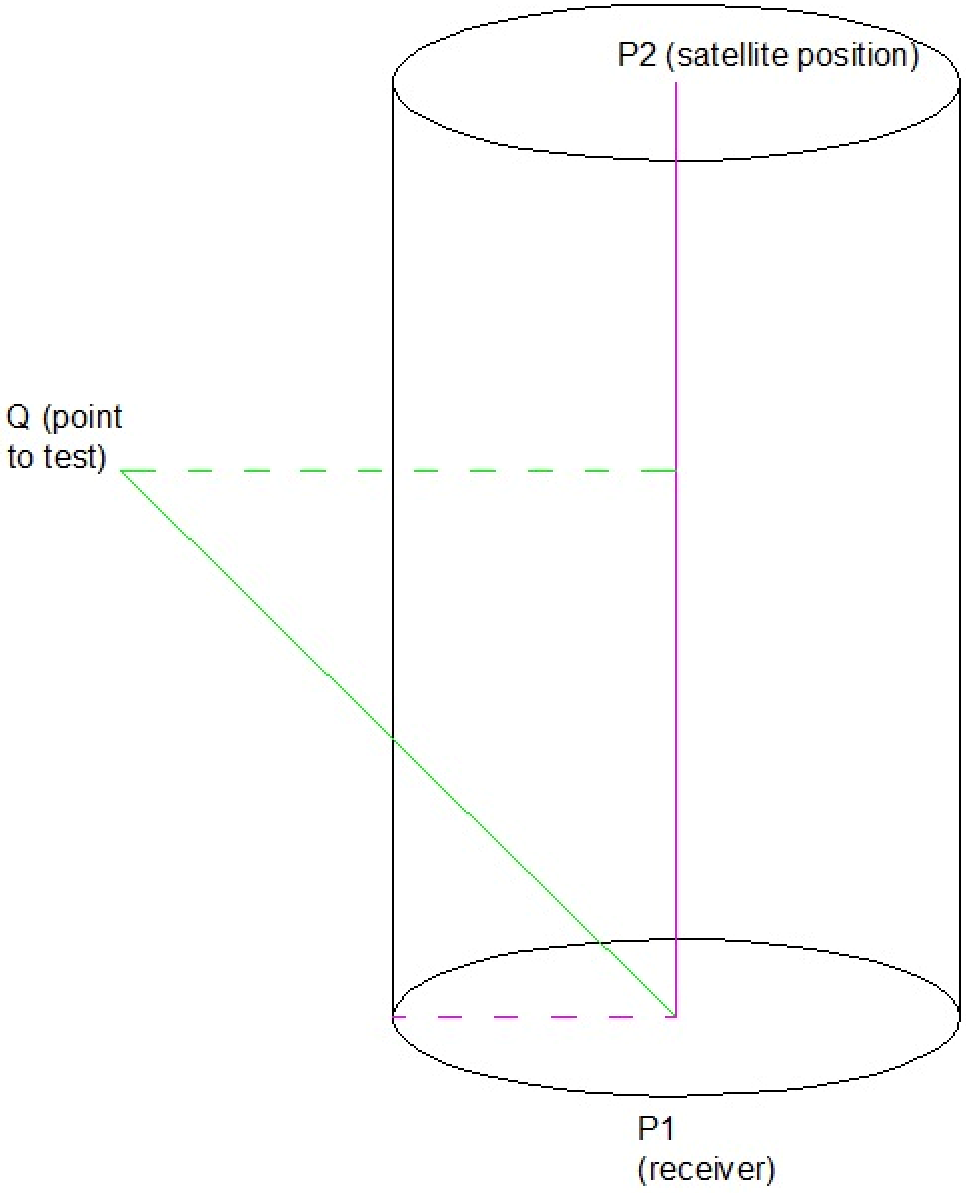
2D algorithm

- creates bounding boxes on the 2D line projection from the satellite to the receiver



3D algorithm

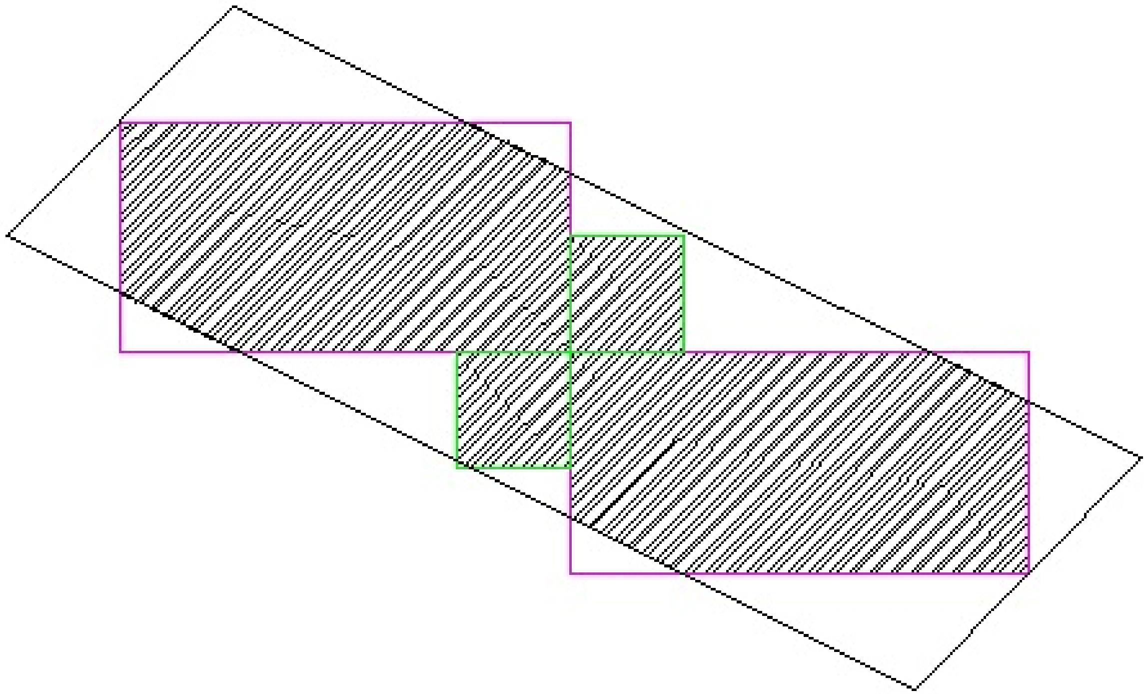
- Projects a cylinder between the satellite and receiver
- Tests if the points filtered using the 2D algorithm are inside the cylinder as well



Choosing thresholds

- A small yet dense point cloud object can contain a few thousand points – a threshold of 9000 points was chosen
- For the square boxes, the size of 5 meters was chosen
- For the diagonal of the rectangular boxes, the size of 220 meters was chosen

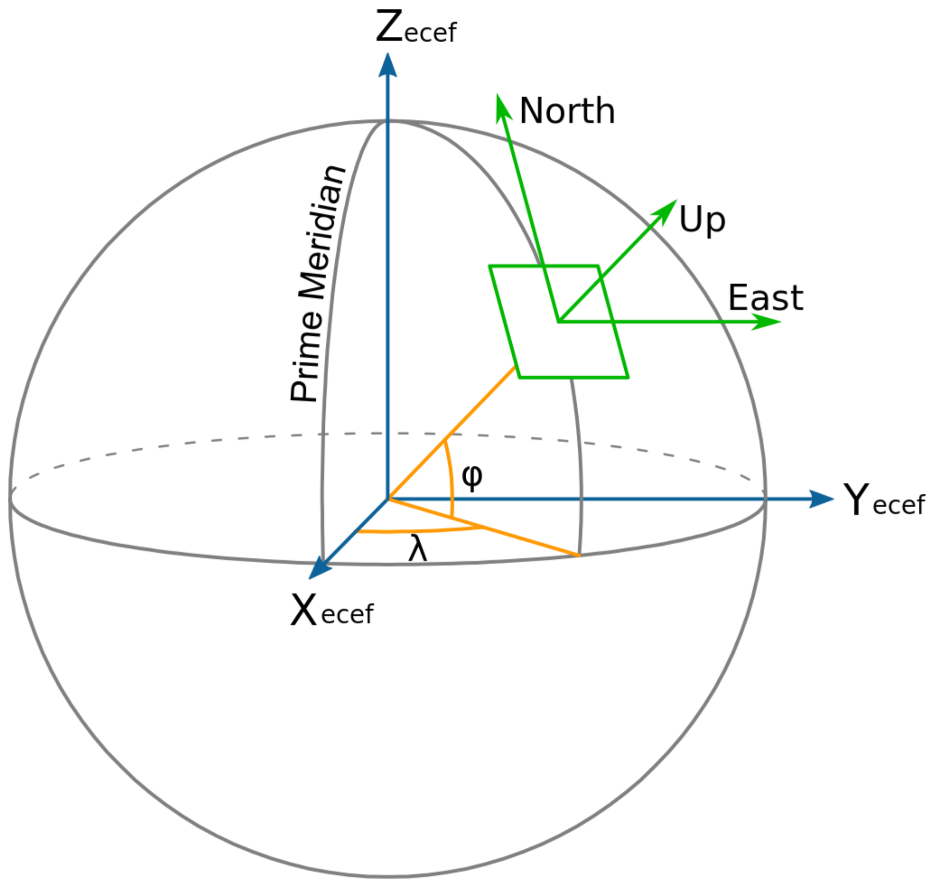
- The radius of the cylinder was linked to the size of the square boxes



$$r_{cylinder} = l * \sqrt{2}$$

DoP calculation

- To easily calculate the DoP values, the ECEF coordinates of visible satellites and of the receiver had to be transformed to ENU in order to have the HDoP related to the Earth's surface



Wikipedia

$$D = \begin{pmatrix} D_{E_1} & D_{N_1} & D_{U_1} & D_{t_1} \\ D_{E_2} & D_{N_2} & D_{U_2} & D_{t_2} \\ ... & ... & ... & ... \\ D_{E_n} & D_{N_n} & D_{U_n} & D_{t_n} \end{pmatrix}$$

$$(D^T * D^-1) = \begin{pmatrix} XDoP^2 & & & \\ & YDoP^2 & & \\ & & VDoP^2 & \\ & & & TDoP^2 \end{pmatrix}$$

- Horizontal DoP

  $$HDoP = \sqrt{XDoP^2 + YDoP^2}$$

- Position DoP

  $$PDoP = \sqrt{XDoP^2 + YDoP^2 + VDoP^2}$$

- Geometrical DoP

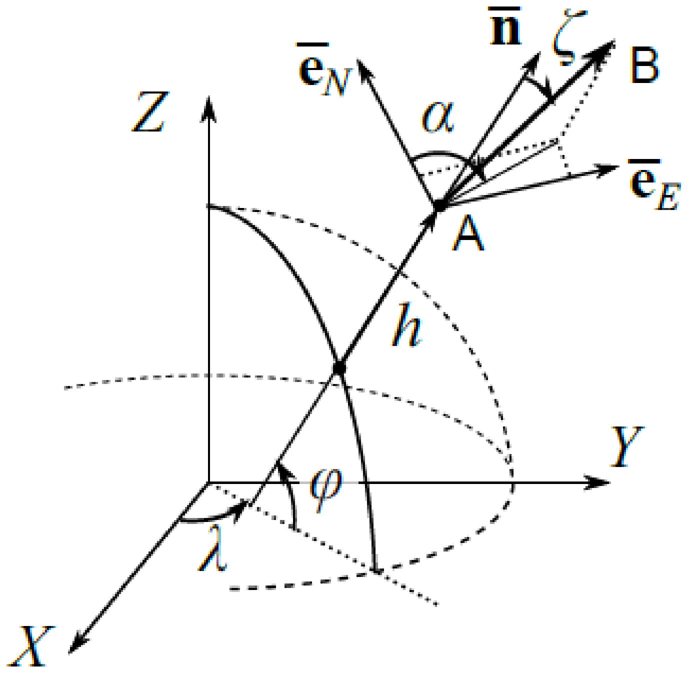
  $$GDoP = \sqrt{XDoP^2 + YDoP^2 + VDoP^2 + TDoP^2}$$

Azimuth and Elevation

- As a further validation, the azimuth and elevation angles were computed and compared to the ones given by the receiver

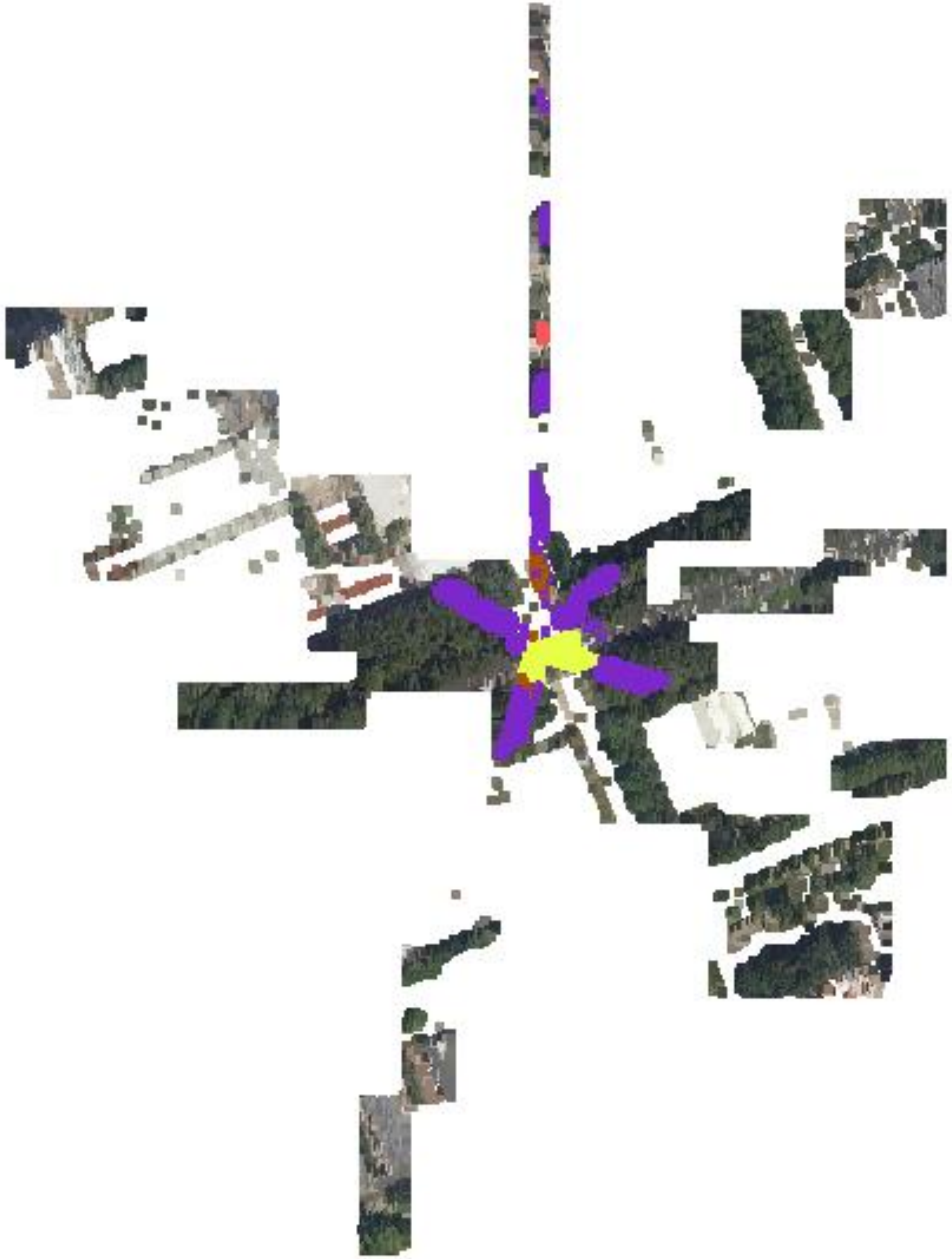
$$\alpha = arctan\frac{dE}{dN} * \frac{180}{\pi} = arctan\frac{dX}{dY} * \frac{180}{\pi}$$

$$\zeta = arctan\frac{H}{D} * \frac{180}{\pi}$$



Van der Marel (2020)

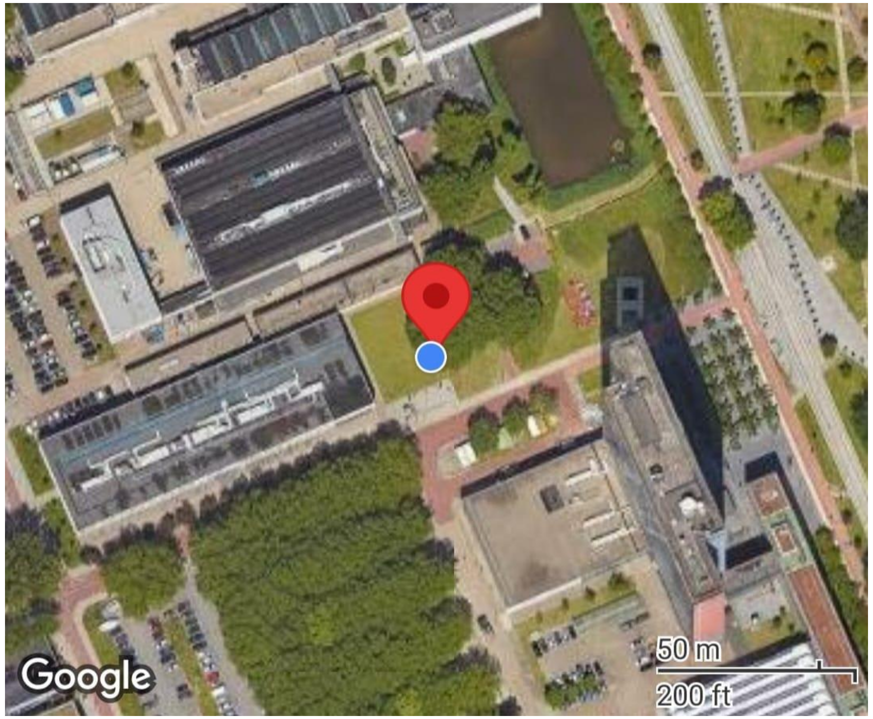
How the visibility algorithms work

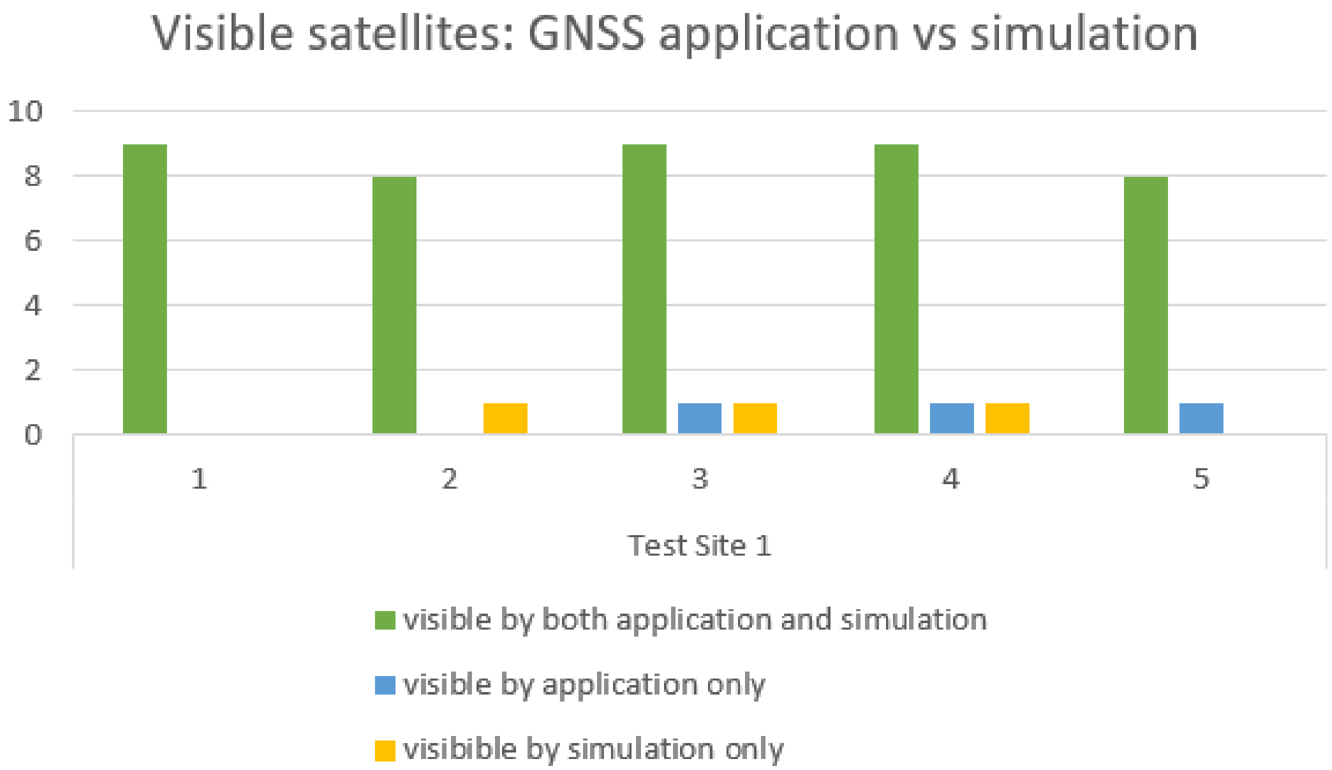


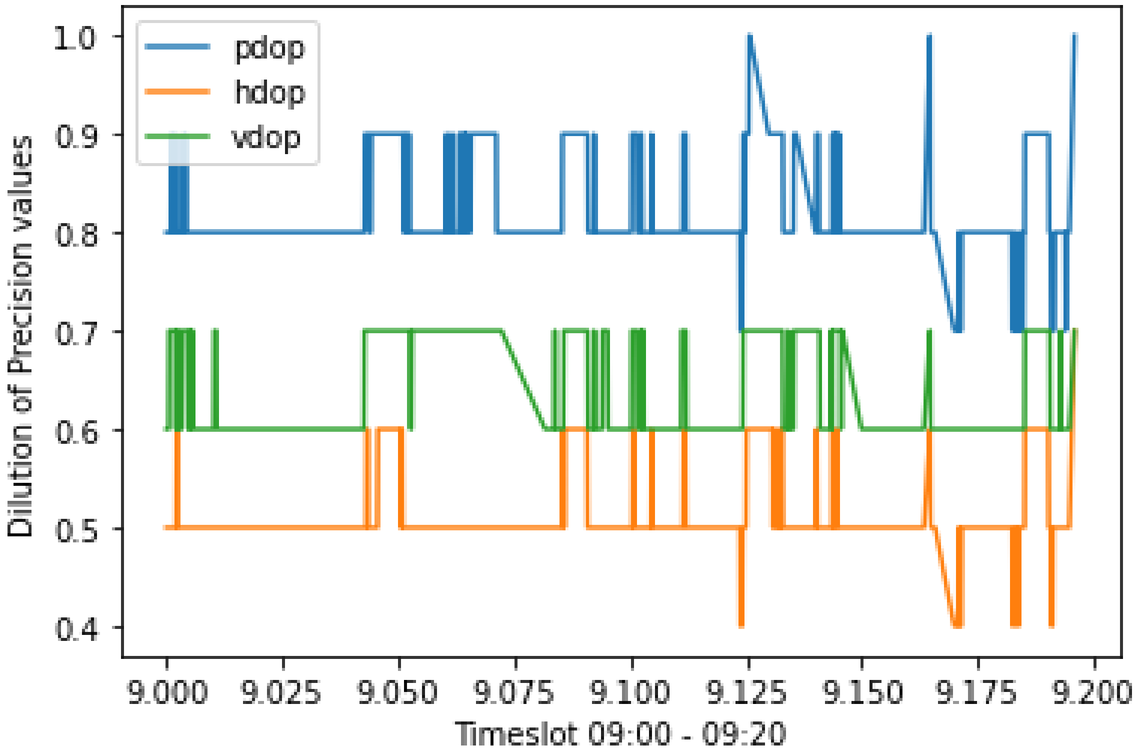
Results

- Simulation tested on 4 sites on the TU Delft Campus (open sky vs obstructed)
- The GNSS data was gathered in the period of late November - December

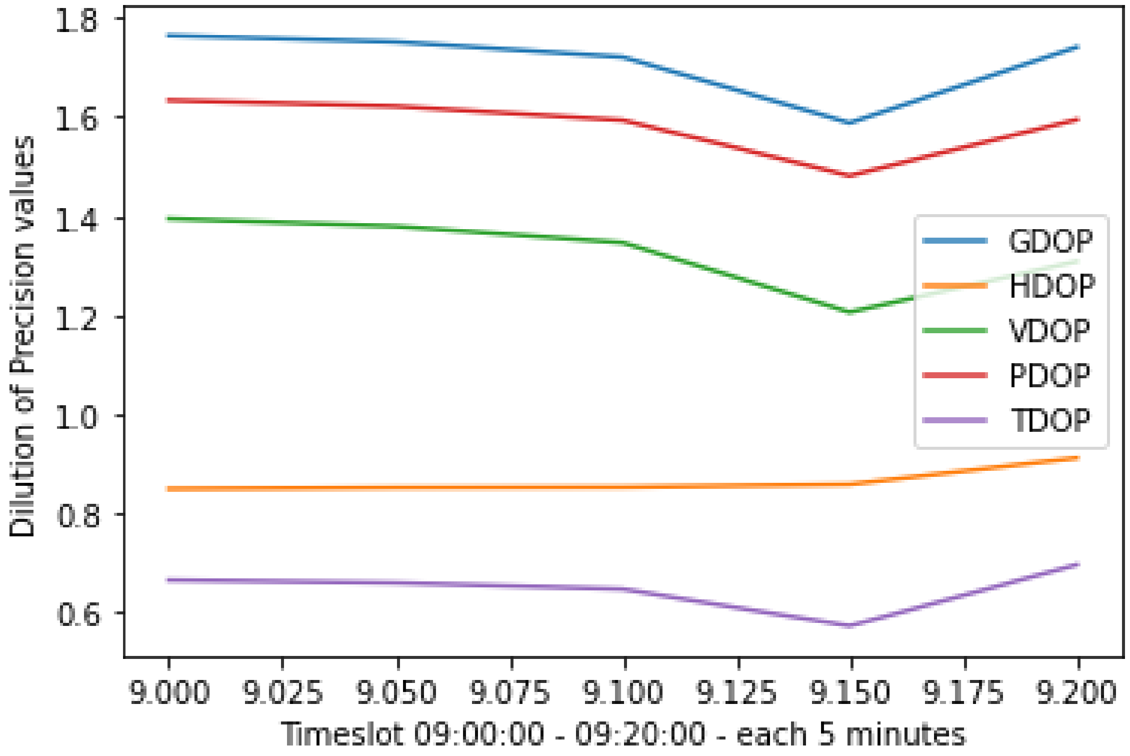
Test Site 1


Google
50 m
200 ft


Visible satellites: GNSS application vs simulation
10
8
6
4
2
0
1
2
3
4
5
Test Site 1
visible by both application and simulation
visible by application only
visibible by simulation only

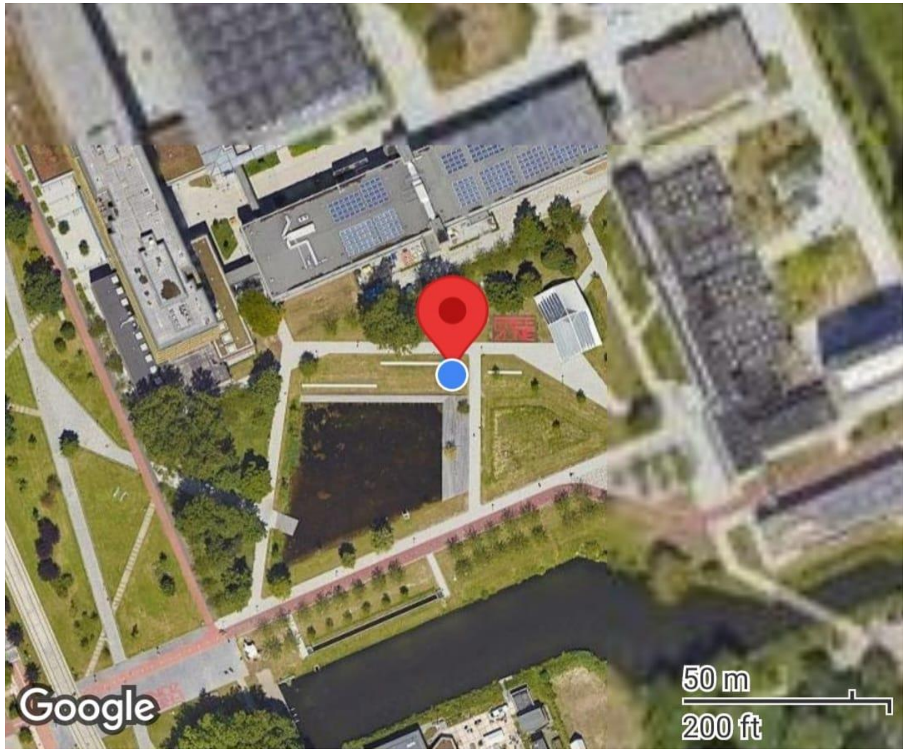


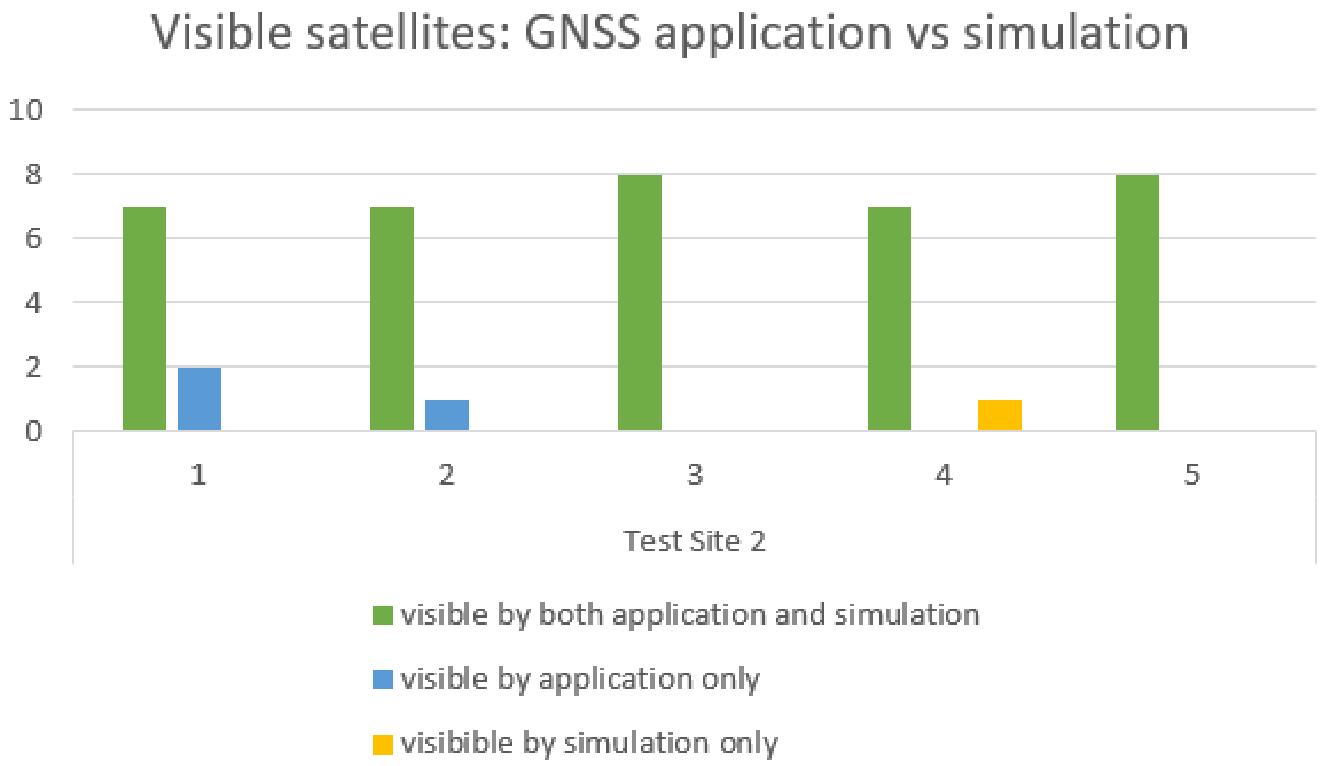
DoP plot – smartphone application



DoP plot – simulation

Test Site 2


50 m
200 ft
Google


Visible satellites: GNSS application vs simulation
10
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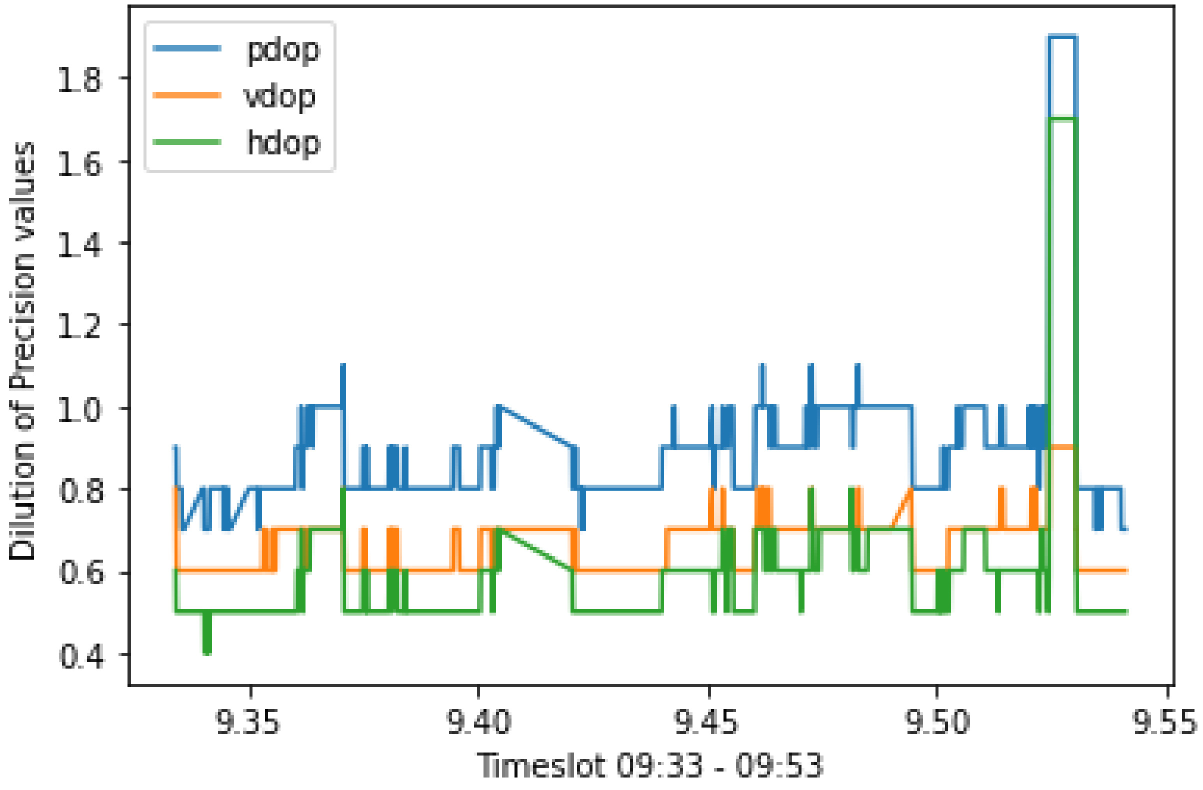
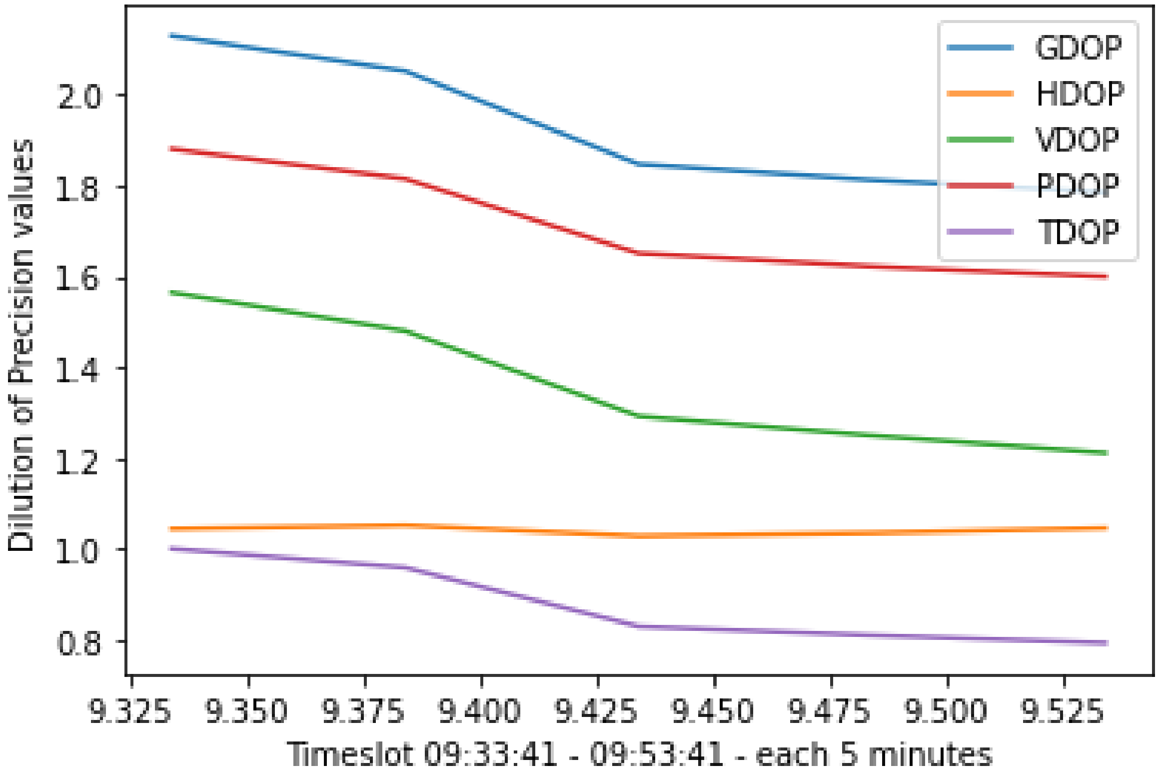
Test Site 2
visible by both application and simulation
visible by application only
visibible by simulation only

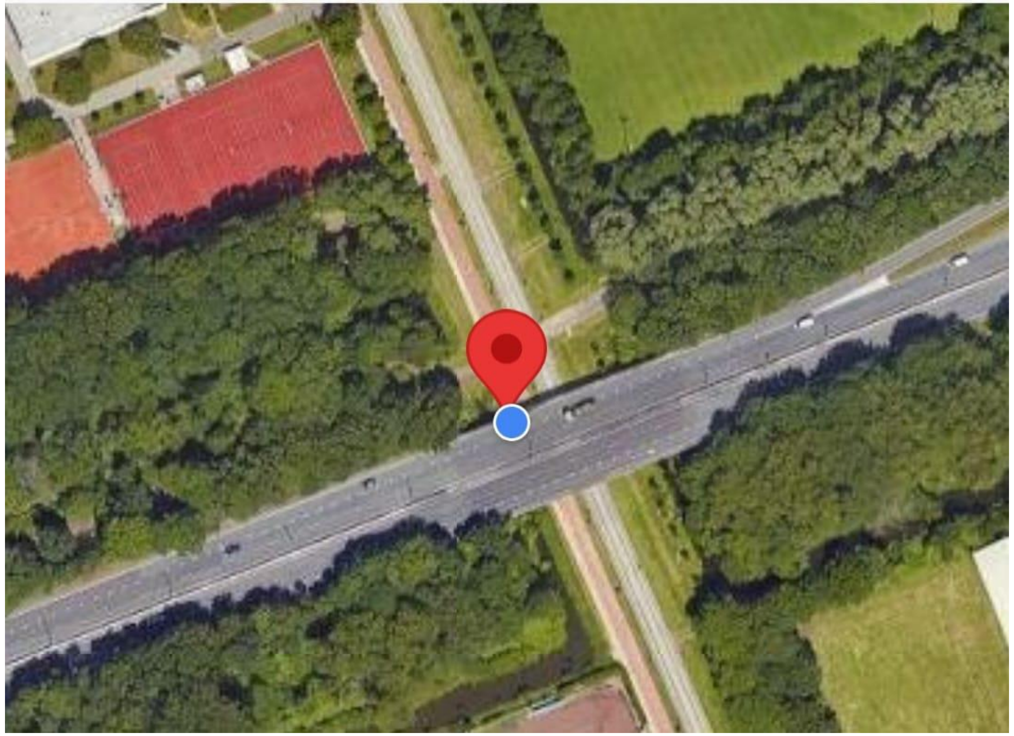


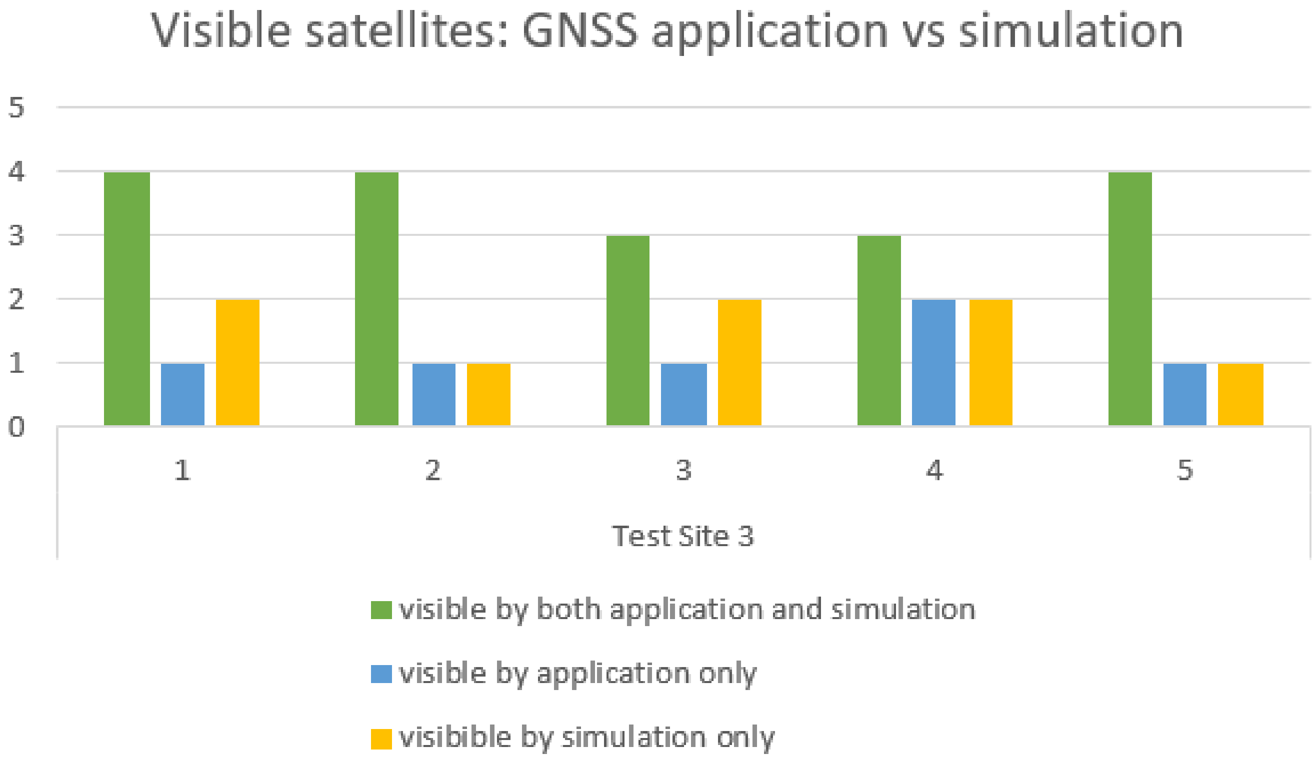
DoP plot – smartphone application



DoP plot – simulation

Test Site 3




Visible satellites: GNSS application vs simulation
5
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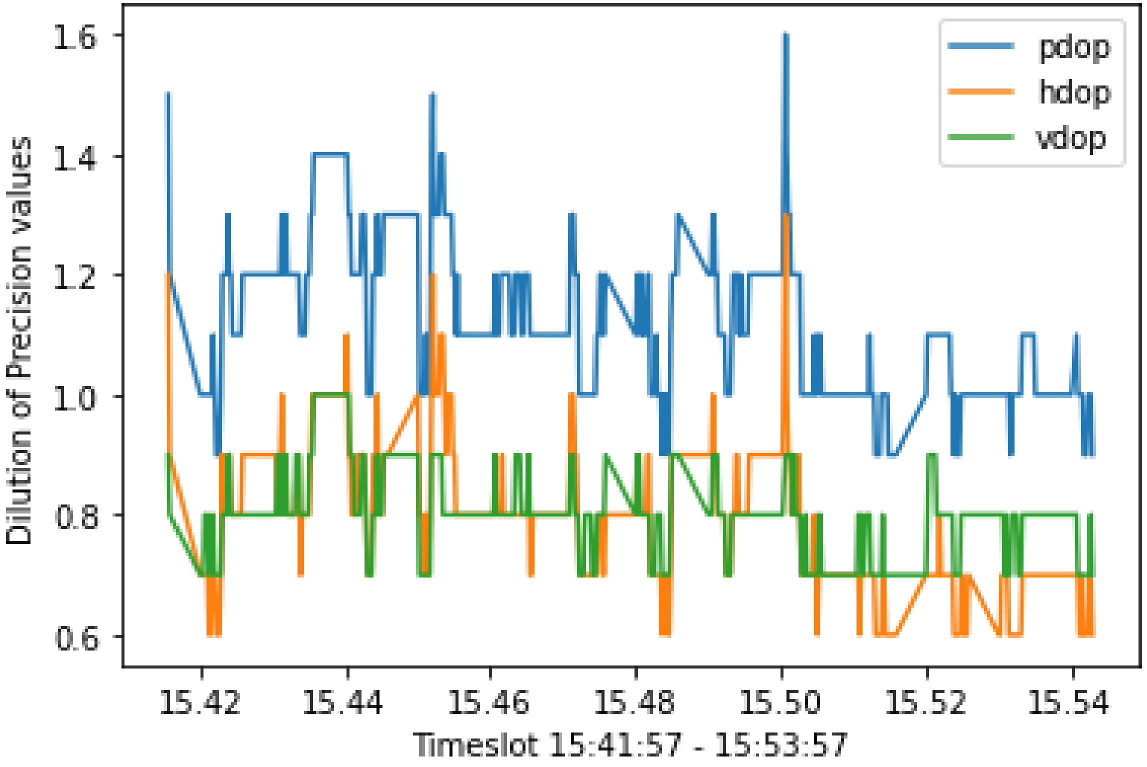
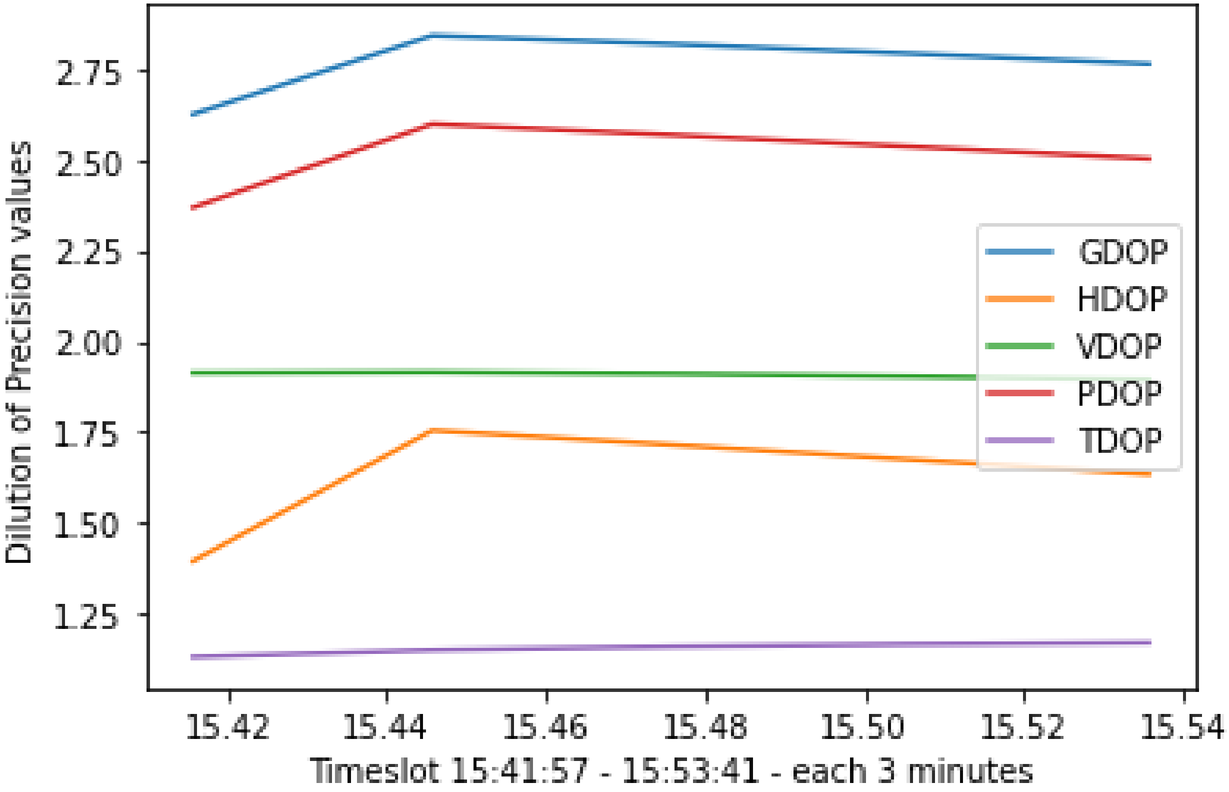
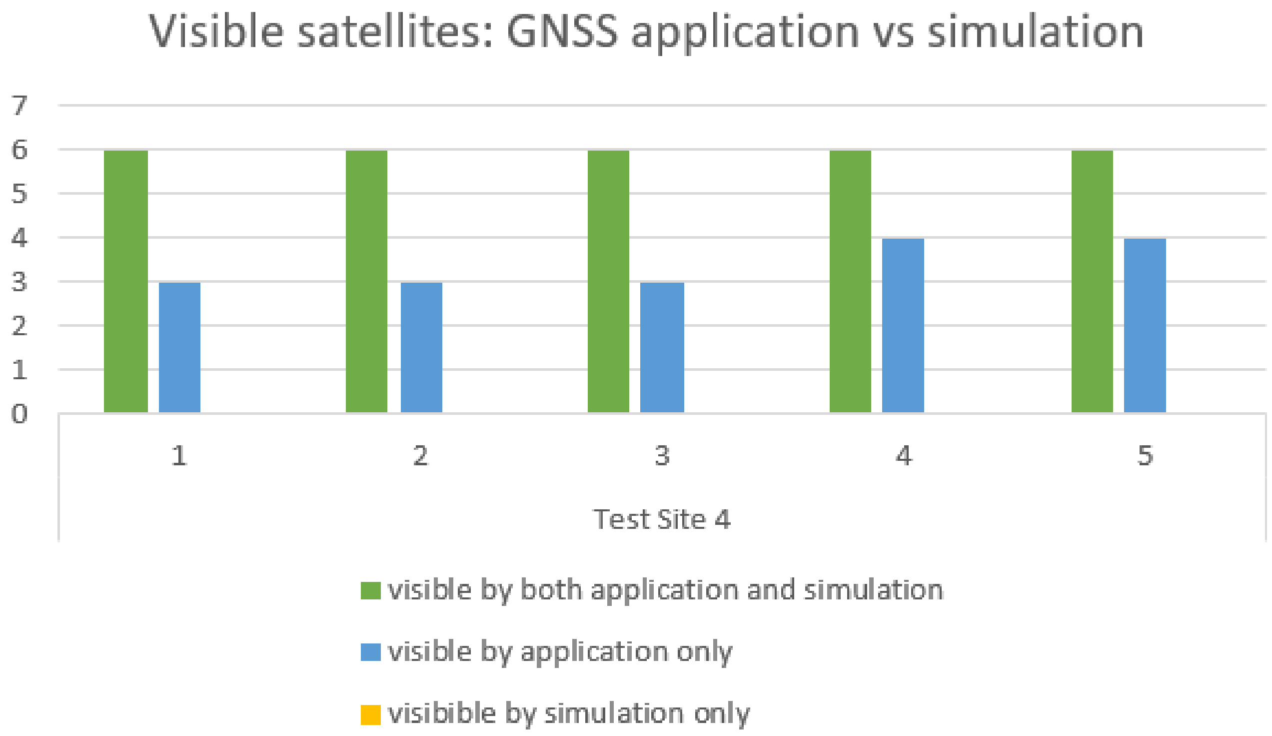
Test Site 3
visible by both application and simulation
visible by application only
visibible by simulation only


pdop
hdop
vdop
Dilution of Precision values
1.6
1.4
1.2
1.0
0.8
0.6
15.42
15.44
15.46
15.48
15.50
15.52
15.54
Timeslot 15:41:57 - 15:53:57


GDOP
HDOP
VDOP
PDOP
TDOP
Dilution of Precision values
2.75
2.50
2.25
2.00
1.75
1.50
1.25
15.42
15.44
15.46
15.48
15.50
15.52
15.54
Timeslot 15:41:57 - 15:53:41 - each 3 minutes

Test Site 4


Schoemakerstraat
TU Delft Faculteit Bouwkunde
Bewegen met Kelly


Visible satellites: GNSS application vs simulation
7
6
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2
3
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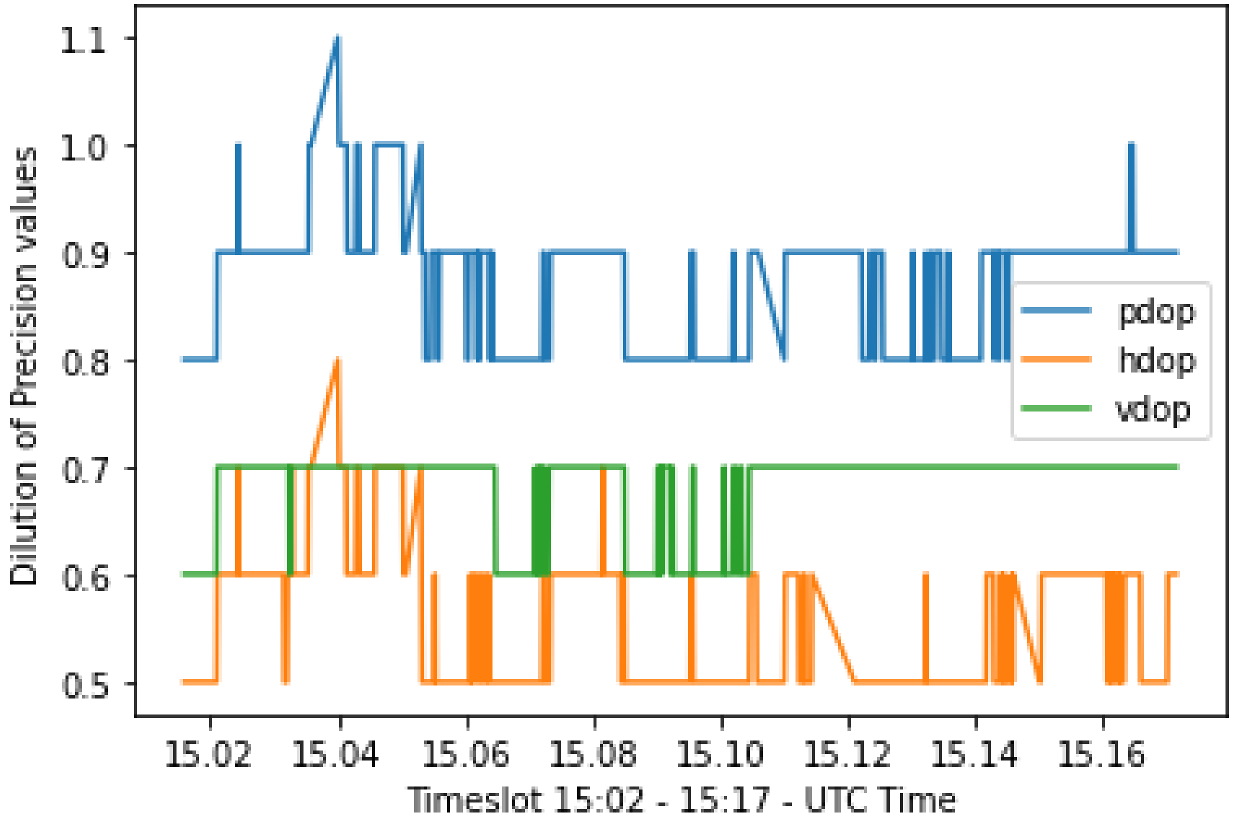
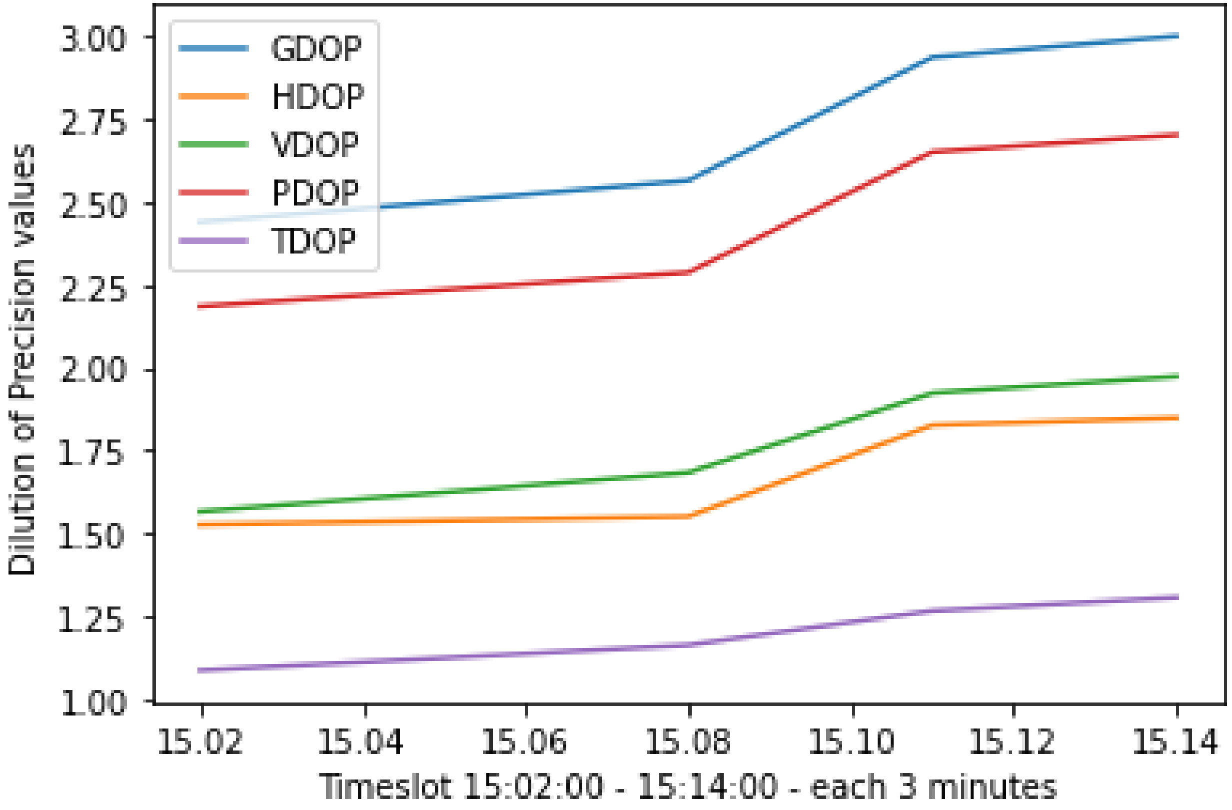
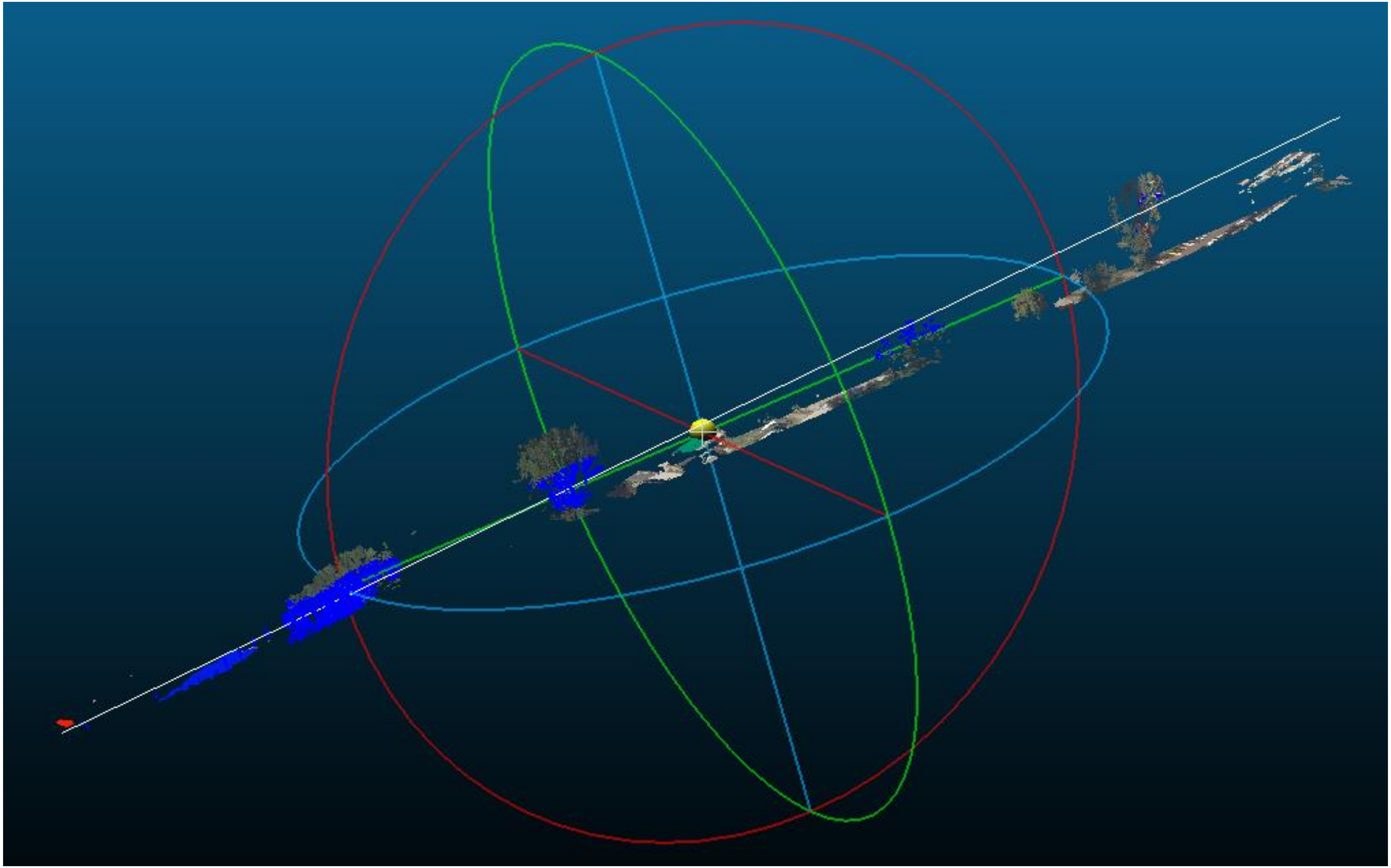
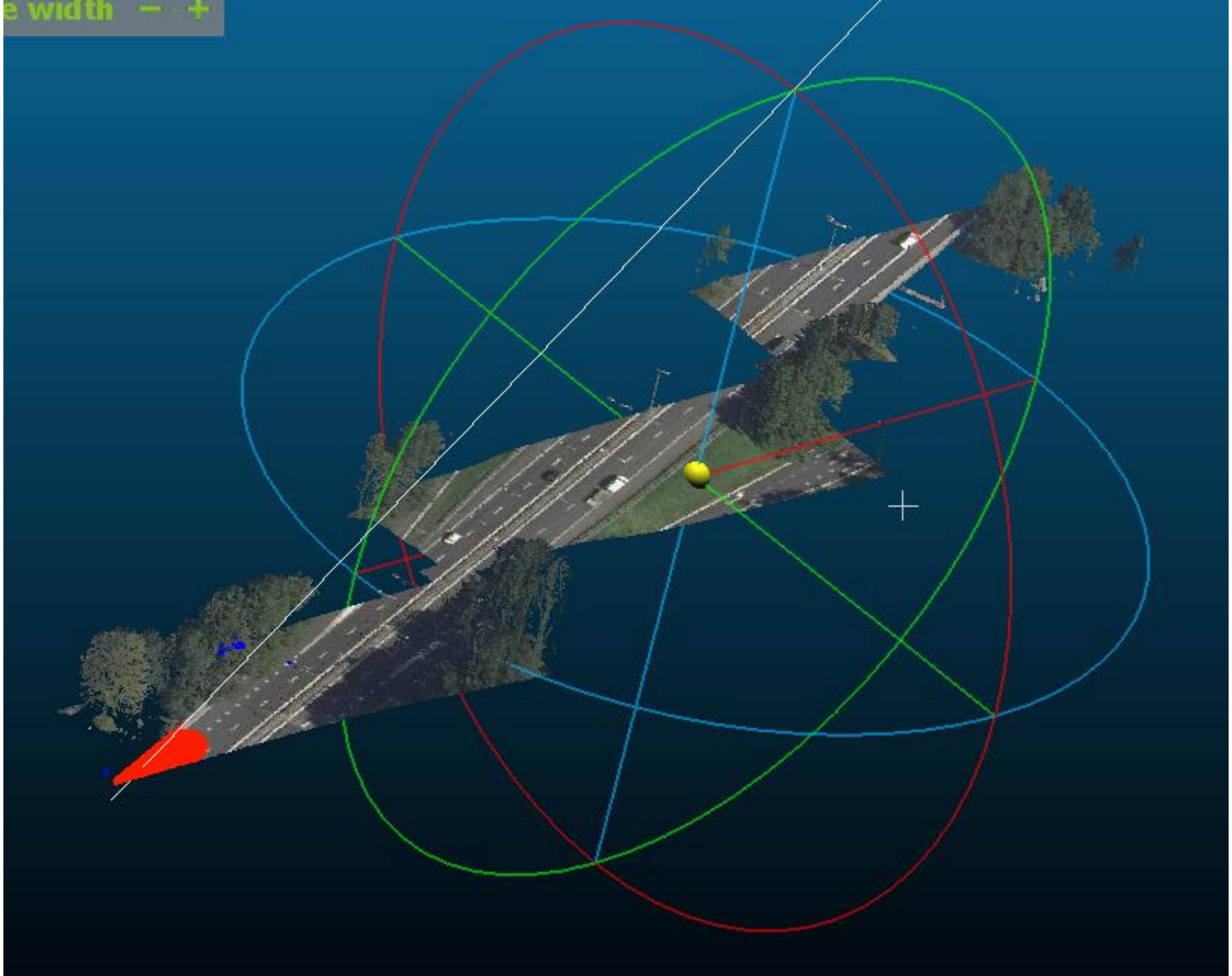
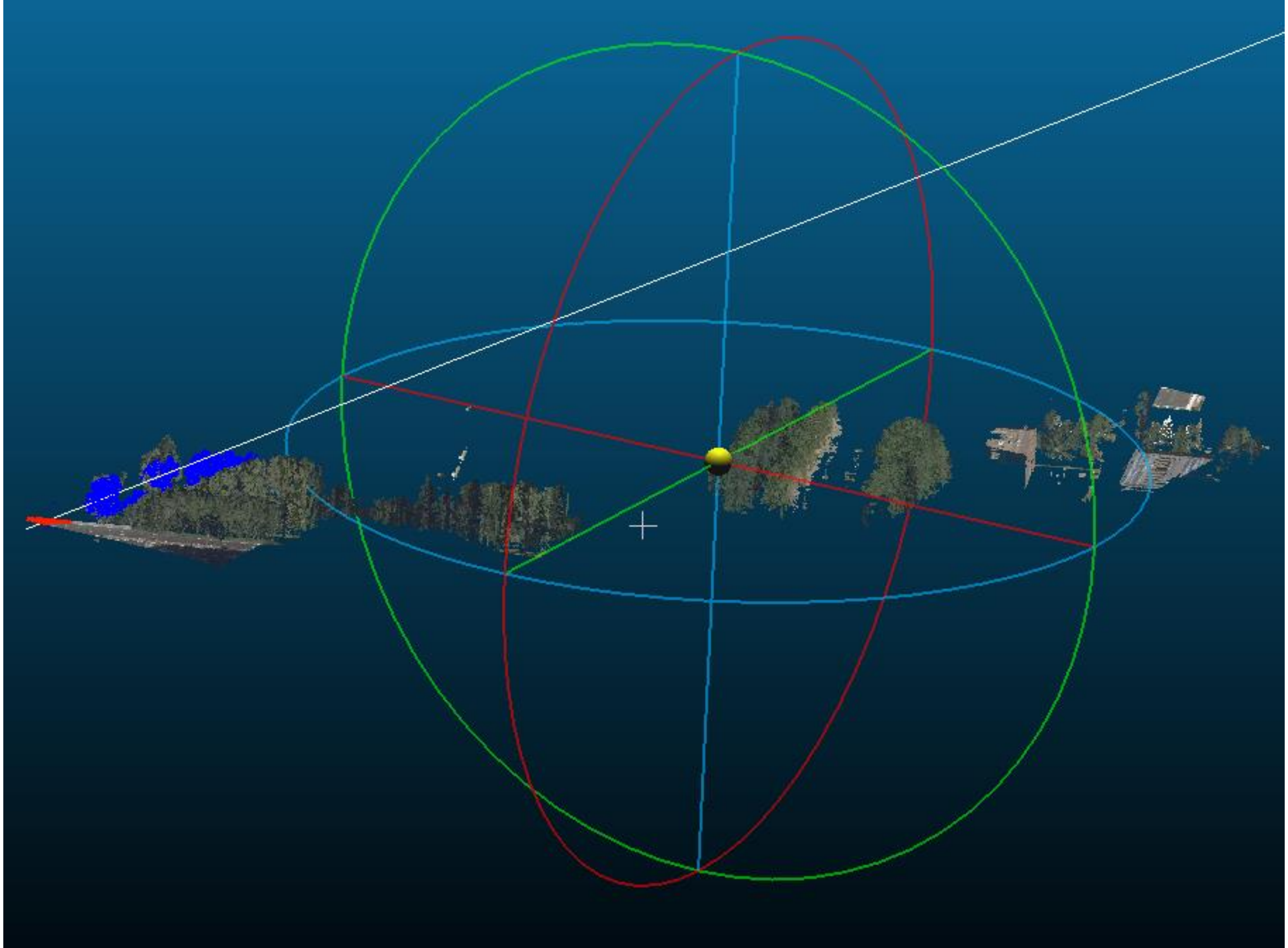
5
Test Site 4
visible by both application and simulation
visible by application only
visibible by simulation only


pdop
hdop
vdop
Dilution of Precision values
Timeslot 15:02 - 15:17 - UTC Time


GDOP
HDOP
VDOP
PDOP
TDOP
Dilution of Precision values
Timeslot 15:02:00 - 15:14:00 - each 3 minutes




e width − +



Answers to the research questions

- How are obstructions represented in calculation of DoP?

- A: An obstruction blocks the access of the receiver to satellites from a certain part of the sky and it results in the calculated DoP values to be larger

- How good is the carried analysis compared with the given result by simulation tools/ GNSS equipment?

- A: The simulation is either optimistic or pessimistic.

- How can such a simulation of a GNSS mission be helpful?

- A: Point Cloud data is a good 3D representation of the environment. Integrating it into GNSS survey planning tools is useful to determine which satellites are visible and therefore the precision quality

- What determines the threshold that decides if a line of sight is visible or not?

- A: It depends on the location of the receiver and on the class the point belong to

Answer to the main research question

- The used point cloud data is 500 MB initially. The data after the filtering operations is diminished by usually a tenth

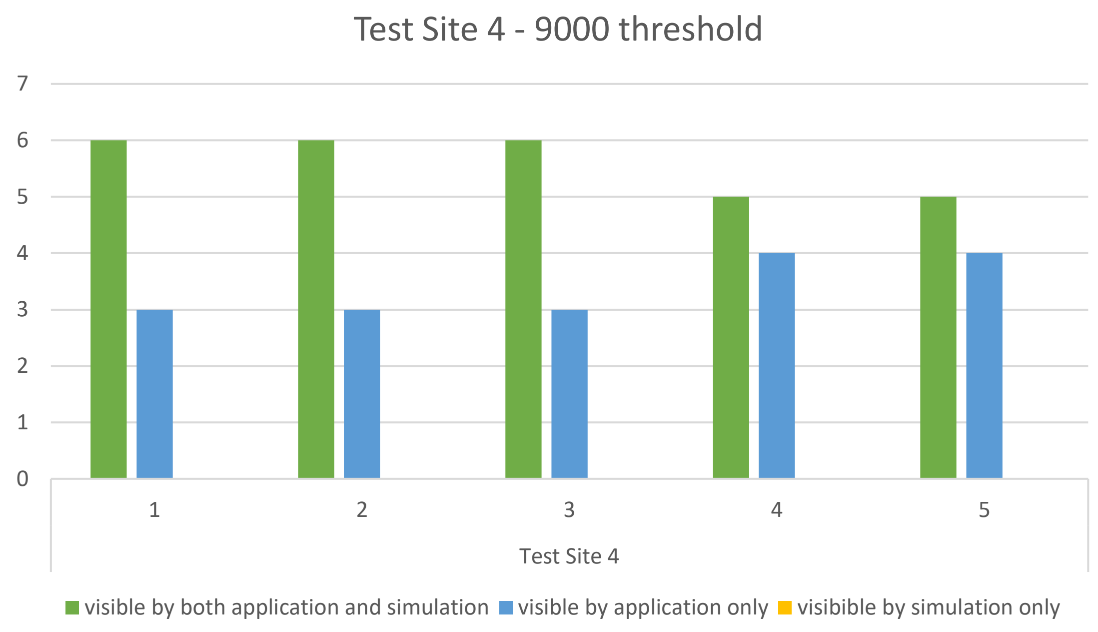
Point Cloud	Size
Initial	500 MB
LAStool height filter	250 - 300 MB
2D algorithm boxes	40 – 55 MB
3D algorithm cylinder	1 - 2 MB

Recommendations

- Finding a link between the volume of the cylinder ray and the number of points threshold
- Analysing the content inside the cylinder based on classes
- Integrating this simulation into an online tool

Thank you for your attention!

Questions


Test Site 4 - 9000 threshold
7
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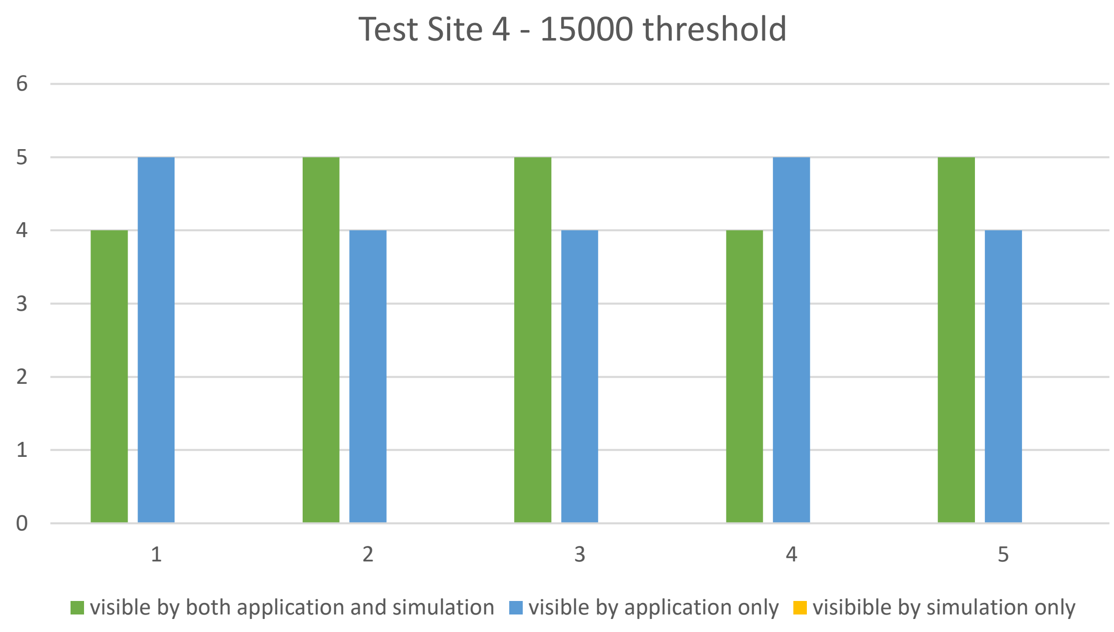
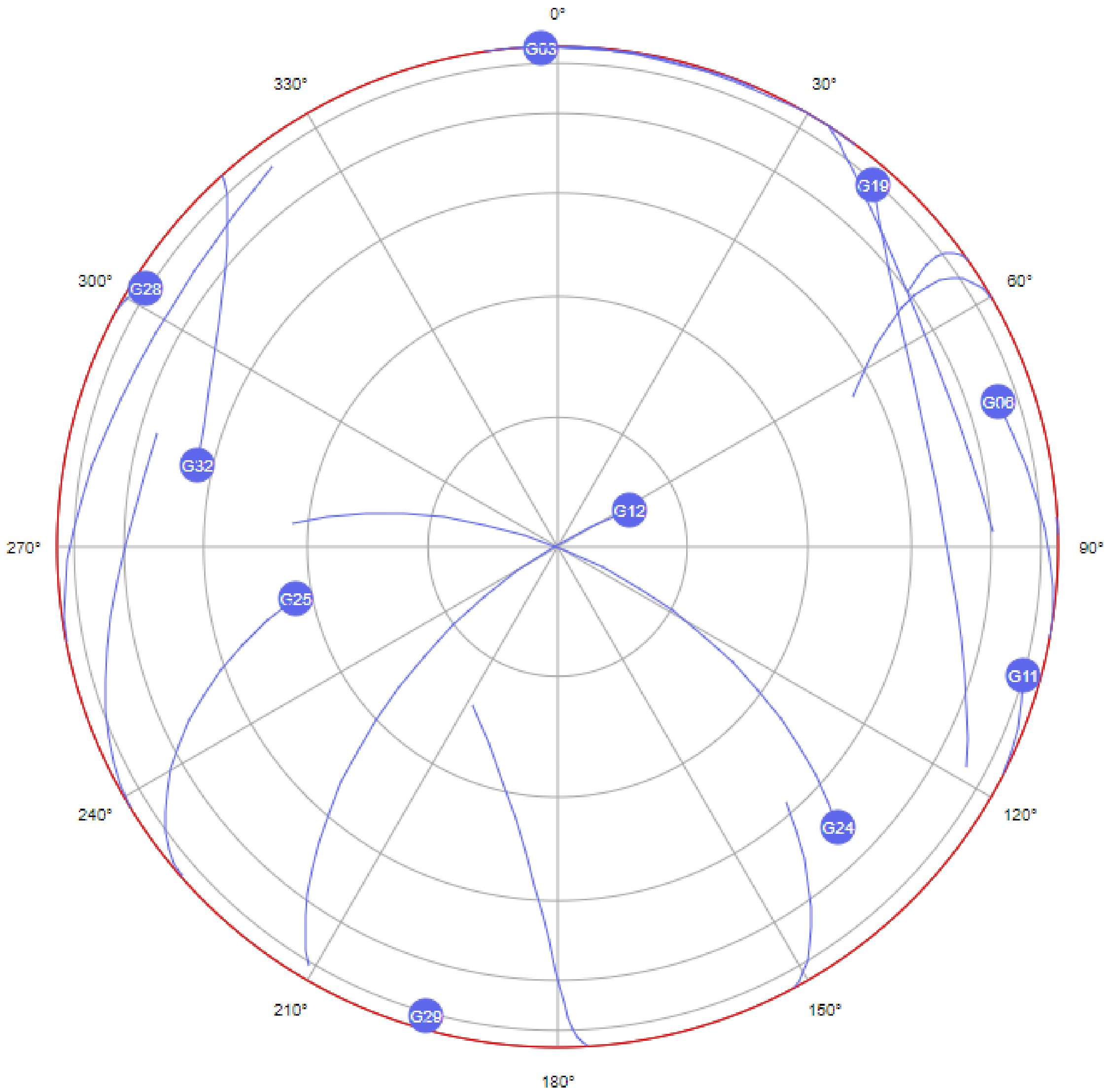
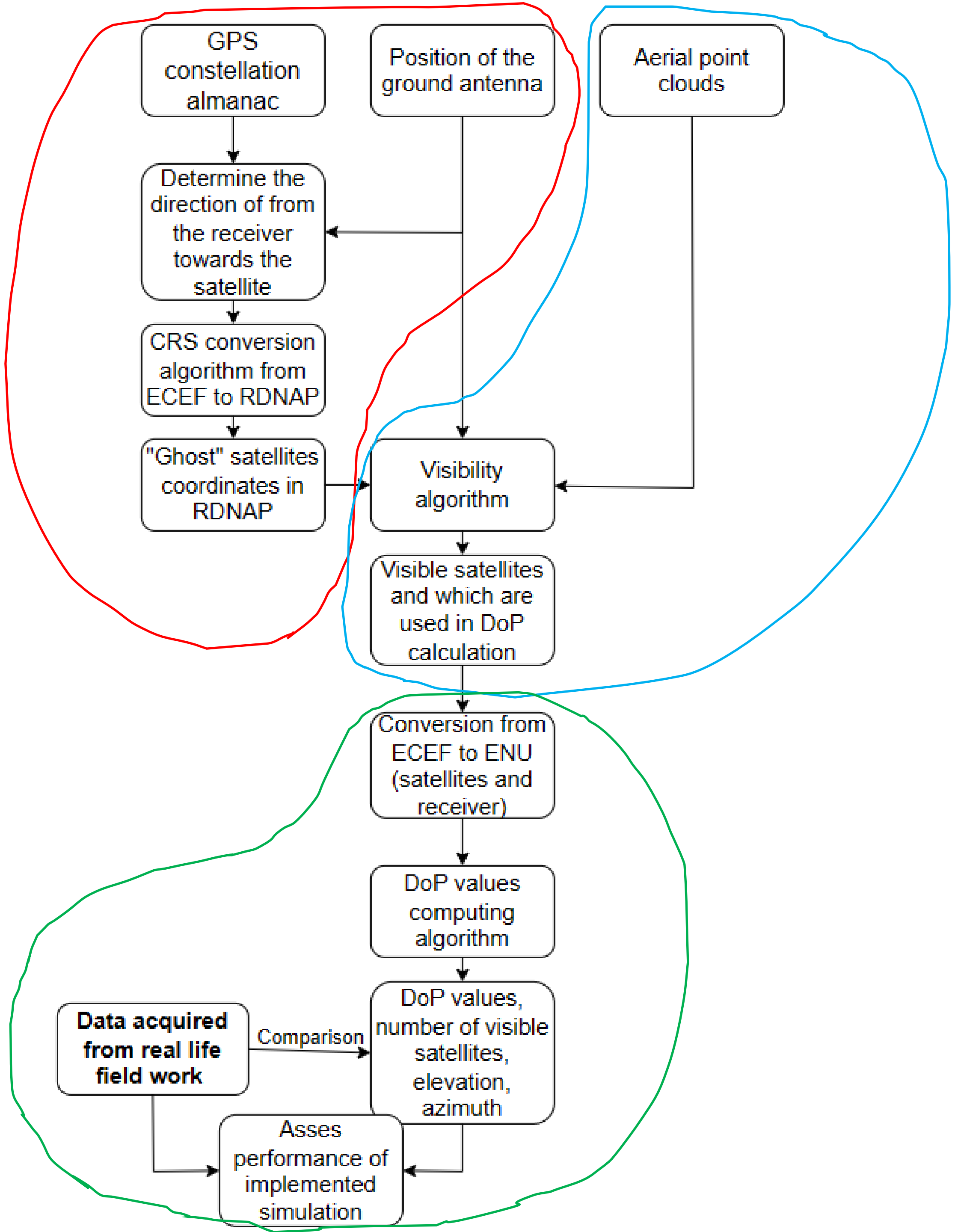
5
Test Site 4
visible by both application and simulation
visible by application only
visibible by simulation only


Test Site 4 - 15000 threshold
6
5
4
3
2
1
0
1
2
3
4
5
visible by both application and simulation
visible by application only
visibible by simulation only



	Visible - smartphone tool	Blocked - smartphone tool
Visible - simulation	06, 12, 25, 32	24
Blocked - simulation	19	


GPS constellation almanac
Position of the ground antenna
Aerial point clouds
Determine the direction of from the receiver towards the satellite
CRS conversion algorithm from ECEF to RDNAP
"Ghost" satellites coordinates in RDNAP
Visibility algorithm
Visible satellites and which are used in DoP calculation
Conversion from ECEF to ENU (satellites and receiver)
DoP values computing algorithm
DoP values, number of visible satellites, elevation, azimuth
Data acquired from real life field work
Comparison
Asses performance of implemented simulation