Department of Aeronautical and Aviation Engineering
航空及民航工程學系

THE HONG KONG POLYTECHNIC UNIVERSITY
香港理工大學

3D Mapping Aided (3DMA) Sky Visibility Matching: An example using a simulated LEO constellation

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Session B2: Navigation in GNSS Challenged Environments,
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Urban GNSS Positioning

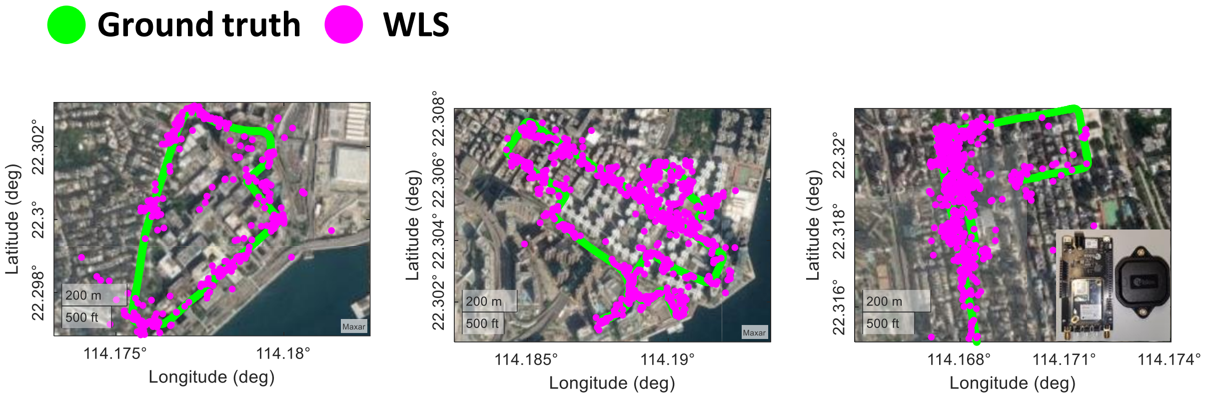
Major **challenges** in Urban Canyon:

- None-Line-of-sight (NLOS) signal:

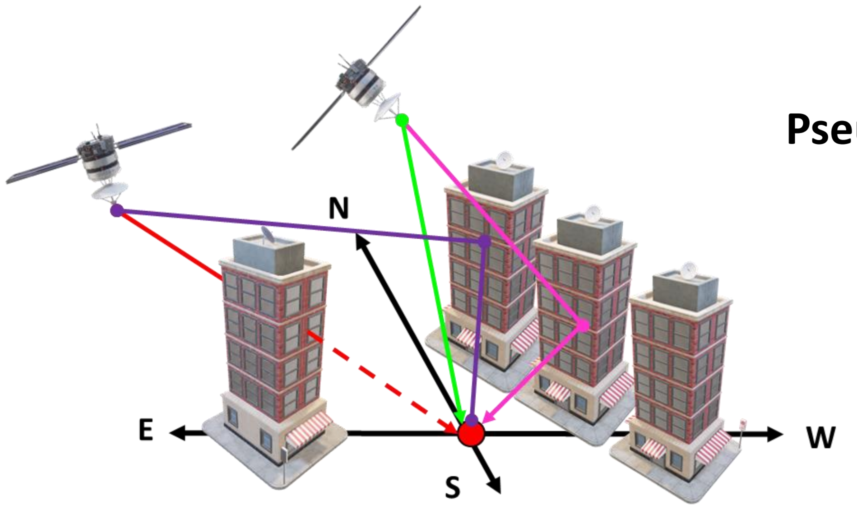
No LOS signal; only receive reflected signal

- Multipath:

receive both LOS signal and reflected signal



Medium-Urban **Deep-Urban** **Harsh-Urban**



Errors resulting in

Pseudorange & Carrier Phase

From Single positioning of **RTKLIB**

	Availability (%)	RMS (m)
Medium	24.65	5.90
Deep	42.37	9.14
Harsh	13.95	67.95

Hsu, Li-Ta, Kubo, Nobuaki, Wen, Weisong, Chen, Wu, Liu, Zhizhao, Suzuki, Taro, Meguro, Junichi, "UrbanNav:An Open-Sourced Multisensory Dataset for Benchmarking Positioning Algorithms Designed for Urban Areas," ION GNSS+ 2021, St. Louis, Missouri, September 2021, pp. 226-256.

3D Building model

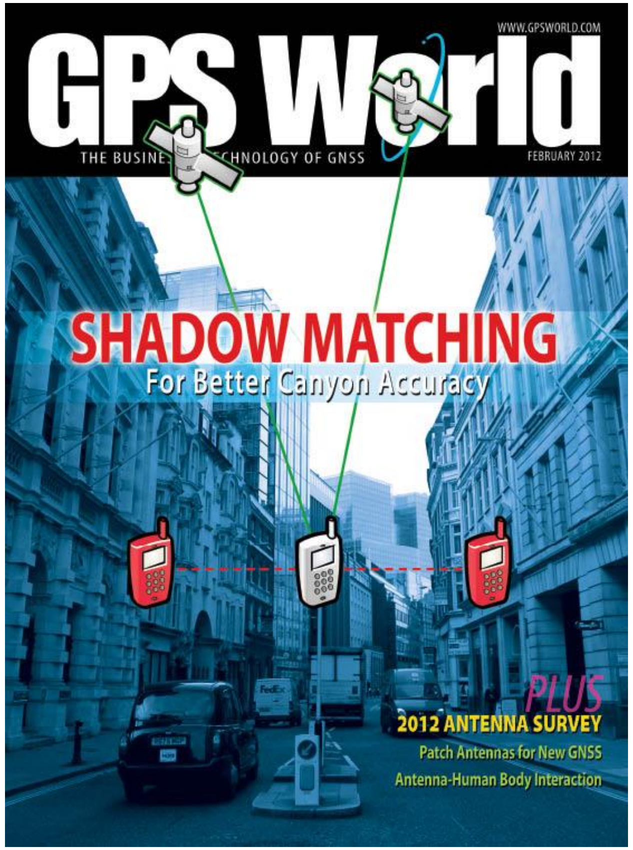
Shadow matching
(Satellite Visibility)

3D building models

GNSS

+

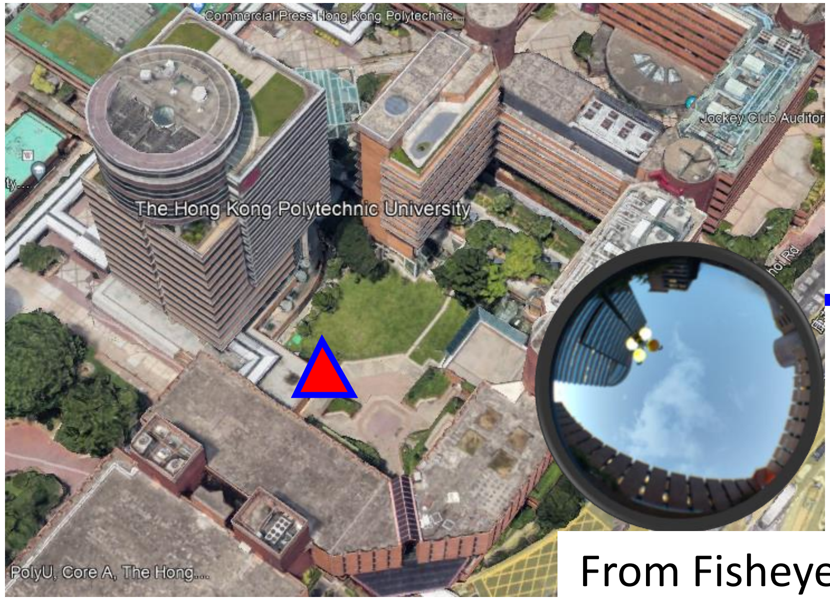
3DMA GNSS



Avoid to use the Bad Measurement directly

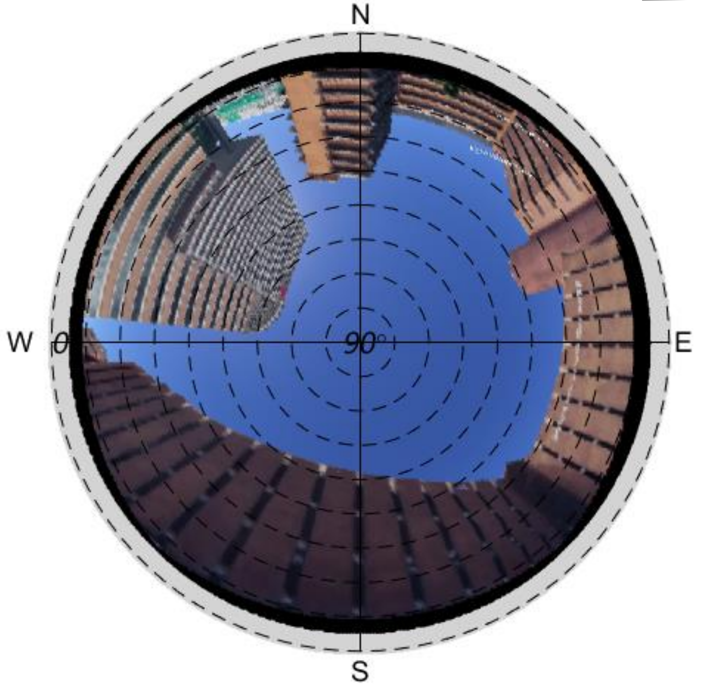
https://geodata.gov.hk/

3D Building model and Sky visibility

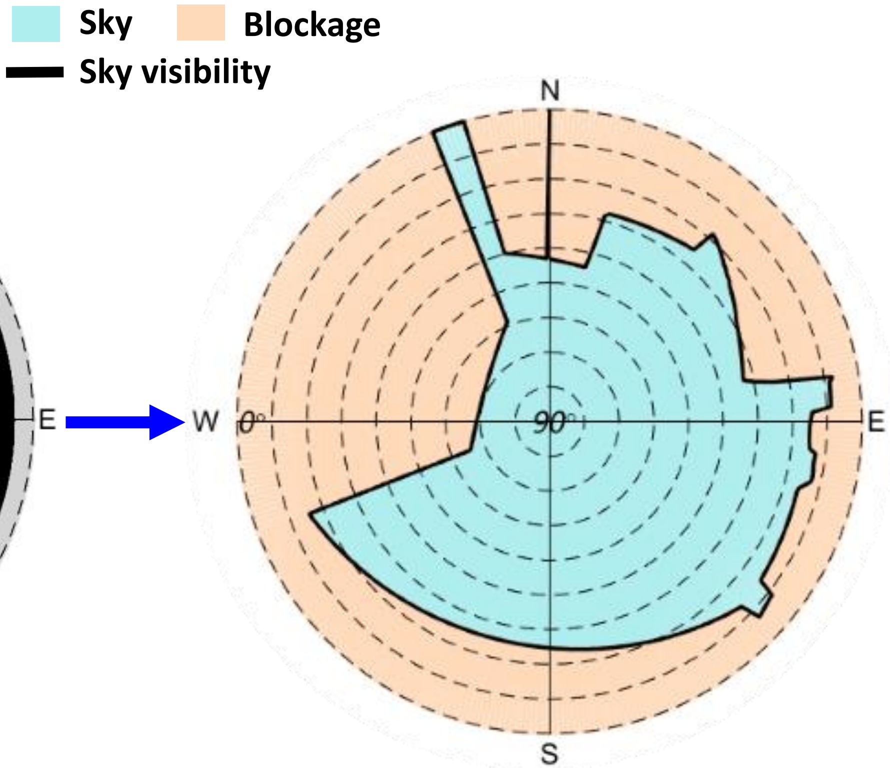


From Fisheye

Select a location on our campus



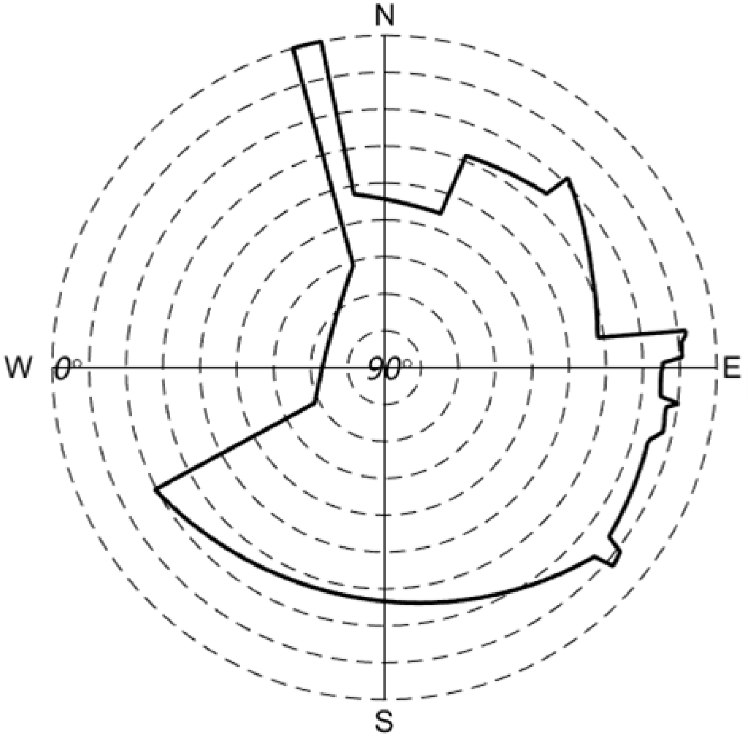
Extract surrounding 3D model



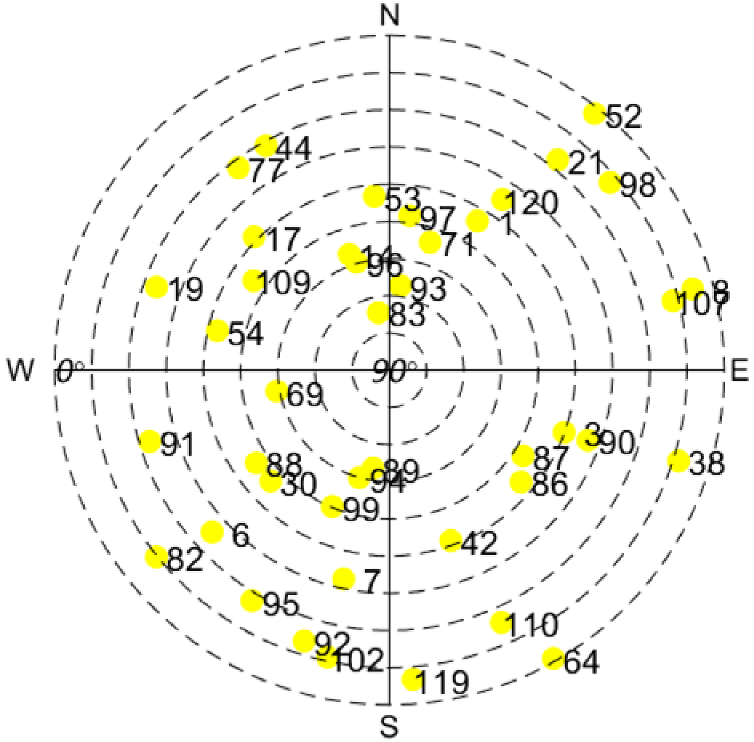
The Boundary between sky and blockage is <u>Sky visibility</u>

Satellite visibility

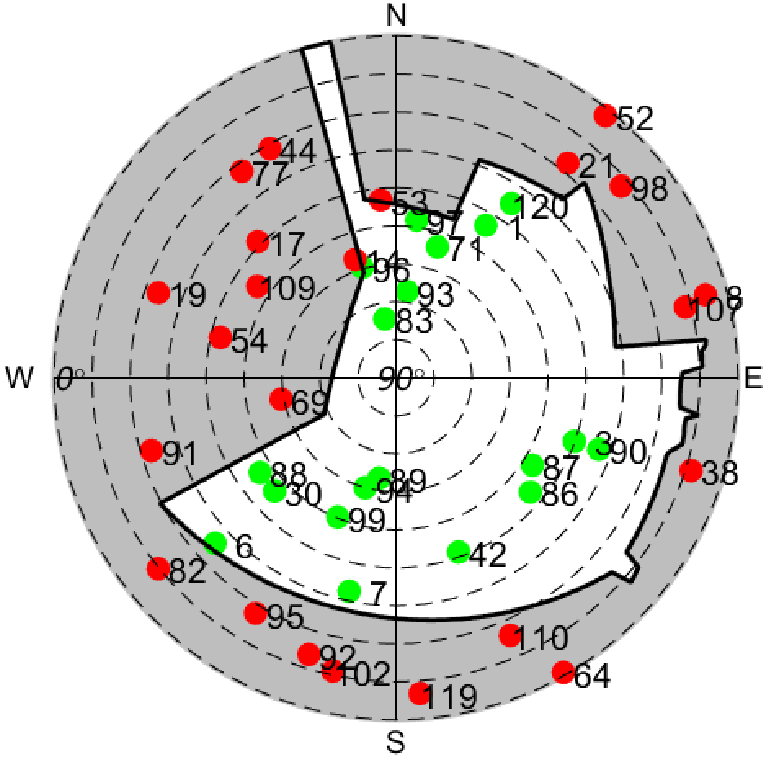
Sky visibility



Satellite Geometry



Satellite Visibility



Satellite labelled by sky visibility

Sky Blockage

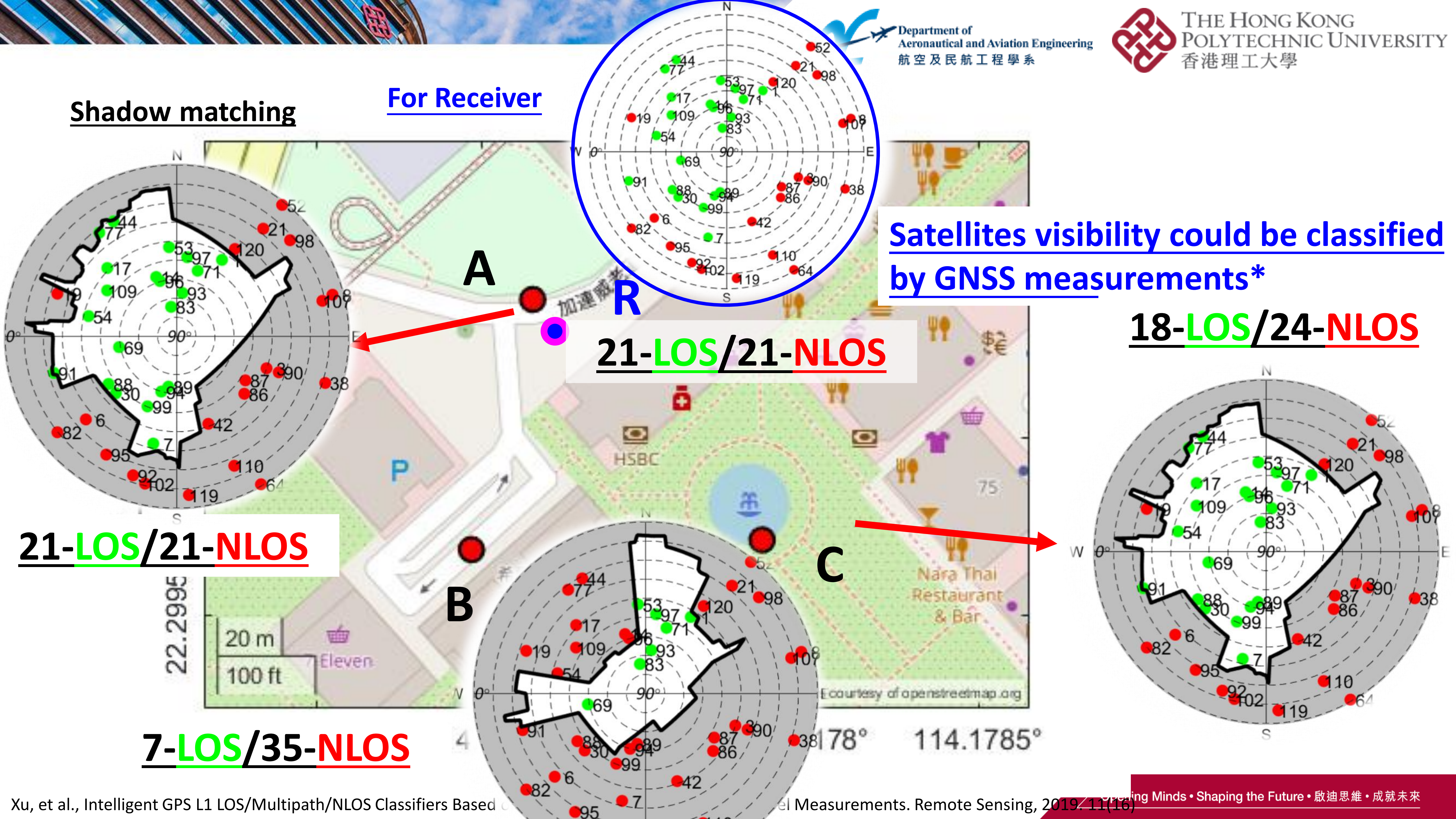
The LOS/ NLOS is named as Satellite Visibility

LOS Sky visibility
NLOS 19 PRN number

Shadow matching

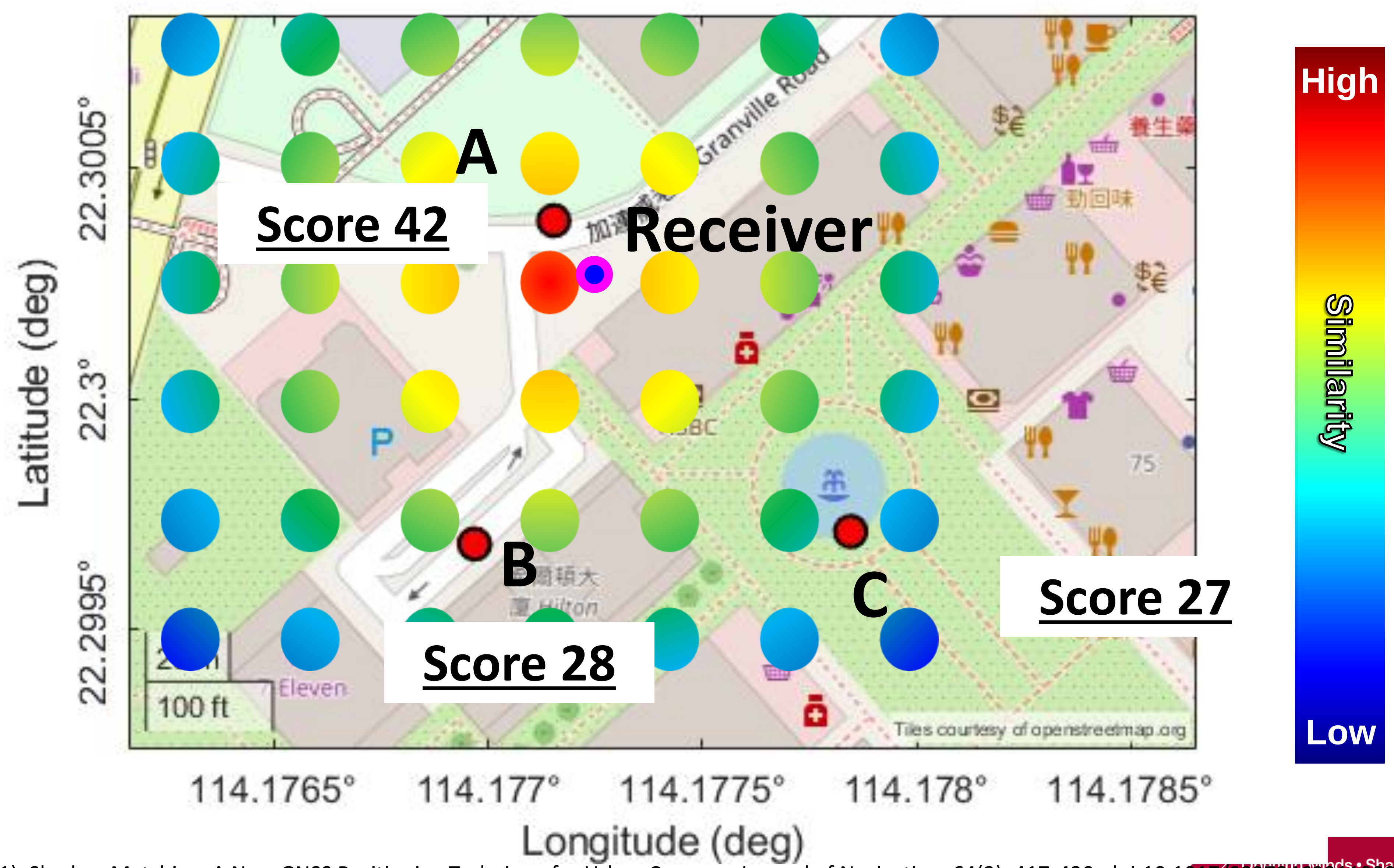
For Receiver

Satellites visibility could be classified by GNSS measurements*



Xu, et al., Intelligent GPS L1 LOS/Multipath/NLOS Classifiers Based ... el Measurements. Remote Sensing, 2019. 11(16)

Shadow matching



Groves, P. (2011). Shadow Matching: A New GNSS Positioning Technique for Urban Canyons. Journal of Navigation, 64(3), 417-430. doi:10.1017/S0373463311000087

Main idea: Shadow matching

Receiver's surrounding buildings (unknown sky visibility)

Influence → GNSS Measurements

Determine → Receiver's Satellites visibility (LOS/NLOS)

GNSS Measurements → Classified by measurements → Receiver's Satellites visibility (LOS/NLOS)

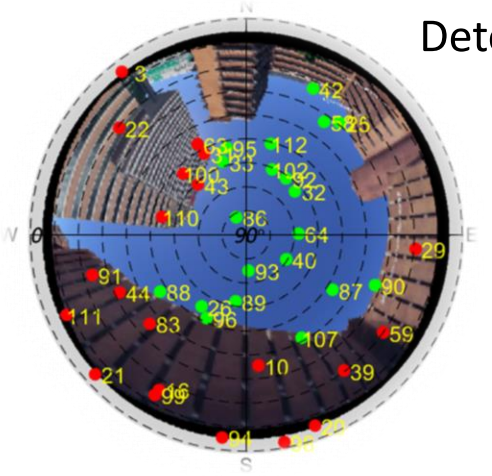
3D Building Model → Locations' sky visibility → Locations' Satellites visibility (LOS/NLOS)

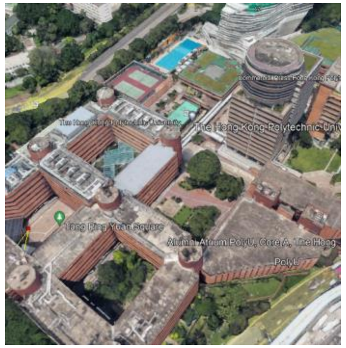
GNSS Measurements → Locations' Satellites visibility (LOS/NLOS)

Receiver's Satellites visibility (LOS/NLOS) → Matching scheme

Locations' Satellites visibility (LOS/NLOS) → Matching scheme

Matching scheme → User Location





GNSS Measurement

- Pseudorange
- Signal to noise ratio
- Doppler

Using the Similarity of Satellite Visibility to match Similarity of sky visibility

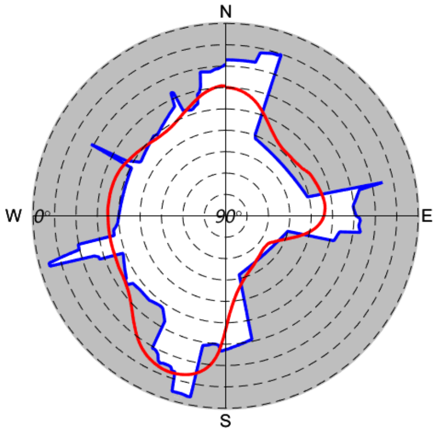
Can we compare the sky visibility directly?

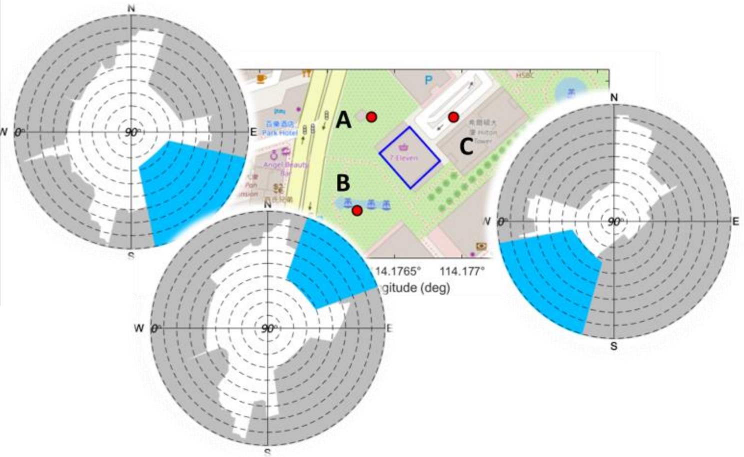
Yes ! By estimating the receiver's sky visibility

Main idea: sky visibility matching

GNSS Measurements → Satellites information → (Proposed sky visibility estimation) → **Receiver's sky visibility** → Proposed Matching score scheme → User Location

3D Building Model → **Locations' sky visibility** → Proposed Matching score scheme



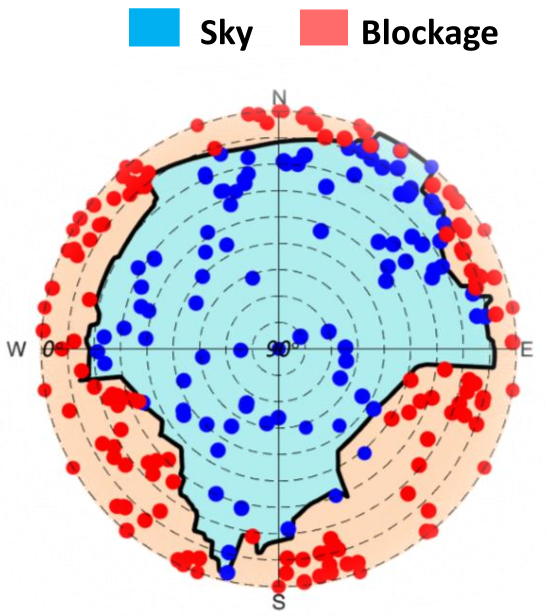


Satellites information

- Azimuth angle
- Elevation angle
- Satellite visibility

	Comparison Domain	Number of Comparison
Shadow matching	Satellites Visibility	About 40 (GNSS in HK)
Sky Visibility Matching	Surrounding Geometry	360 (whole sky view)

Sky visibility estimation

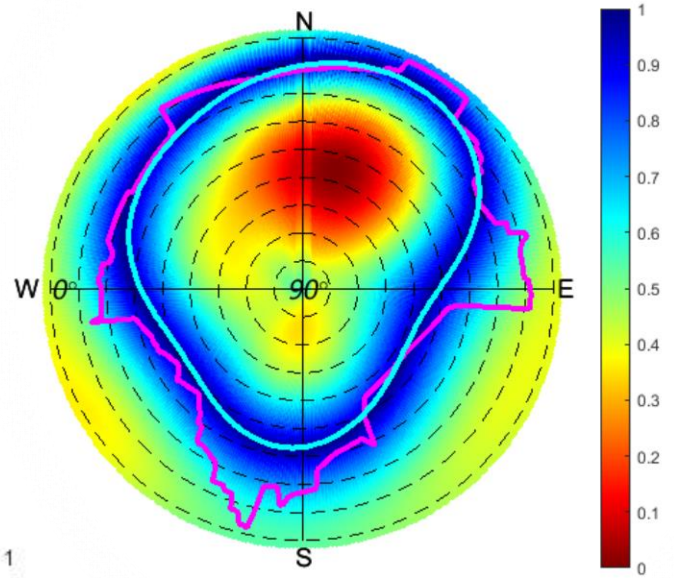


To find the **boundary** between Sky and Blockage

The support vector machine (SVM) regression

$$y = f(x) = < w, x > + b = \sum_{j=1}^{M} w_j x_j + b$$

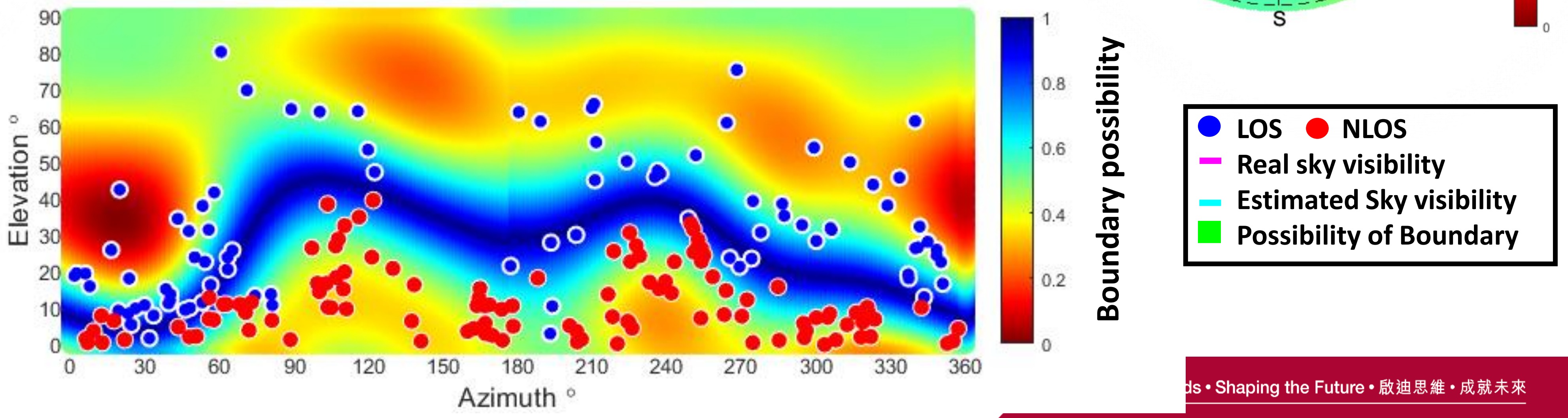
$$x_j = (az_j, el_j), y_j = vis_{sat}^j$$



Then, Possibility of Boundary are calculated for whole sky view

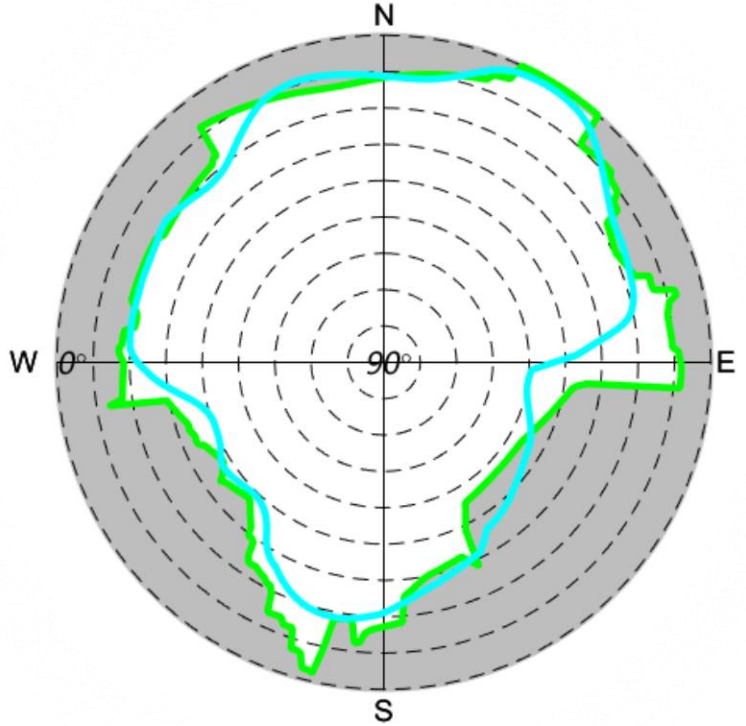
Satellites Measurement

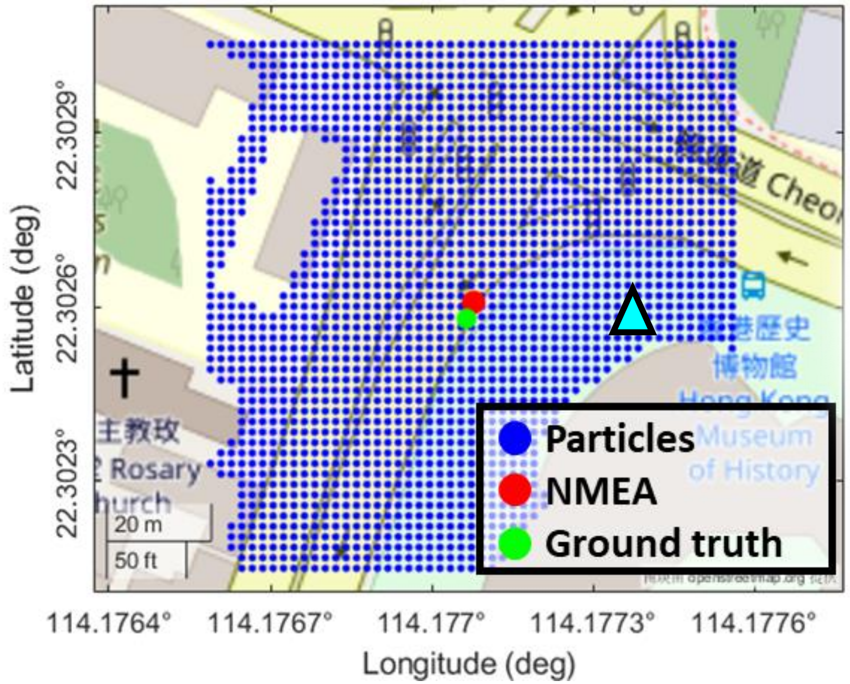
- Azimuth angle az_j
- Elevation angle el_j
- Satellite visibility vis_{sat}^j



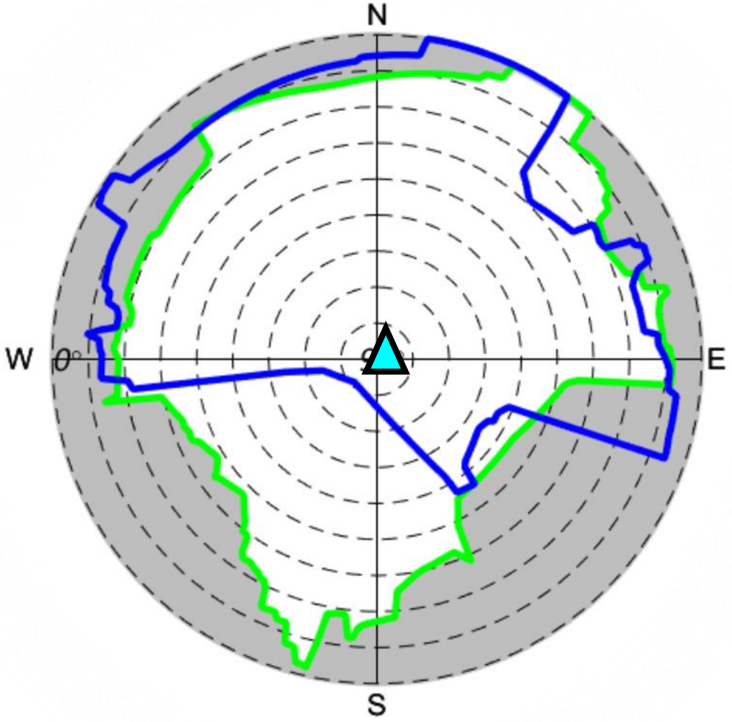
Sky visibility estimation

Estimated Sky visibility





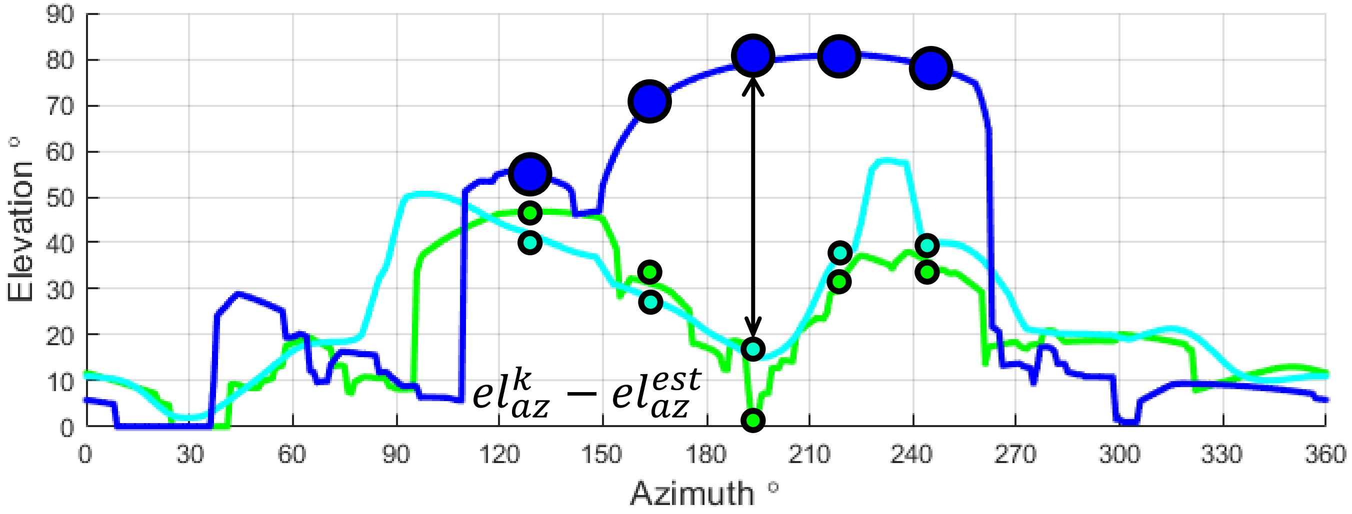
Sky visibility of Particle



GT sky visibility — Estimated Sky visibility — Candidates' sky visibility

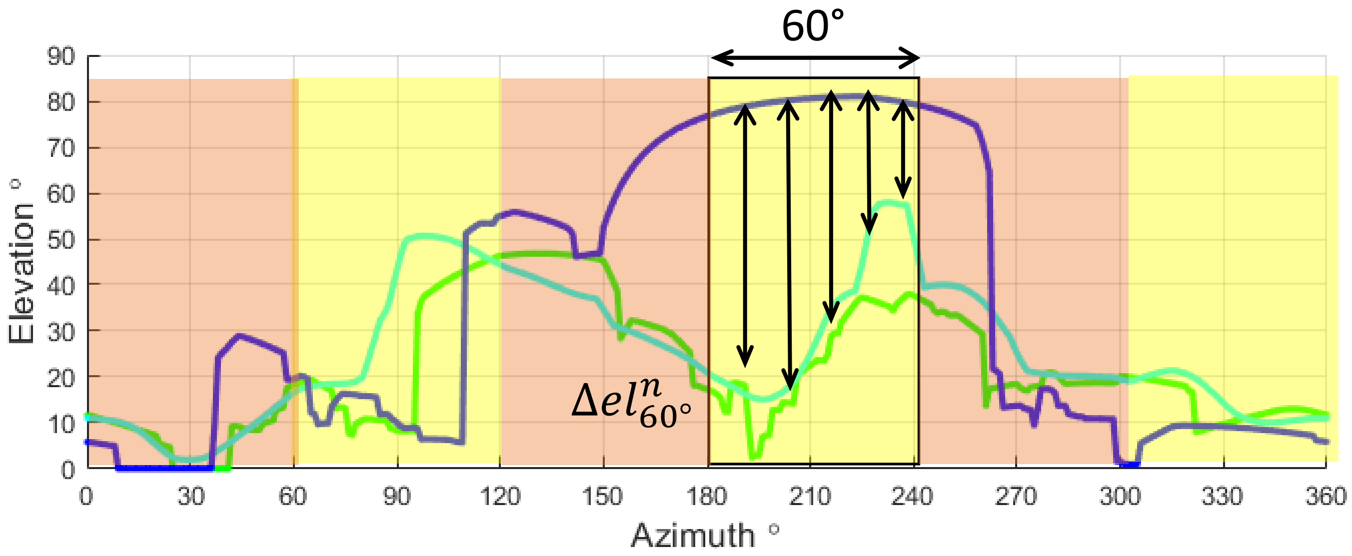
Sky visibility matching score scheme

GT sky visibility
Estimated Sky visibility
Particle' sky visibility



- **Point-wise**

Calculating the Elevation angle difference of each azimuth and summing it all.



- **Feature-wise**

Azimuth angles are segmented by every 60° azimuth angles.

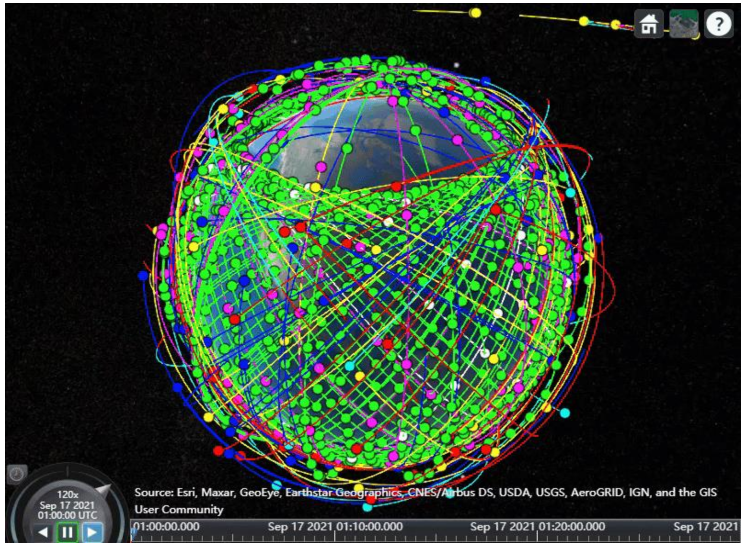
$$score^{k} = \prod_{n=1}^{6} \Delta el_{60°}^{n}$$

The elevation angle difference of each azimuth segment (feature) are integrated.

Q: What about more satellites?

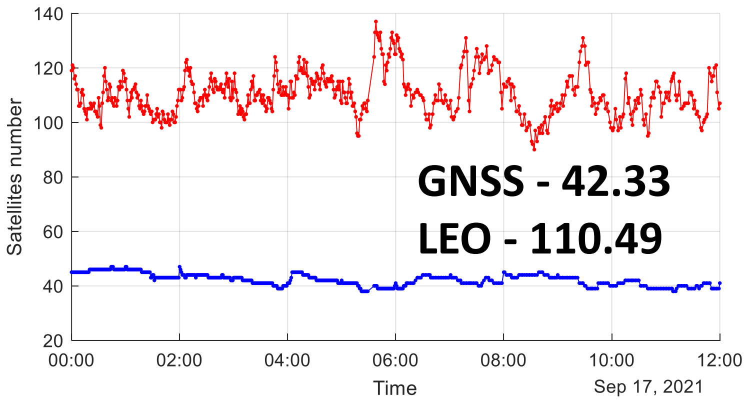
Setting of our LEO orbits

- **Orbit Element** (**TLE**) from http://celestrak.com/
- Six conventional LEO constellations
- **Orbit Trajectory** from Simplified General Perturbations (**SGP**) models



Globalstar | Iridium | Orbcomm | Other
Intelsat | Oneweb | Starlink

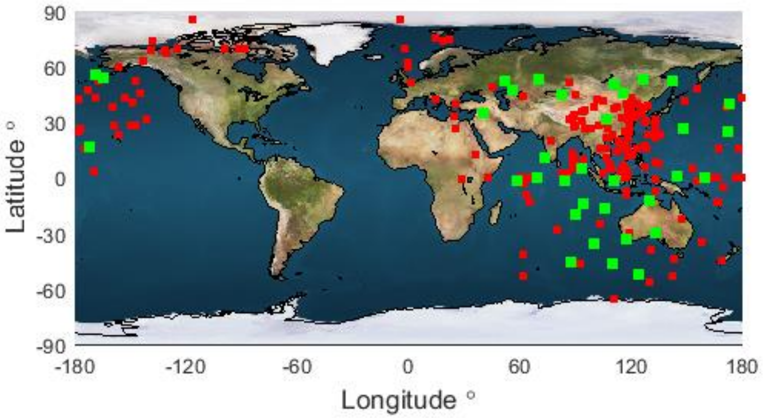
Satellite number of 12 Hours in HK

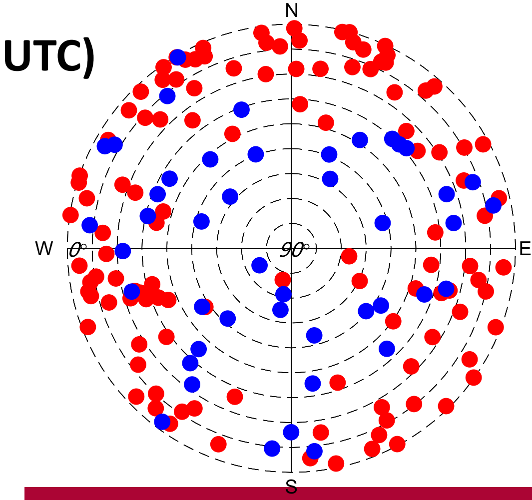


GNSS
LEO

Time of 00:00 am, Sep,17,2021
GNSS from HK-QT/LEO from celestrak

Satellite position at 2021.1.15/10:05:01 (UTC)





Experiment setup

Sky visibility estimation

GNSS vs GNSS+LEO

- **GNSS**

Constellation:

GPS, GLONASS, Galileo, and BeiDou

Receiver: Ublox F9p with 15 mins measurements

- **LEO**

Constellation:

Globalstar, Intelsat, OneWeb, Orbcomm, and Starlink

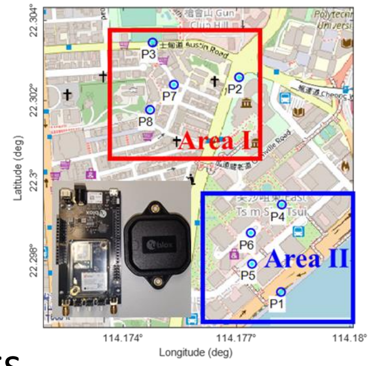
Sky visibility matching

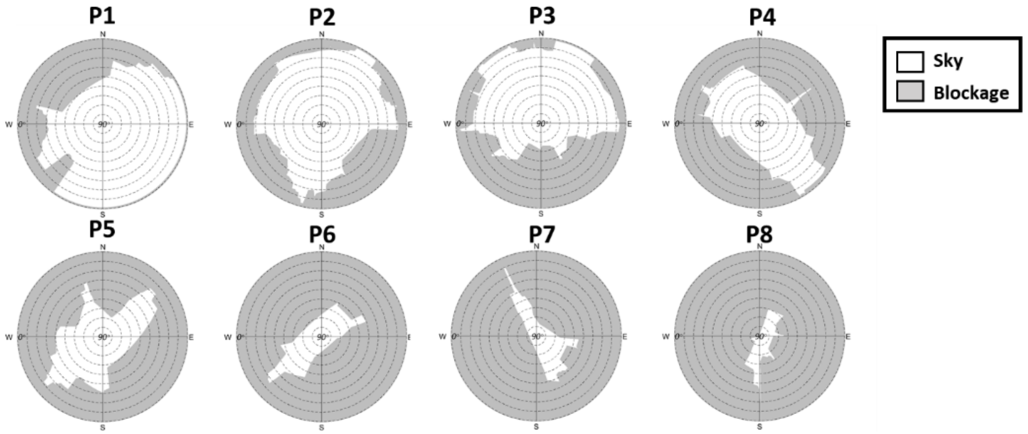
Real Sky visibility vs Estimated Sky visibility

squared: 50m

Separation: 2m

Initial location: NMEA



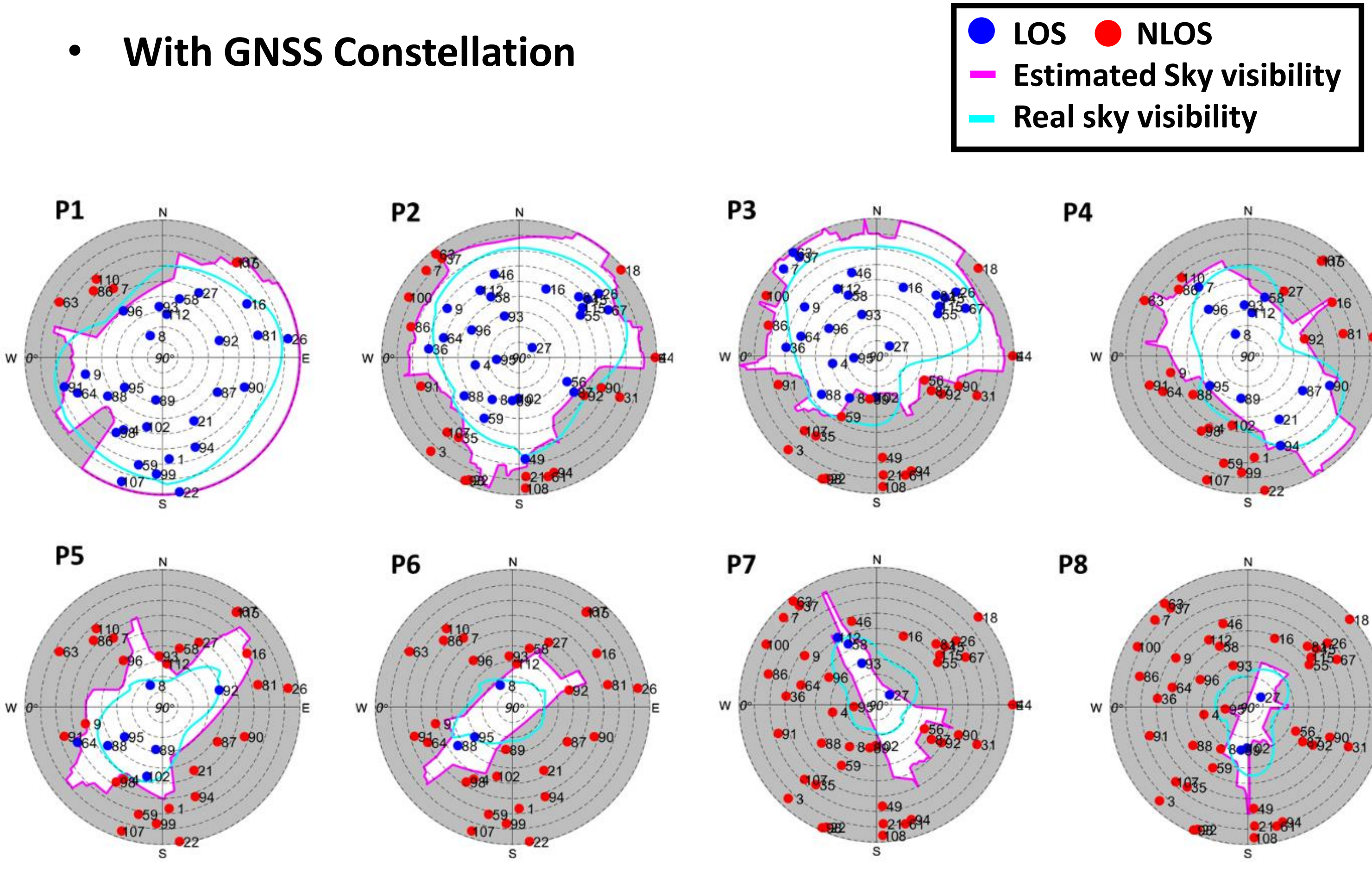


Number of Satellites

Area	Location	LEO	GNSS	
		/	Ephemeris	Received
I	1	192.71	34.00	21.42
	4			26.35
	5			23.59
	6			19.32
II	2	173.72	45.57	26.35
	3			23.59
	7			19.32
	8			19.56

The Performance of sky visibility estimation

- With GNSS Constellation

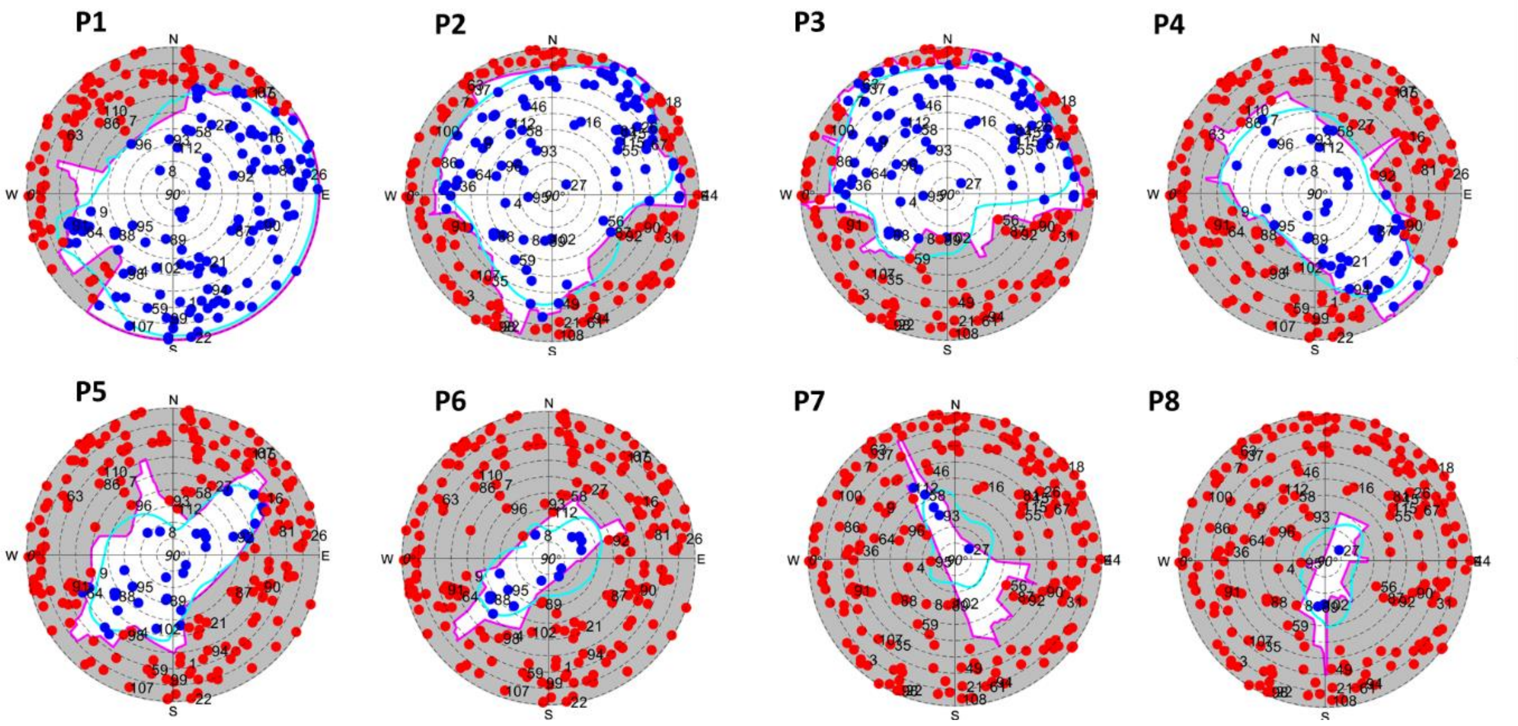


Estimation Error (Unit: degree)				
Location	**Mean**	**STD**	**Min**	**Max**
1	10.77	5.79	0.09	26.11
2	9.24	5.78	0.10	30.23
3	11.68	7.69	0.07	42.59
4	11.11	7.36	0.08	41.52
5	13.03	9.82	0.09	42.86
6	8.82	6.79	0.07	37.73
7	13.04	7.43	0.16	41.03
8	11.25	6.75	0.13	26.13

The Performance of sky visibility estimation

- **With GNSS+LEO Constellation**

LOS NLOS
Estimated Sky visibility
Real sky visibility



	GNSS		GNSS+LEO
The mean estimation error	9~13	→	5~9

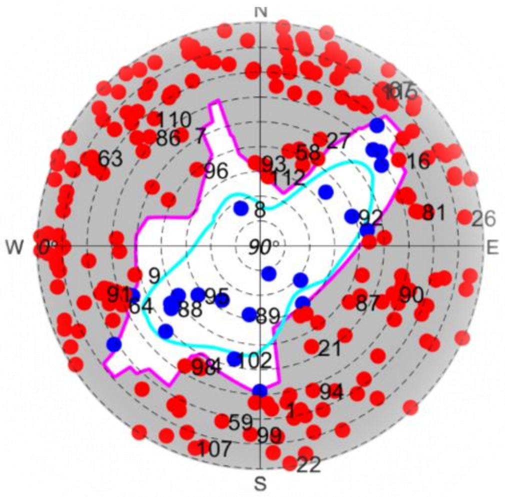
Estimation Error (Unit: degree)				
Location	**Mean**	**STD**	**Min**	**Max**
1	5.32	5.45	0.07	27.76
2	4.60	4.49	0.02	24.88
3	6.56	6.28	0.02	32.47
4	6.04	5.27	0.03	32.12
5	8.05	6.17	0.04	31.54
6	6.22	5.16	0.03	25.92
7	8.59	6.65	0.05	35.31
8	8.69	5.59	0.06	29.50

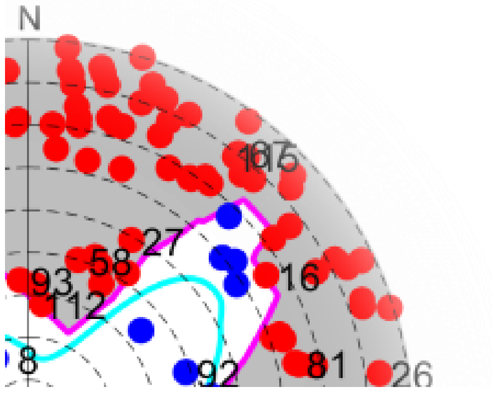
The Performance of sky visibility estimation

- **The satellite geometry**

	Mean estimation error
A	11.18
B	11.32
C	3.37

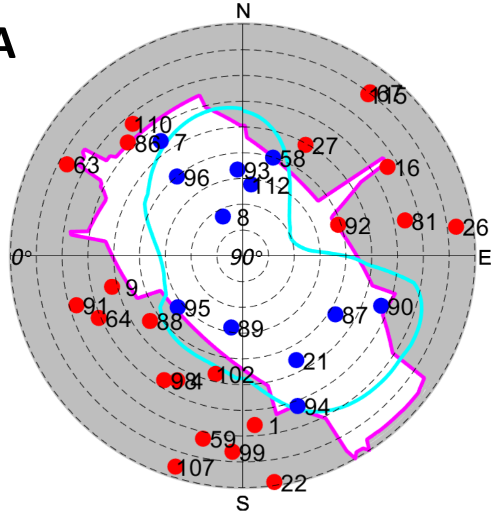
- **The Lose of detail**





- **With GNSS Constellation**

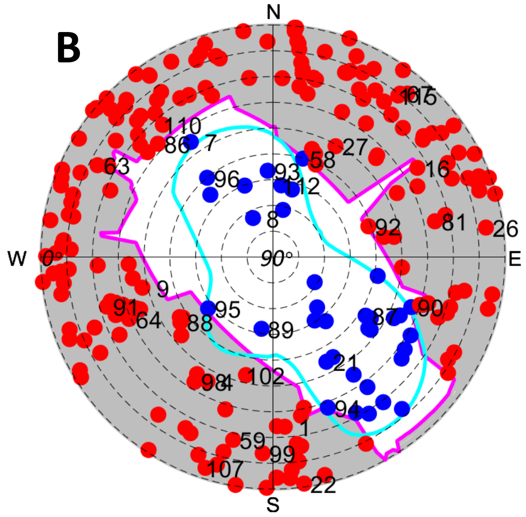
A



Epoch No.326

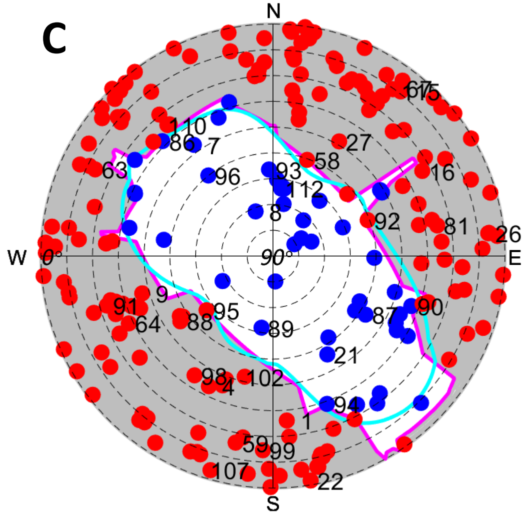
- **With GNSS+LEO Constellation**

B

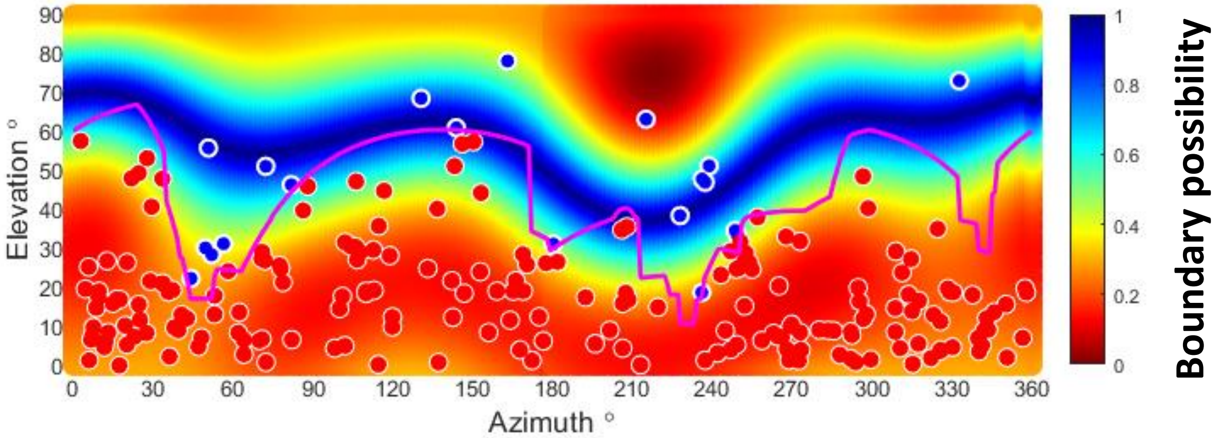


Epoch No.326

C



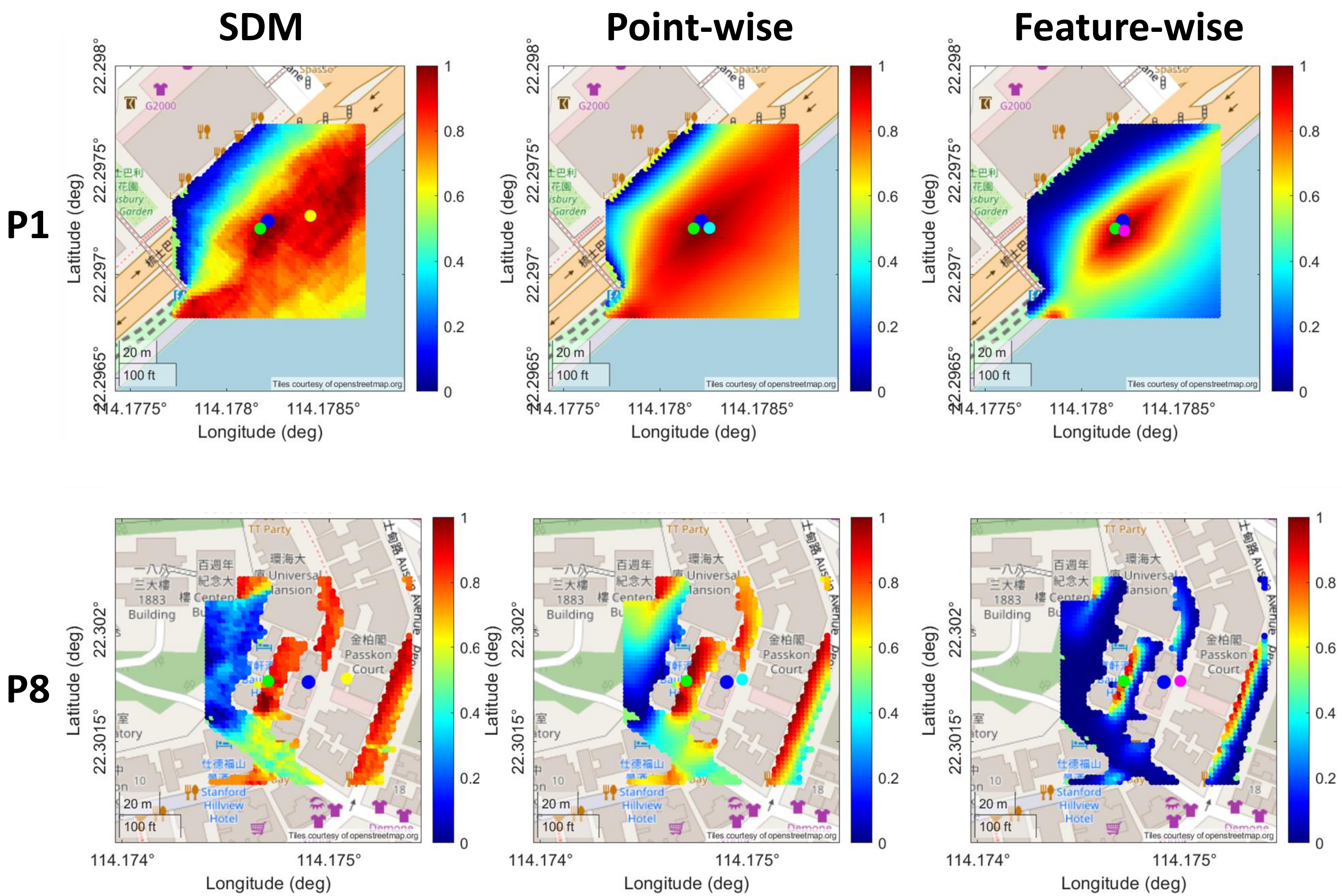
Epoch No.583



The Performance of sky visibility matching

- Ground truth sky visibility matching in Particles

NMEA
SDM
Ground truth
Point-wise
Feature-wise



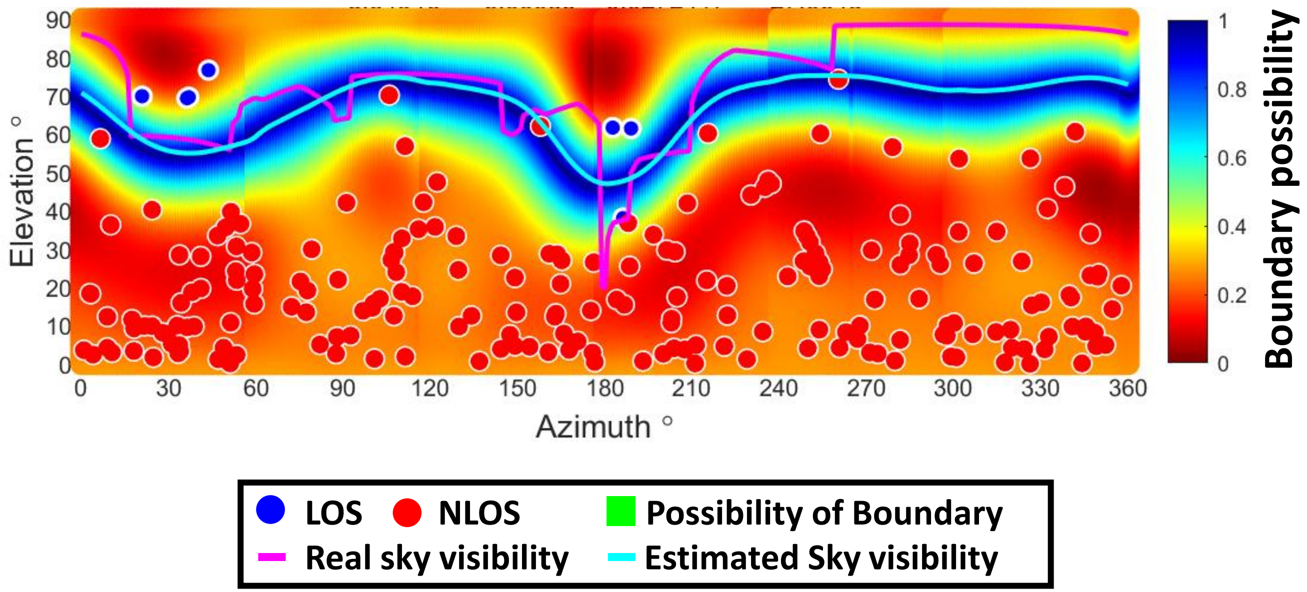
Means of 2D error (m)				
		SDM	Visibility matching	
		\	Point-wise	Feature-wise
Position	1	17.97	8.46	4.88
	2	8.01	2.45	1.98
	3	7.90	8.39	3.50
	4	5.84	1.08	0.48
	5	2.11	0.99	0.99
	6	4.22	0.36	0.52
	7	5.02	1.42	1.52
	8	23.09	26.50	21.84

The Performance of sky visibility matching

- Estimated sky visibility matching in Particles

Imperfect sky visibility estimations

With only 4 LOS available in GNSS+LEO



Means of 2D error (m)				
		SDM	Visibility matching	
		\	Point-wise	Feature-wise
Position	1	17.88	20.91	17.72
	2	8.04	5.23	6.39
	3	7.84	12.24	11.48
	4	5.98	5.41	10.20
	5	2.13	4.16	4.67
	6	4.28	4.24	4.90
	7	5.01	11.55	11.55
	8	23.12	52.96	44.93

Conclusions

- **Sky visibility estimation**

1. SVM Regression for estimation
2. Satellite geometry is the main issue to be solved
3. The LEO constellation benefit in most of the time

- **Sky visibility matching**

1. Two matching score schemes for Sky visibility
2. Verify the potential application in 3DMA GNSS
3. Local minimum and bad visibility estimation need to be solved

Future work

- **Sky visibility estimation**

1. Algorithm would be improved by **Epoch wise**
2. Provide the **estimation quality** for positioning usage
3. Test in **non-prefect** LOS/NLOS condition

- **Sky visibility matching**

1. Applying the estimation quality into matching scheme
2. Testing in **non-prefect** LOS/NLOS condition and dynamic environment
3. Trying to migrate the impact of the Local minimum

Thank you for your attention

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