GNSS Performance

Group 8: Ming-Chieh Hu, Ákos Sárkány, Daan Schlosser, Neelabh Singh

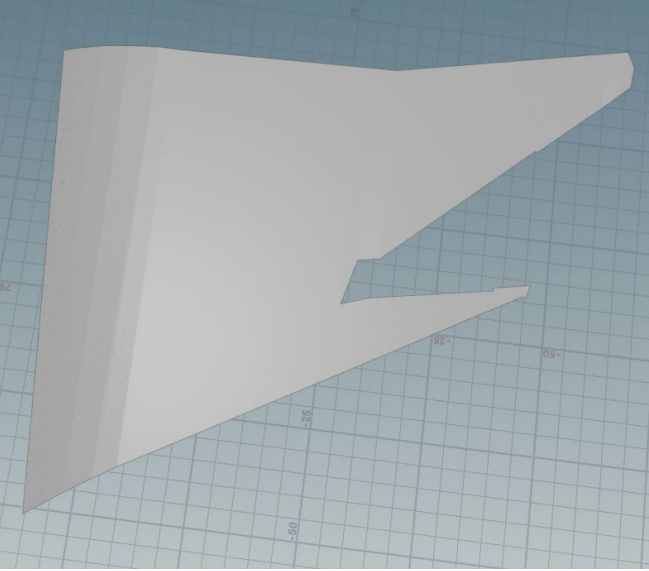
Part 1

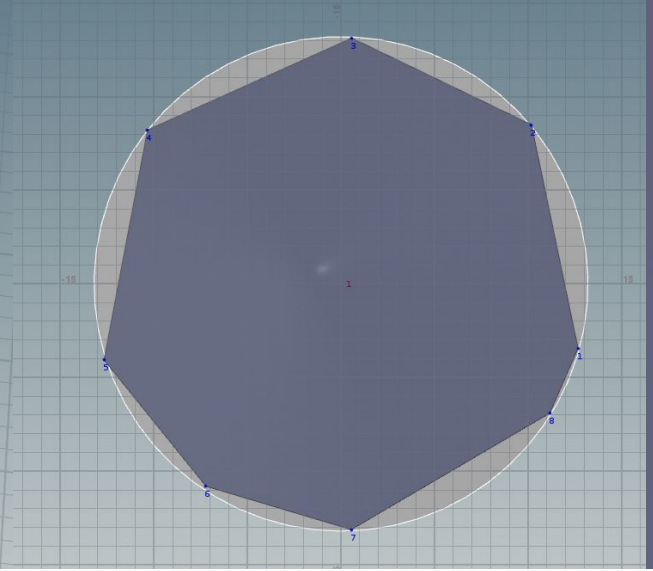
Simple GNSS receiver: R10
- No IMU
- Accuracy: ± 1cm
- ETRS89

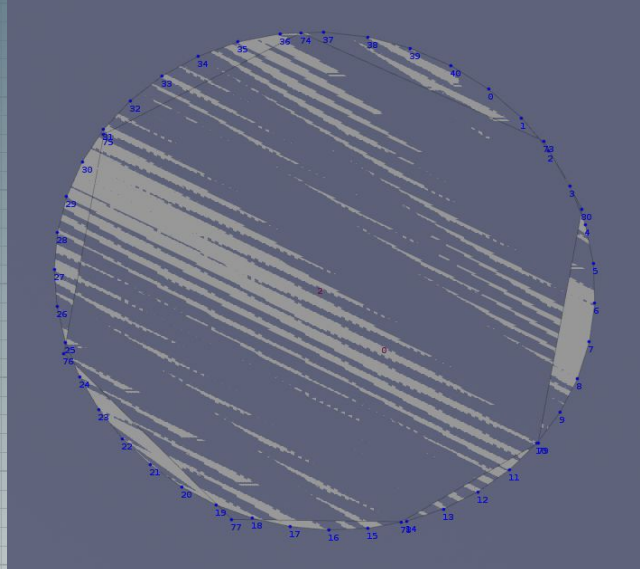
Perimeter corners + Cone outline

Few points on curve for better approximation

Measure points counter-clockwise for easier polygon reconstruction

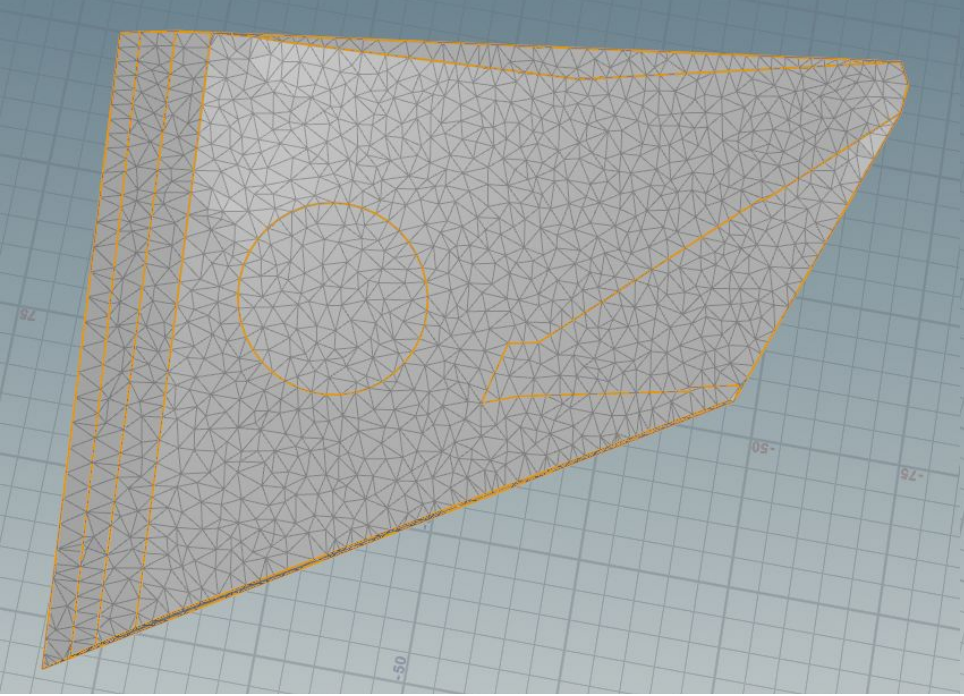


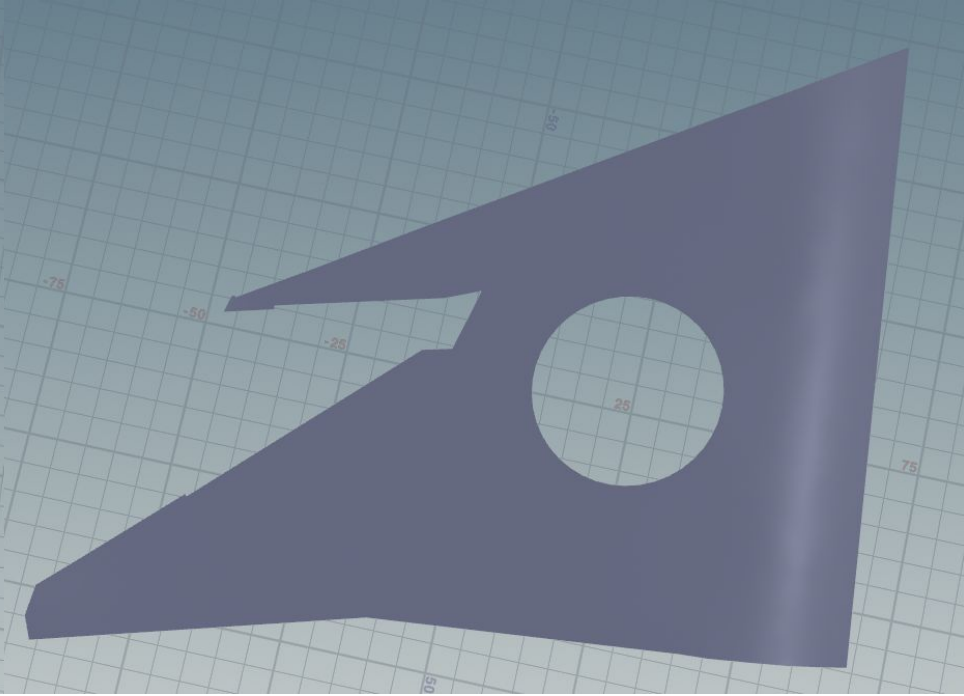




Base polygon & Circle Fitting

1. Project points to EPSG:28992 (in QGIS). This way point coordinates are in meters.
2. Connect the points on the perimeter to construct a polygon of the surface.
3. Then, fit a geometric circle through the points in 2D.
4. Then fit circle to the geometry from step 2.





Triangulation & Result

Compute a constrained triangulation using:

- the two overlapping surfaces
- some extra support points

Project surface to 2D to highlight difference in area.

	3D	2D
Surface Area	5277.56 m²	5192.45 m²
Perimeter length	515.89 m	512.04 m

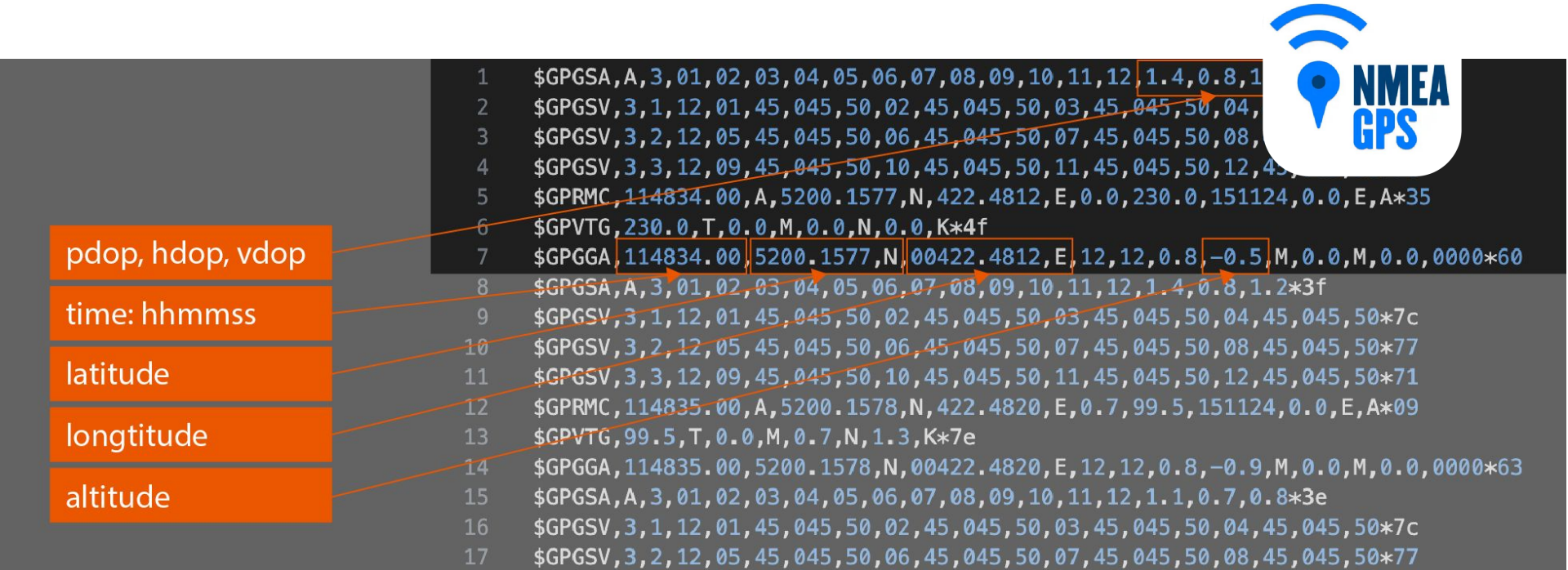
Part 2

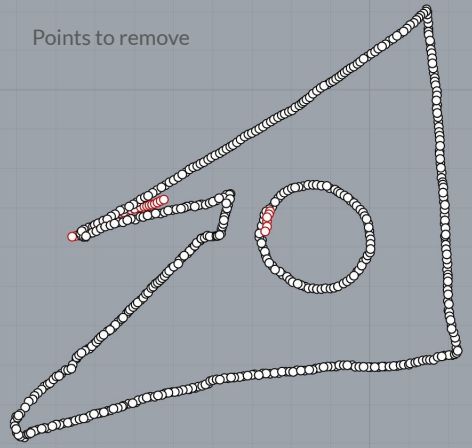
iPhone 13 with
- app: NMEA GPS
- EPSG:4979

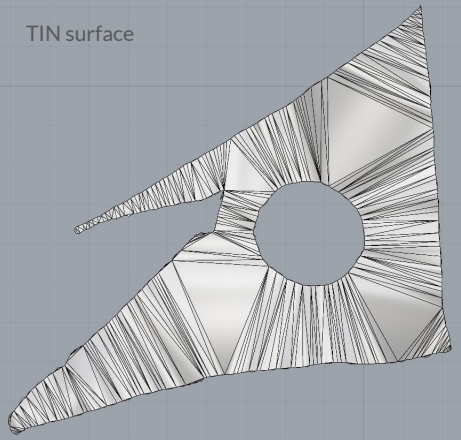
Perimeter corners + Cone outline

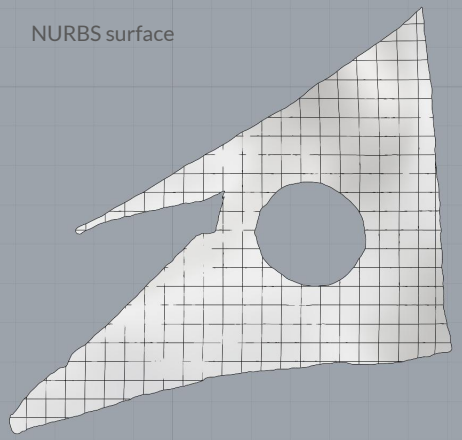
Data Extraction & Cleansing

1. Extract data from NMEA sentences.
2. Project points to EPSG:28992 (in Python). This way point coordinates are in meters.
3. To prune and trim some data points that might cause misunderstanding of shape.
4. Approximate surfaces using inner (79 points) and outer (446 points) boundaries.



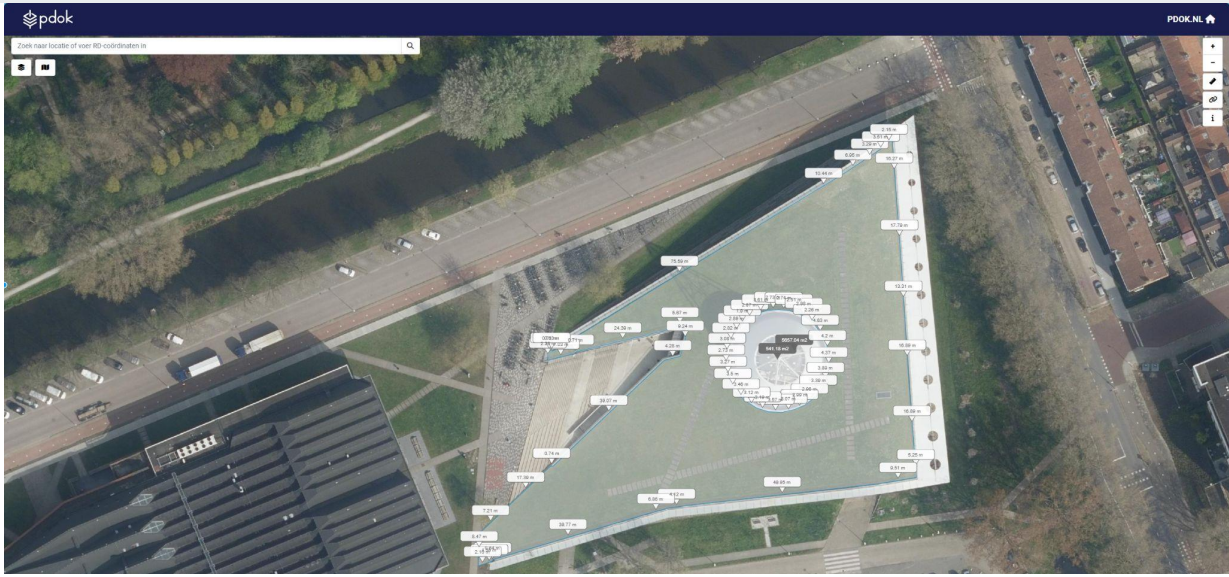






	Approximated TIN Surface	Approximated NURBS Surface
Area (m^2)	5137.54	5045.20
Perimeter (m)	549.24	535.30
Area projected on xy plane (m^2)	4920.04	4925.66
Perimeter projected on xy plane (m)	529.56	522.64

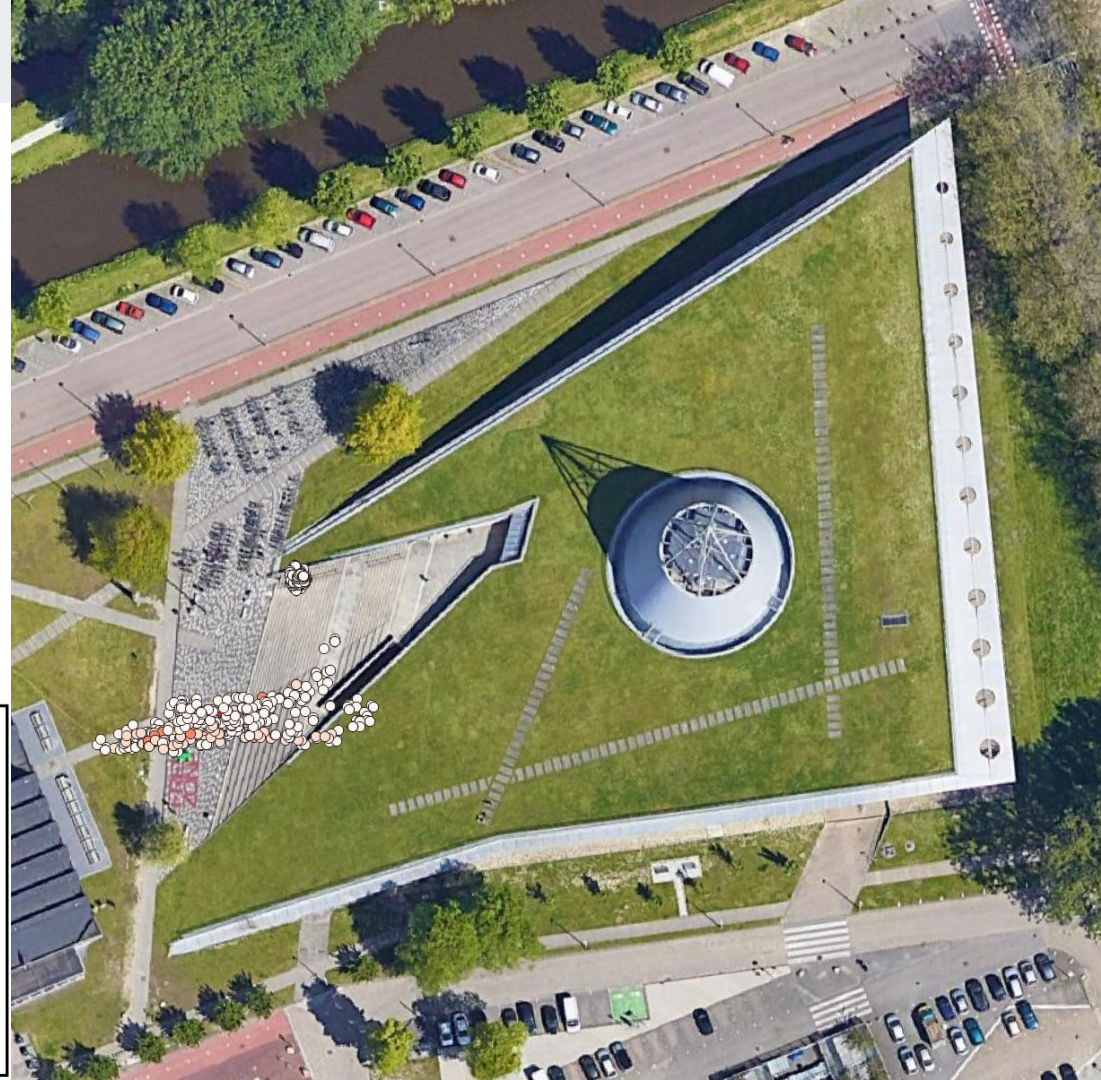
Part 3



Results Comparison	Data from GNSS receiver	Data from iPhone	Data from pdok
Area (m^2)	5277.56	5137.54	
Perimeter (m)	515.89	549.24	
Area projected on xy plane (m^2)	5192.45	4920.04	5115.86
Perimeter projected on xy plane (m)	512.04	529.56	508.17

Part 4

iPhone 13 with
- app: NMEA GPS
- EPSG:4979
- PDOP, HDOP, VDOP, time



Part 4a

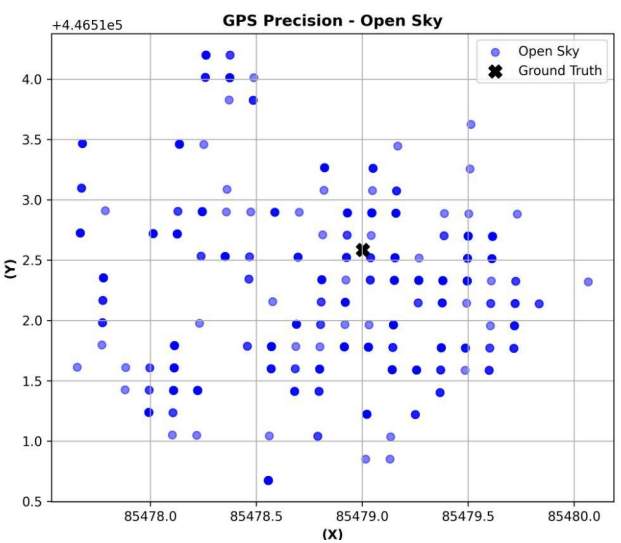
Scatter Plot for Open Sky and Blocked Line of Sight, in X-,Y- and Z-coordinates.

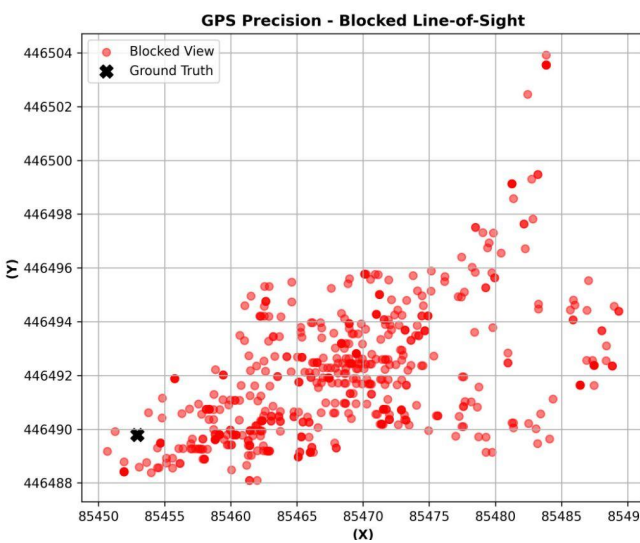
Open Sky:
Data closely aligned around Ground Truth Values, less error.

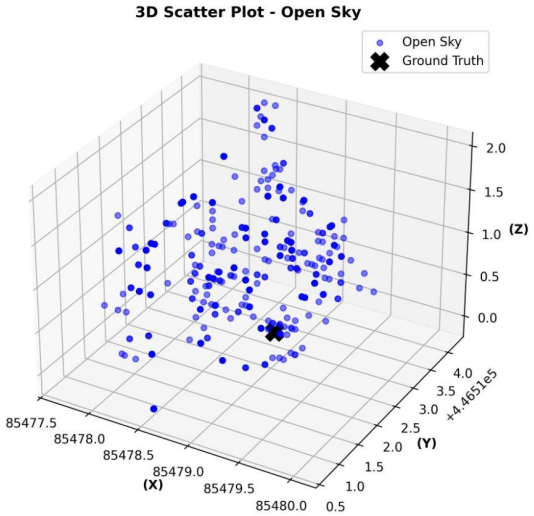
Blocked Line of Sight:
Data loosely aligned and skewed around Ground Truth Values, high error.

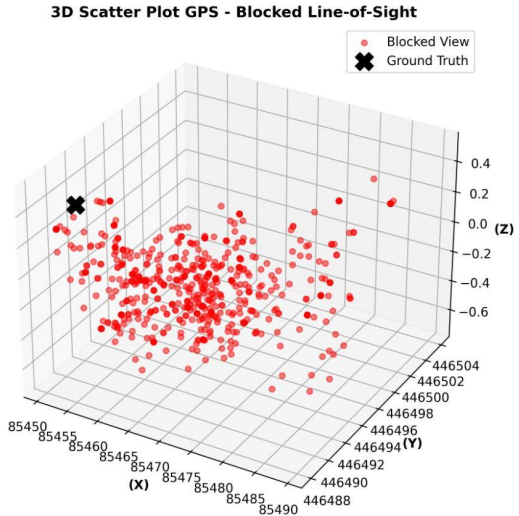
Open Sky:
Min-Max X: (85477.653 , 85480.067) = 3.4
Min-Max Y: (446510.672 , 446514.200) = 3.8
Min-Max Z : (-0.2 , 0.5) = 0.7

Obstructed Sky:
Min-Max X: (85450.671 , 85489.317) = 38.7
Min-Max Y: (446488.092 , 446503.922) = 15.8
Min-Max Z : (-0.1 , 2.0) = 2.1









Part 4b Obstructed vs. Open Sky GNSS Measurements

	Open Sky	Obstructed Sky
Horizontal Precision	**Mean X: 85478.752 Std, Deviation X: 0.557** **Mean Y: 446512.277 Std. Deviation Y: 0.764**	**Mean X: 85468.695 Std. Deviation X: 9.112** **Mean Y: 446492.090 Std. Deviation Y: 2.838**
Less std. Deviation better accuracy.	Min Max values ranges around 3.5, And standard deviation is around 0.6. Closely aligned around ground truth.	Min Max value ranges around 39 to 15. Standard deviation for x 18 times higher and for Y 3 times. Skewed and loose around ground truth.
Vertical Precision	**Mean X: 85478.752 Std. Deviation X: 0.0.070**	**Mean Z : -0.030 Std. Deviation X: 0.231**
Low Range and Std. Deviation bet	Min-Max Z : (-0.2 , 0.5) = 0.7 Standard Deviation 3 times more and range is also 3 times more than open sky.	Min-Max Z : (-0.1 , 2.0) = 2.1 Standard Deviation 3 times more and range is also 3 times more than open sky.
DOP	**Mean PDOP: 1.199** **Mean HDOP: 0.903** **Mean VDOP: 0.700**	**Mean PDOP: 1.226** **Mean HDOP: 1.041** **Mean VDOP: 0.639**
LOW DOP more accuracy.	DOP values are very low and are near to 1 signifying high accuracy.	DOP values are very similar to values of Open sky, slightly higher than the open sky location, much higher if closer to the object.

Part 4c - Open Sky Location

DOPs values for Open Sky location. GDOP is highest around **0.6-0.8**. Lowest is HDOP **0.3-0.4.**

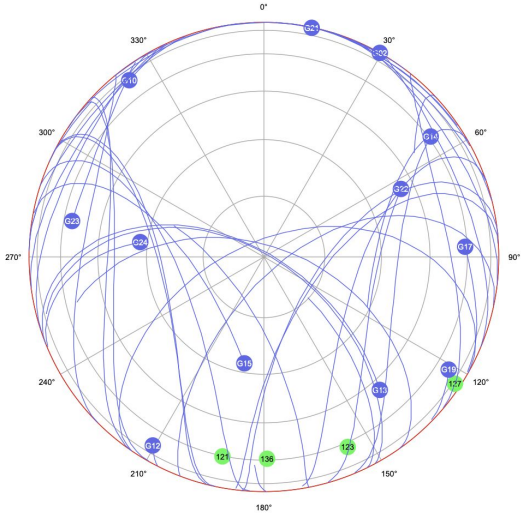
Min-Max of GPS Satellites **- 10-14**

Sky Plot at the location of the satellites at 1:30pm (black line) on 15th Nov.

Path of satellites showing a circular coverage of satellites all around the horizon.

13 GPS and 4 SBAS satellites present at time of survey.

Sky plot

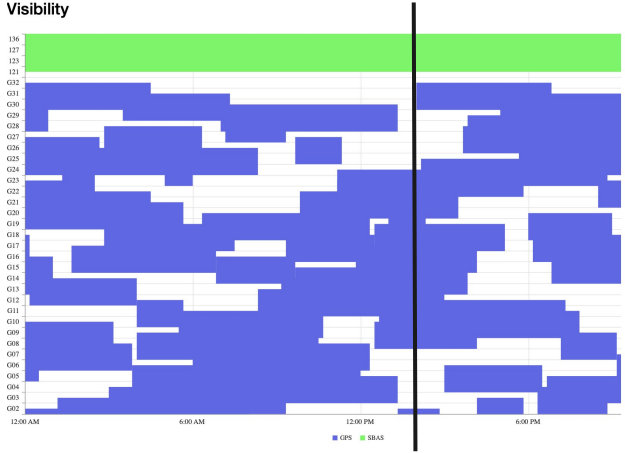


Number of satellites

Lat: 52.00262° Height: 0 m From: Fri, 15 Nov 2024 00:00:00 UTC+00:00
Lon: 4.37471° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

1:30 pm

Visibility



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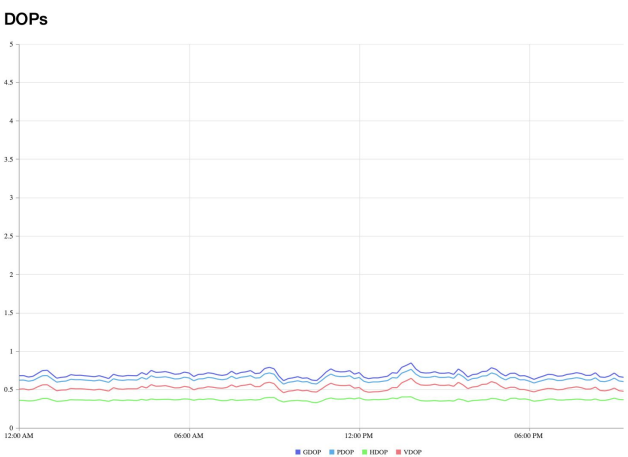
Lon: 4.37471° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

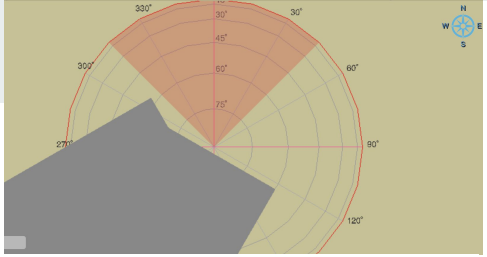
1:30 pm

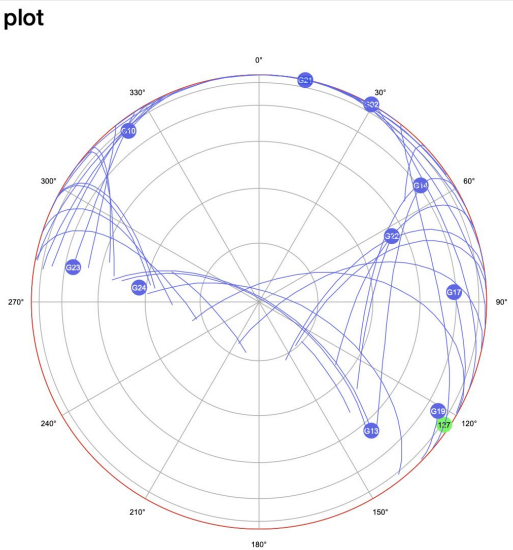
DOPs



Lat: 52.00262° Height: 0 m From: Fri, 15 Nov 2024 00:00:00 UTC+00:00
Lon: 4.3747° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

Part 4d - Obstructed Sky



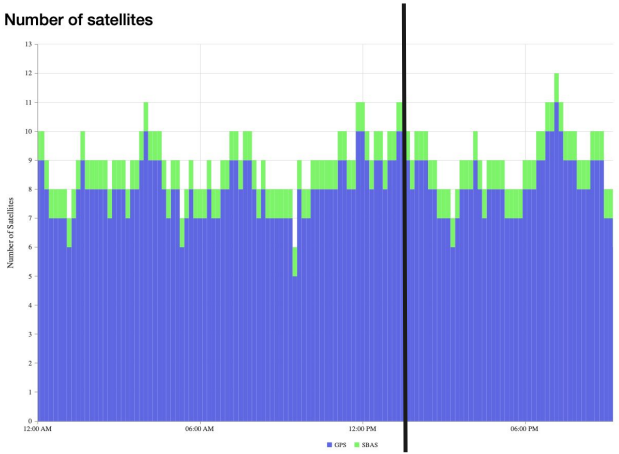


DOPs values for Open Sky location.
GDOP is highest around **1.2 - 1.8**.
Lowest is HDOP **0.8 - 1.2.**

Min-Max of GPS Satellites **- 5-10**

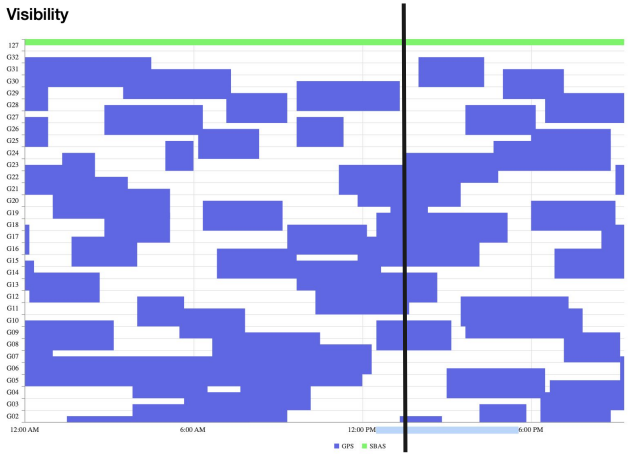
Path of satellites showing a semi-circular coverage of satellites around the horizon.

10 GPS and 1 SBAS satellites connected at time of survey.



Lat: 52.00262° Height: 0 m From: Fri, 15 Nov 2024 00:00:00 UTC+00:00
Lon: 4.37471° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

1:30 pm



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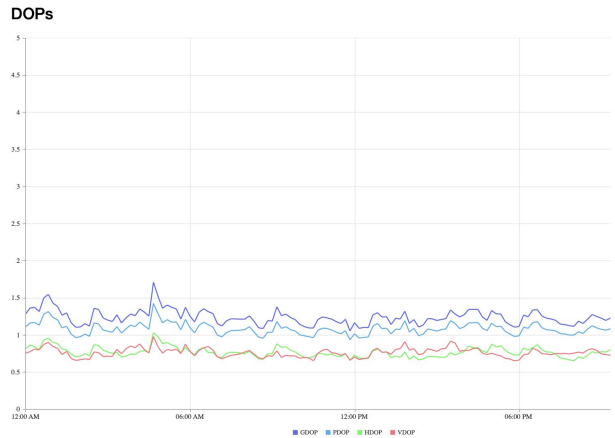
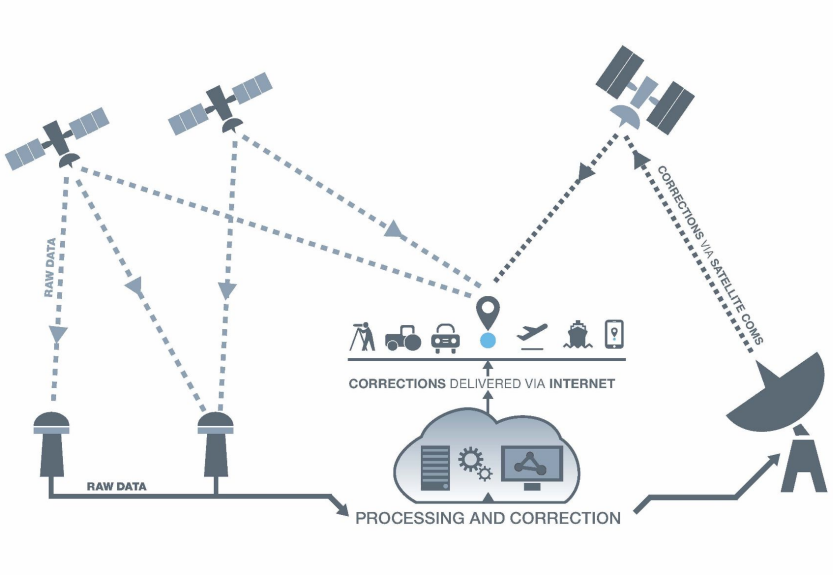
Lon: 4.37471° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

1:30 pm



Lat: 52.00238° Height: 0 m From: Fri, 15 Nov 2024 00:00:00 UTC+00:00
Lon: 4.37423° Cutoff: 0° To: Sat, 16 Nov 2024 00:00:00 UTC+00:00

Part 4e - Satellite Based Augmentation System



Left - Differential GPS based on transferring correction data through internet, from ground.

Right - Satellite Based Augmentation system, transferring correction through satellite's.

Satellite-Based Augmentation System improves GNSS accuracy using correction data from geostationary satellites.

Corrects errors of **atmospheric delays and satellite clock/drift,** not locally like RTK or GBAS, but on much more lager region.

Limitations:

- Performance depends on satellite visibility and the region's augmentation coverage.
- Less effective in heavily obstructed environments compared to GBAS. As, it needs clear sky for connection to receiver.

SBAS significantly improves GNSS performance in open areas but cannot fully compensate for urban canyon effects, obstructed sky.

RTK - Use the phase of the carrier signal for precise distance measurement. Instead of code based pseudorange measurements. Centimeter level accuracy.

Part 4e - Obstructed vs. Open Sky GNSS Measurements

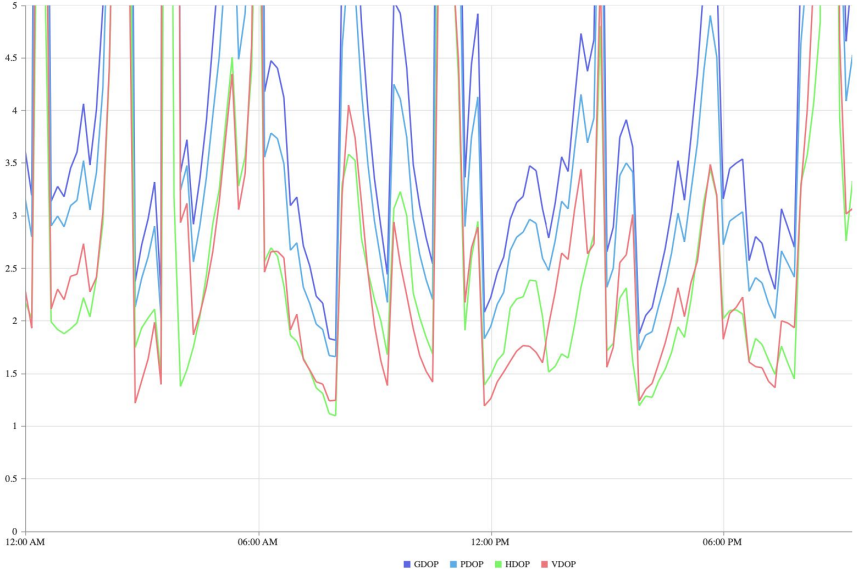
	Open Sky	Obstructed Sky
DOP - values	GDOP is highest around **0.6 - 0.8**. Lowest is HDOP : **0.3 - 0.4.** **VDOP : 0.4 - 0.6.** **PDOP : 0.5 - 0.7**	GDOP is highest around **1.2 - 1.8**. Lowest is HDOP **0.8 - 1.2.** **VDOP : 0.8 - 1.2** **PDOP : 1.0 - 1.3**
Lower DOP better accuracy. Satellite connected and visible widely all around the horizon.	Low DOP values: PDOP, HDOP, VDOP remain stable and minimal.	Higher DOP values, especially VDOP and GDOP.
Visibility - Number of Satellites	**Min-Max of GPS Satellites - 10 to 14**	**Min-Max of GPS Satellites - 5 to10**
Higher number of satellites more accuracy.	High satellite visibility: Consistently 10+ satellites visible.	Reduced satellite visibility inconsistent and less that 10.
Sky Plot	**13 GPS and 4 SBAS satellites available.**	**10 GPS and 1 SBAS satellites available.**
More coverage better accuracy.	Circular coverage all around the horizon.	Poor satellite geometry due to urban canyon effect. Especially at the position of object,
DOP - values Collected mobile app	**Mean PDOP: 1.199** **Mean HDOP: 0.903** **Mean VDOP: 0.700**	**Mean PDOP: 1.226** **Mean HDOP: 1.041** **Mean VDOP: 0.639**
	DOP values are near 1 which are signifying high acc.	DOP values similar to Open Sky a little higher.

Part 4e - When the location is under 1m from the AULA

Observations of influence of distance from Obstructing object: (Urban Canyon Effect)

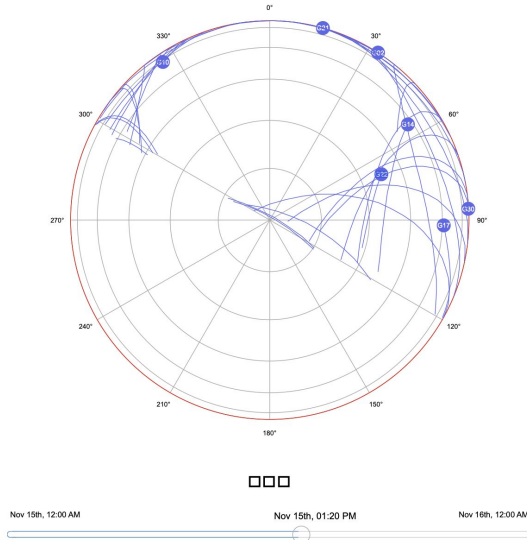
- DOP values are significantly higher than 1, and reaches to infinity at some instances.
- Visibility is less than 10 satellites always, more error prone data - pseudo-range calculations.
- No presence of any SBAS satellite in this scenario.
- More multi-plath effect probability.

DOPs



Lat: 52.00262° **Height:** 0 m **From:** Fri, 15 Nov 2024 00:00:00 UTC+00:00
Lon: 4.37471° **Cutoff:** 0° **To:** Sat, 16 Nov 2024 00:00:00 UTC+00:00

Sky plot



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Lon: 4.37471° **Cutoff:** 0° **To:** Sat, 16 Nov 2024 00:00:00 UTC+00:00