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CHINESE ACADEMY OF SCIENCES

华南特大城市风速垂直变化研究

Vertical variation of Wind Speed in a Metropolitan City in South China

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◆ Outlines

1. Background
2. Data and Methodology
3. Results and Discussion
4. Conclusion



Background

Shenzhen
in 1982





Background

Nowadays







Background

深圳138座超200米+的摩天

大楼!

播报文章



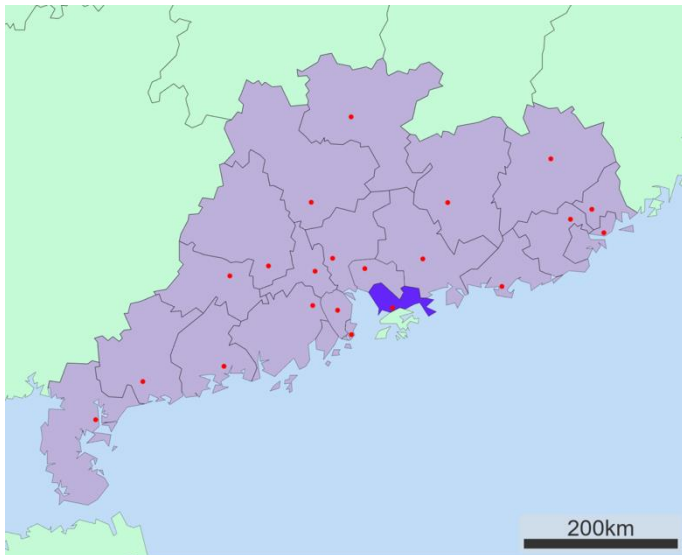
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关注

截止目前，深圳已建成或封顶的200+摩天大楼数量为138座，数量排名全球第一

除了平安金融中心599.05米和京基100是441.8米之外，高度300 - 400米的有15座，其中华润大厦392.5米，深业上城产业研发大厦388.1米，信兴广场383.95米；高度在200 - 300米的摩天大楼深圳也有121座。

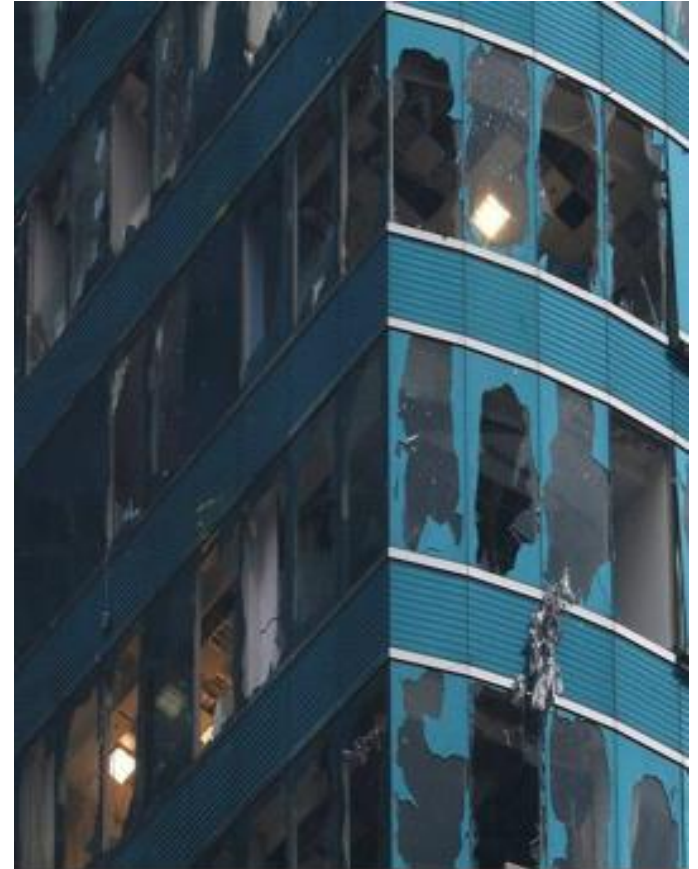


深圳是我国的经济特区，已经成为一个有国际影响力的城市。现在的深圳已经是中国超高层最多的城市了，据统计，深圳200米高楼 121幢 300米 15幢，400米1幢，500米1幢，第一高楼是592米的平安金融中心。

Shenzhen has the most skyscrapers in China.



Background



Vertical wind disaster during Typhoon Mangkhurt landfall



Data and Methodology



Meteorological Gradient Tower
Shenzhen Ping An Building

356 m
592 m

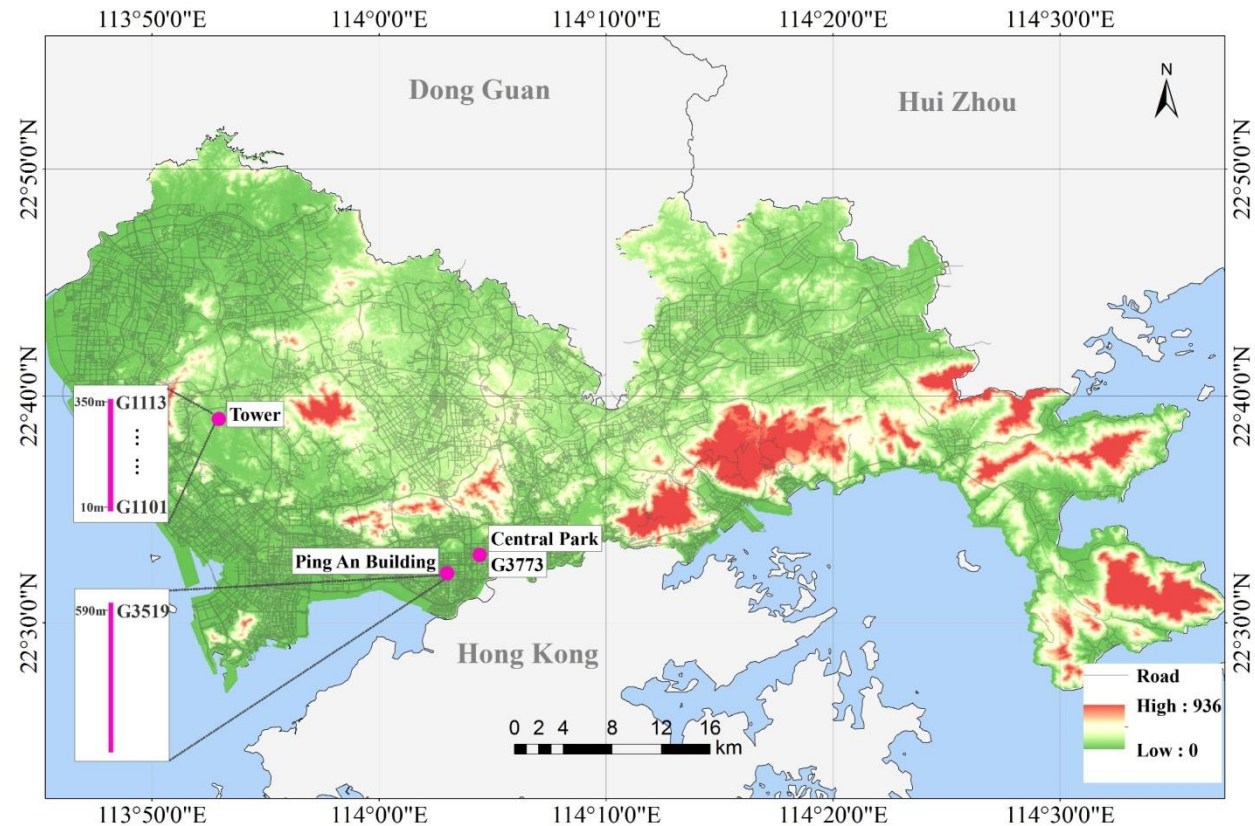




Data and Methodology

Station ID	Station Name	Height above ground (m)	Meteorological elements used	Duration of wind speed data
G1101	Tower F1	10	gust, awind, T	Oct 2016 - Jan 2020
G1102	Tower F2	20	gust, awind	Oct 2016 - Jan 2020
G1103	Tower F3	40	gust, awind	Oct 2016 - Jan 2020
G1104	Tower F4	50	gust, awind	Oct 2016 - Jan 2020
G1105	Tower F5	80	gust, awind	Oct 2016 - Jan 2020
G1106	Tower F6	100	gust, awind	Oct 2016 - Jan 2020
G1107	Tower F7	150	gust, awind	Oct 2016 - Jan 2020
G1108	Tower F8	160	gust, awind	Oct 2016 - Jan 2020
G1109	Tower F9	200	gust, awind	Oct 2016 - Jan 2020
G1110	Tower F10	250	gust, awind	Oct 2016 - Jan 2020
G1111	Tower F11	300	gust, awind	Oct 2016 - Jan 2020
G1112	Tower F12	320	gust, awind	Oct 2016 - Jan 2020
G1113	Tower F13	350	gust, awind	Oct 2016 - Jan 2020
G3519	Ping An Building	570	gust, awind	Aug 2018 - Jan 2021
G3773	Central Park	14	gust, awind, T	Aug 2018 - Jan 2021

The wind data used in this study are the maximum 10 min average wind speeds (avg-wind speed) and the maximum 3 sec wind speeds (gust wind speed) within an hour observed at the stations.



The locations of the Meteorological Gradient Tower and Ping An Building, and the Central Park



Data and Methodology

Power law equation:

$$\frac{V}{V_0} = \left(\frac{H}{H_0} \right)^\alpha$$

V : wind speed at the height H
 V_0 : wind speed at the height H_0
 α : Hellman coefficient

$$\alpha = \frac{\lg(V / V_0)}{\lg(H / H_0)}$$

Least square estimation

The Hellmann coefficient depends upon roughness and atmospheric stability.

location	α
Unstable air above open water surface:	0.06
Neutral air above open water surface:	0.10
Stable air above open water surface:	0.27
Unstable air above flat open coast:	0.11
Neutral air above flat open coast:	0.16
Stable air above flat open coast:	0.40
Unstable air above human inhabited areas:	0.27
Neutral air above human inhabited areas:	0.34
Stable air above human inhabited areas:	0.60

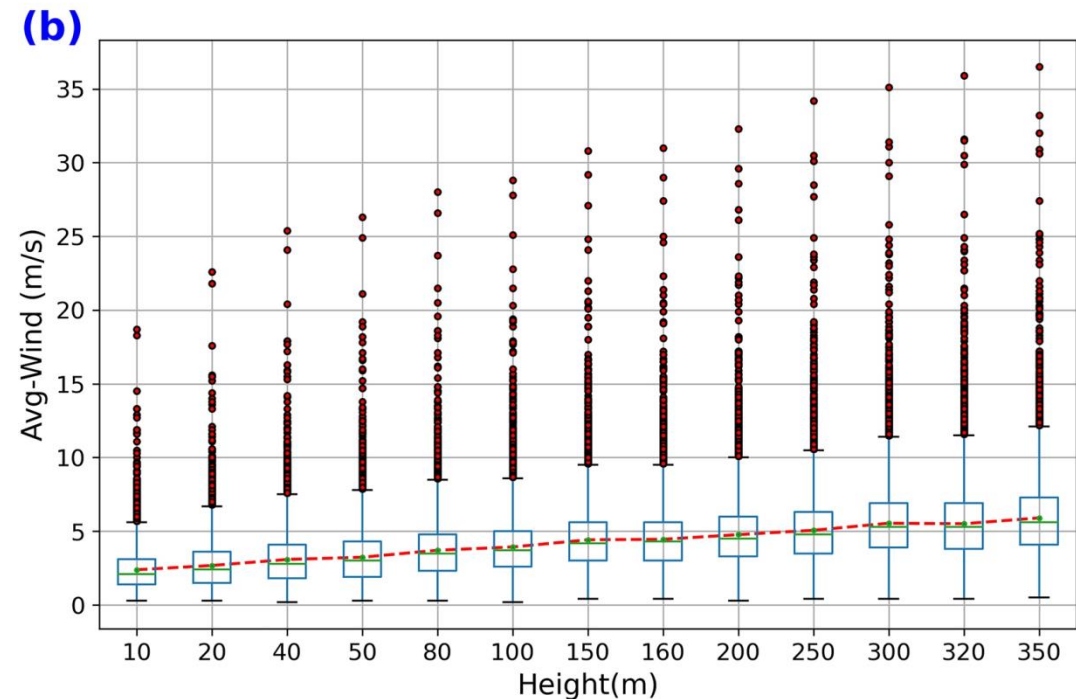
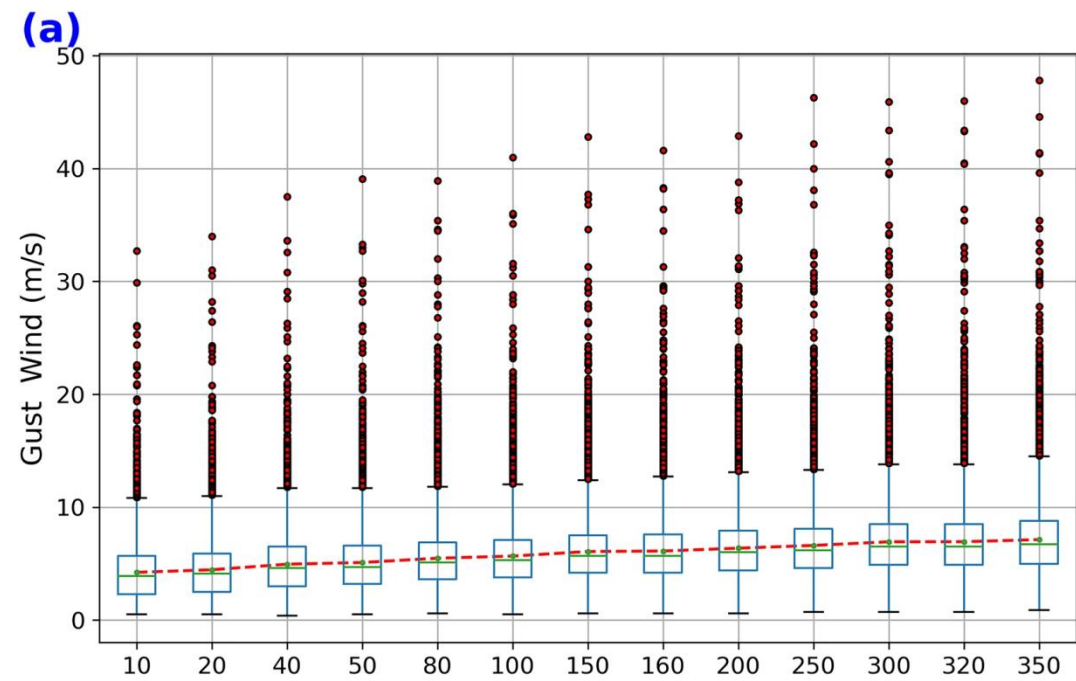
https://en.wikipedia.org/wiki/Wind_gradient



Results and Discussions

Boxplots of the wind observations at the 13 stations on Shenzhen Meteorological Tower from 1 October 2016 to 1 January 2020.

(a) for gust wind speed; (b) for avg-wind speed. For each subplot, the means (**medians**) of the wind samples at different height levels are marked by **green dots (lines)** in the interquartile box, and the **mean values** at different heights are connected by **red dash lines**.





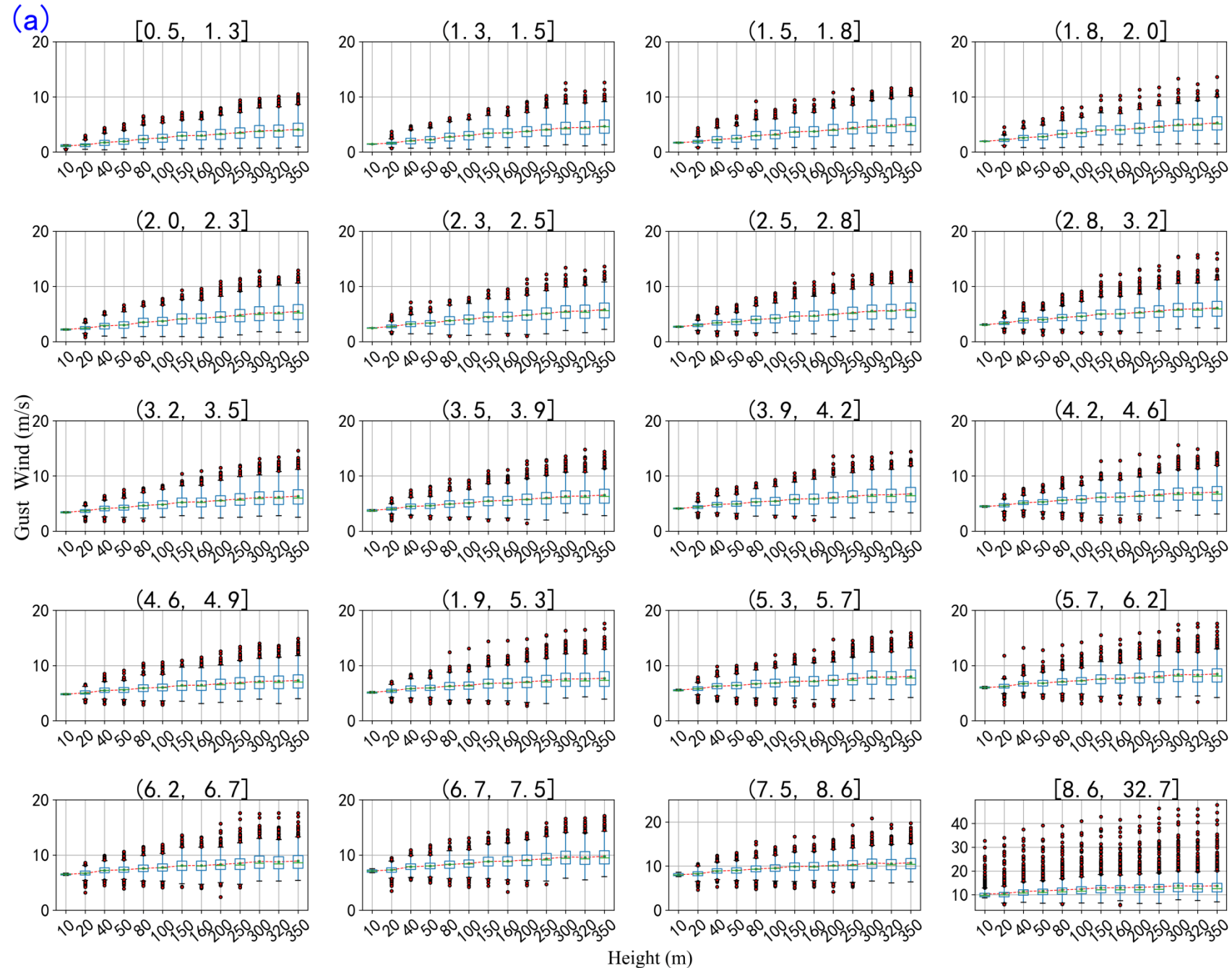
Results and Discussions (rural area)

Information of sample numbers in different percentile groups of wind speeds and for different seasons based on the G1101 station.

Approximate Percentile range	Gust wind				Avg-wind			
	Wind speed ranges (ms ⁻¹)	Sample size for different ranges			Wind speed ranges (ms ⁻¹)	Sample size for different ranges		
		Sub-total	Apr-Aug	Sep-Mar		Sub-total	Apr-Aug	Sep-Mar
0%-5%	[0.5, 1.3]	1389	411	978	[0.3, 0.8]	1505	347	1158
5%-10%	(1.3, 1.5]	882	295	587	(0.8, 1.0]	1491	429	1062
10%-15%	(1.5, 1.8]	1416	504	912	(1.0, 1.1]	797	245	552
15%-20%	(1.8, 2.0]	901	350	551	(1.1, 1.3]	1516	454	1062
20%-25%	(2.0, 2.3]	1251	443	808	(1.3, 1.4]	879	278	601
25%-30%	(2.3, 2.5]	760	278	482	(1.4, 1.5]	852	289	563
30%-35%	(2.5, 2.8]	1055	398	657	(1.5, 1.7]	1608	534	1074
35%-40%	(2.8, 3.2]	1378	508	870	(1.7, 1.8]	828	283	545
40%-45%	(3.2, 3.5]	940	378	562	(1.8, 2.0]	1470	481	989
45%-50%	(3.5, 3.9]	1220	497	723	(2.0, 2.1]	654	239	415
50%-55%	(3.9, 4.2]	955	408	547	(2.1, 2.3]	1266	468	798
55%-60%	(4.2, 4.6]	1278	536	742	(2.3, 2.5]	1233	456	777
60%-65%	(4.6, 4.9]	892	375	517	(2.5, 2.7]	1089	455	634
65%-70%	(4.9, 5.3]	1104	480	624	(2.7, 2.9]	1076	476	600
70%-75%	(5.3, 5.7]	1066	508	558	(2.9, 3.2]	1373	644	729
75%-80%	(5.7, 6.2]	1146	535	611	(3.2, 3.5]	1219	684	535
80%-85%	(6.2, 6.7]	964	462	502	(3.5, 3.8]	906	524	382
85%-90%	(6.7, 7.5]	1141	572	569	(3.8, 4.3]	1240	775	465
90%-95%	(7.5, 8.6]	1032	547	485	(4.3, 4.9]	1021	714	307
95%-100%	(8.6, 32.7]	1071	581	490	(4.9, 18.7]	1152	881	271
Total Range	[0.5, 32.7]	21841	9066	12775	[0.3, 18.7]	23175	9656	13519



Results and Discussions



Boxplots of the different wind range groups at the 13 instrumented booms on Shenzhen Meteorological Gradient Tower (rural area).

(a) for gust wind speed; (b) for avg-wind speed.

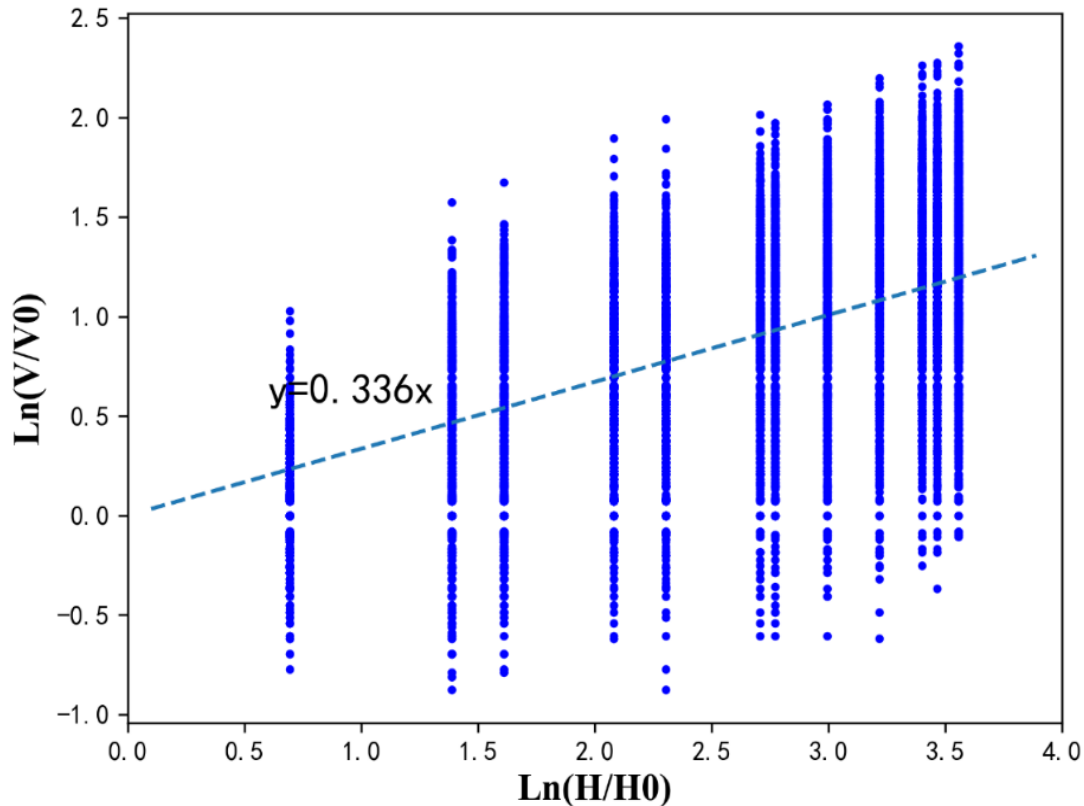
For each subplot, the means (medians) of the wind samples at different height levels are marked by green dots (lines) in the interquartile box, and the mean values at different heights are connected by red dash lines.



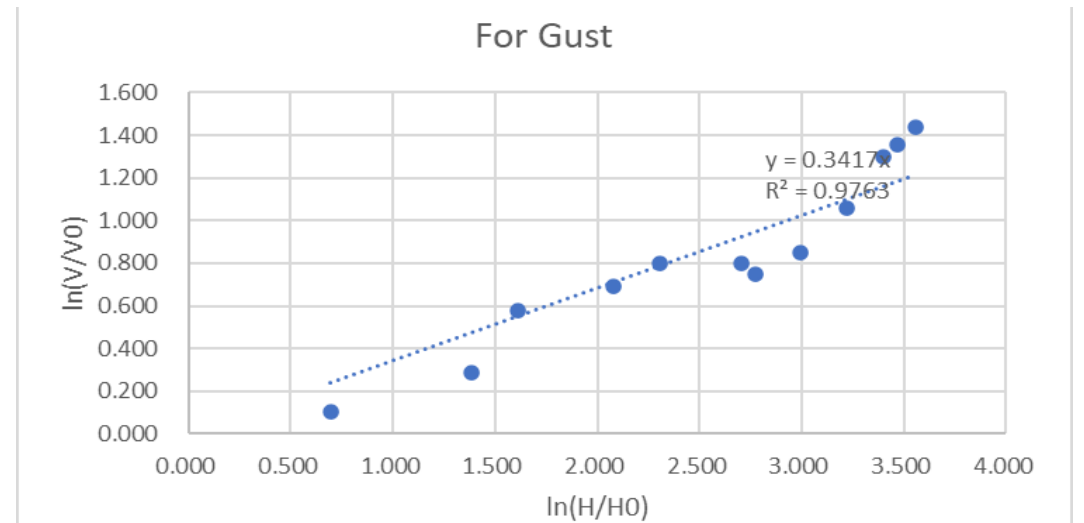
Results and Discussions

Approximate Percentile range	Gust wind	
	Wind speed ranges (ms ⁻¹)	Sample size / Sub-total
0%-5%	[0.5, 1.3]	1389

$$\alpha = \frac{\lg(V/V_0)}{\lg(H/H_0)}$$



Stations Name	Height above ground (m)	Gust (m/s)	Awind (m/s)	H/H0	Gust V/V0	ln(H/H0)	ln(V/V0)
Tower F1	10	0.9	0.5				
Tower F2	20	1	0.5	2	1.111	0.693	0.105
Tower F3	40	1.2	0.9	4	1.333	1.386	0.288
Tower F4	50	1.6	1.1	5	1.778	1.609	0.575
Tower F5	80	1.8	1.6	8	2.000	2.079	0.693
Tower F6	100	2	1.8	10	2.222	2.303	0.799
Tower F7	150	2	1.7	15	2.222	2.708	0.799
Tower F8	160	1.9	1.7	16	2.111	2.773	0.747
Tower F9	200	2.1	1.9	20	2.333	2.996	0.847
Tower F10	250	2.6	2.3	25	2.889	3.219	1.061
Tower F11	300	3.3	3.1	30	3.667	3.401	1.299
Tower F12	320	3.5	3.2	32	3.889	3.466	1.358
Tower F13	350	3.8	3.5	35	4.222	3.555	1.440





Results and Discussions (rural area)

The fitted Hellman coefficients for the different wind ranges' conditions based on the wind observations at the G1101 station.

Approximate Percentile range	Gust wind				Avg-wind			
	Wind speed ranges (ms ⁻¹)	α for different speed ranges			Wind speed ranges (ms ⁻¹)	α for different speed ranges		
		Sub-group	Apr-Aug	Sep-Mar		Sub-group	Apr-Aug	Sep-Mar
0%-5%	[0.5, 1.3]	0.336	0.336	0.336	[0.3, 0.8]	0.491	0.465	0.498
5%-10%	(1.3, 1.5]	0.293	0.285	0.298	(0.8, 1.0]	0.387	0.377	0.391
10%-15%	(1.5, 1.8]	0.265	0.265	0.265	(1.0, 1.1]	0.335	0.328	0.339
15%-20%	(1.8, 2.0]	0.248	0.246	0.250	(1.1, 1.3]	0.306	0.311	0.303
20%-25%	(2.0, 2.3]	0.221	0.219	0.222	(1.3, 1.4]	0.279	0.294	0.273
25%-30%	(2.3, 2.5]	0.211	0.212	0.210	(1.4, 1.5]	0.276	0.274	0.276
30%-35%	(2.5, 2.8]	0.188	0.187	0.189	(1.5, 1.7]	0.246	0.261	0.239
35%-40%	(2.8, 3.2]	0.173	0.175	0.172	(1.7, 1.8]	0.232	0.243	0.226
40%-45%	(3.2, 3.5]	0.154	0.161	0.148	(1.8, 2.0]	0.218	0.233	0.211
45%-50%	(3.5, 3.9]	0.136	0.140	0.134	(2.0, 2.1]	0.211	0.236	0.198
50%-55%	(3.9, 4.2]	0.124	0.131	0.119	(2.1, 2.3]	0.198	0.217	0.187
55%-60%	(4.2, 4.6]	0.114	0.121	0.109	(2.3, 2.5]	0.191	0.209	0.181
60%-65%	(4.6, 4.9]	0.103	0.110	0.0983	(2.5, 2.7]	0.192	0.207	0.180
65%-70%	(4.9, 5.3]	0.0988	0.101	0.0968	(2.7, 2.9]	0.175	0.187	0.165
70%-75%	(5.3, 5.7]	0.0909	0.093	0.089	(2.9, 3.2]	0.167	0.179	0.156
75%-80%	(5.7, 6.2]	0.085	0.0863	0.0838	(3.2, 3.5]	0.166	0.173	0.158
80%-85%	(6.2, 6.7]	0.0787	0.0821	0.0756	(3.5, 3.8]	0.160	0.163	0.156
85%-90%	(6.7, 7.5]	0.0792	0.0823	0.0761	(3.8, 4.3]	0.152	0.155	0.147
90%-95%	(7.5, 8.6]	0.0738	0.0744	0.0732	(4.3, 4.9]	0.151	0.152	0.147
95%-100%	(8.6, 32.7]	0.0755	0.0758	0.0751	(4.9, 18.7]	0.150	0.148	0.157

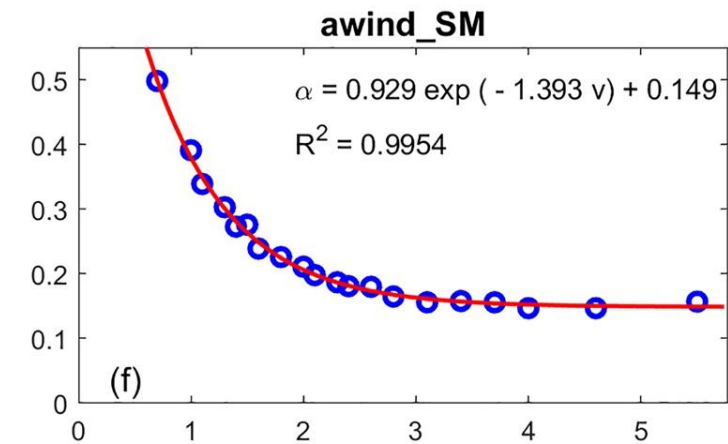
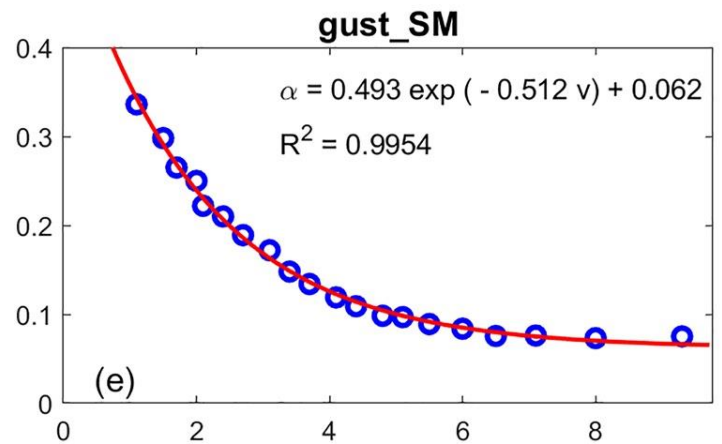
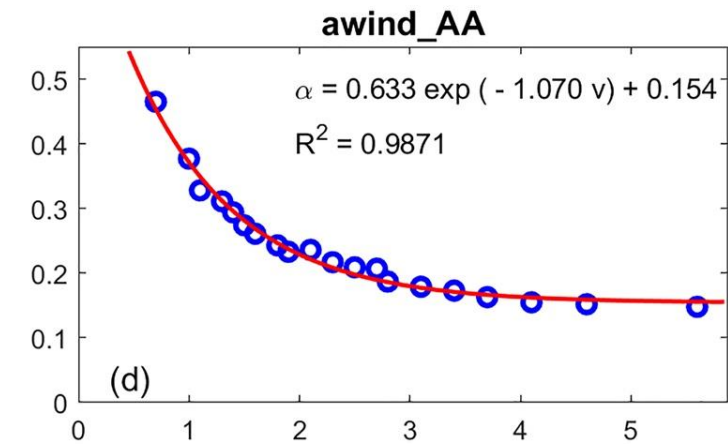
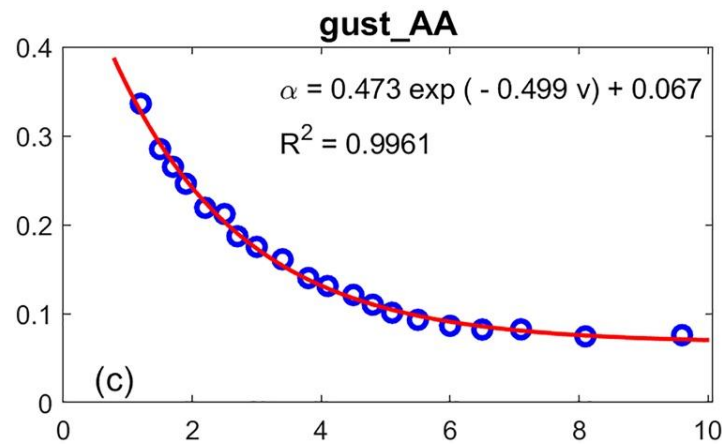
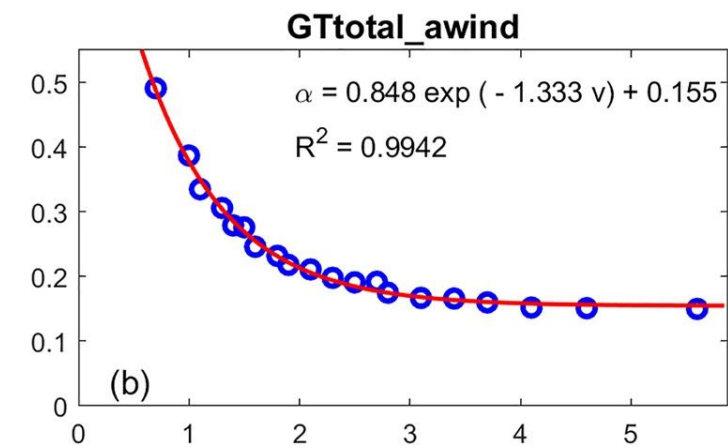
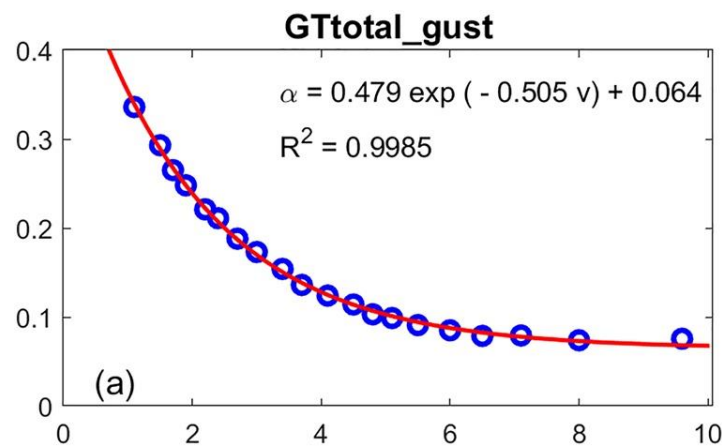


Results and Discussions

(rural area)

Fitting curve between the Hellman coefficients and the wind speeds on Shenzhen Meteorological Gradient Tower (GT) from 1 October 2016 to 1 January 2020

Vertical variation characteristics of Wind Speed in rural areas



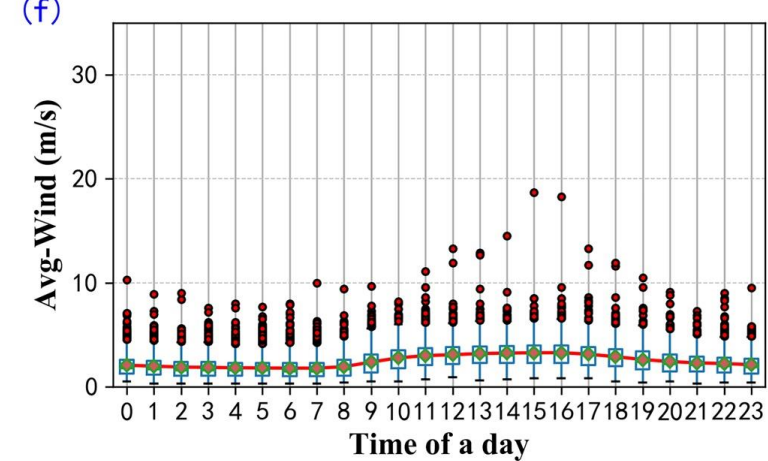
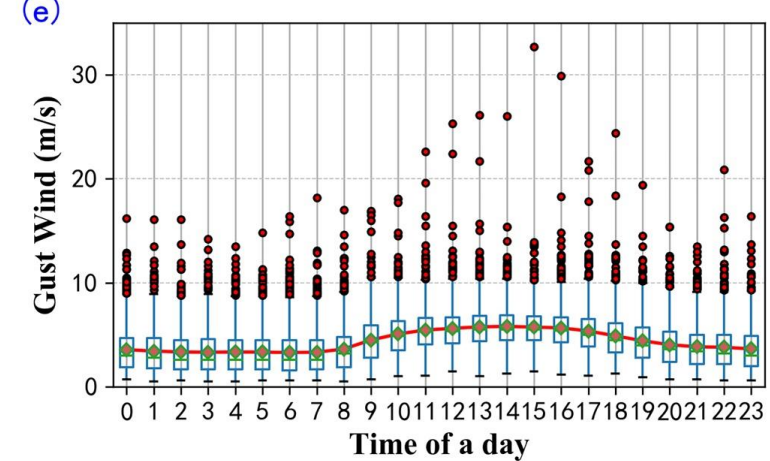
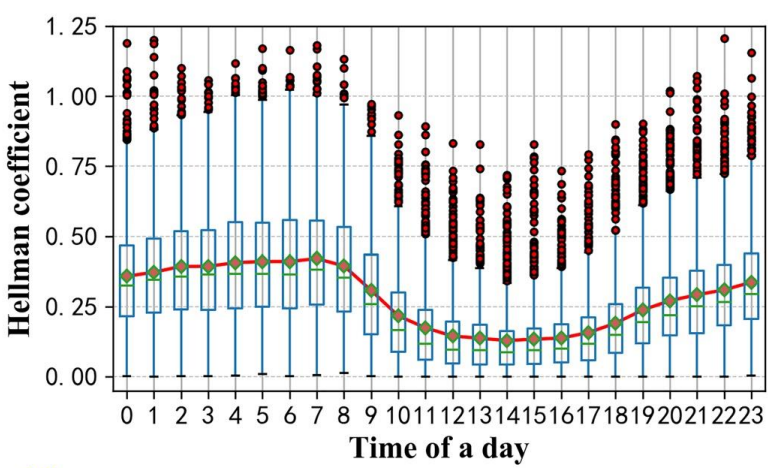
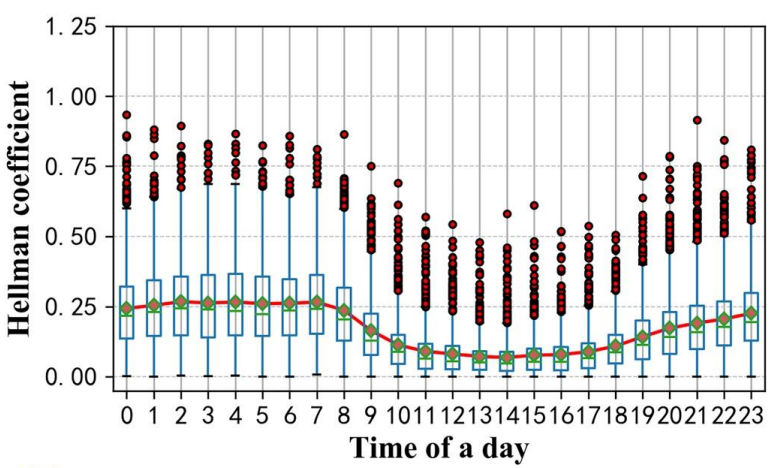
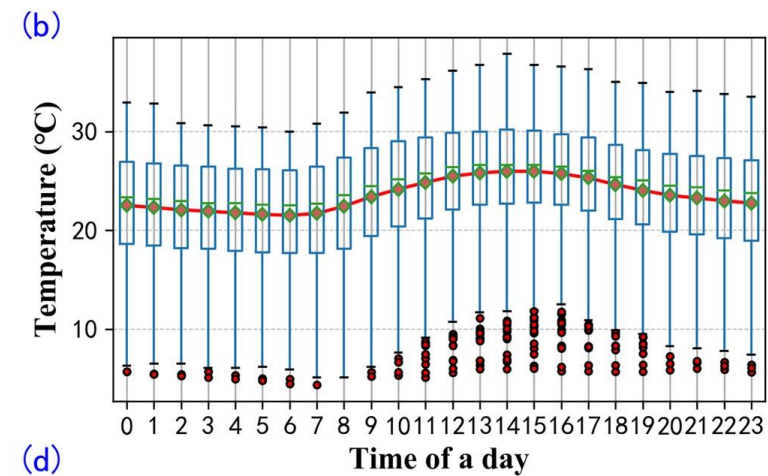
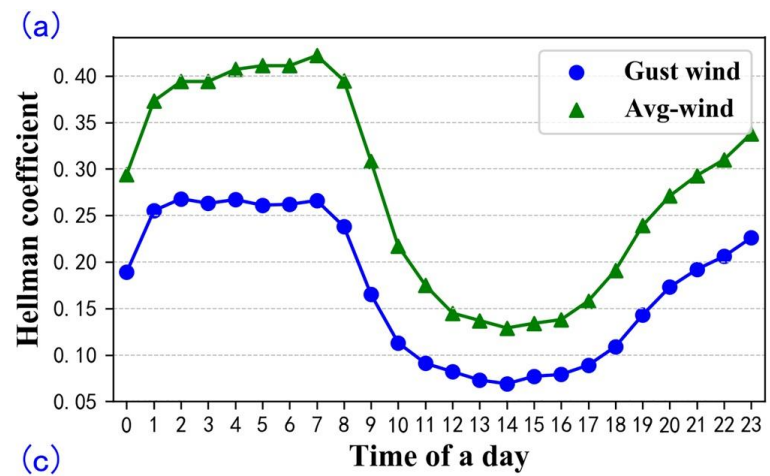


Results and Discussions

(rural area)

Diurnal variation characteristics of the vertical wind speeds over the rural area (a) the mean Hellman coefficient, (b) 10 m Temperature, (c) detailed Hellman coefficients for gust wind, (d) detailed Hellman coefficients for avg-wind (e) gust wind speeds at the G1101 station, and (f) avg-wind speeds at the G1101 station.

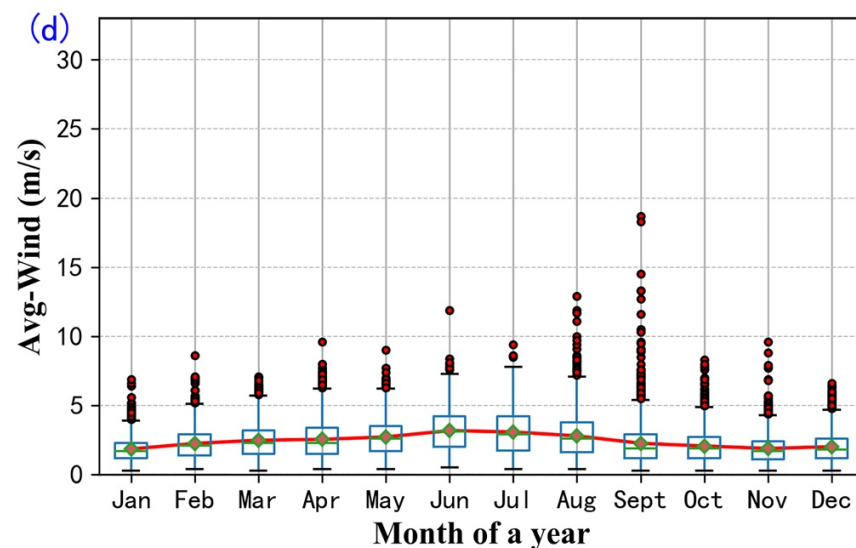
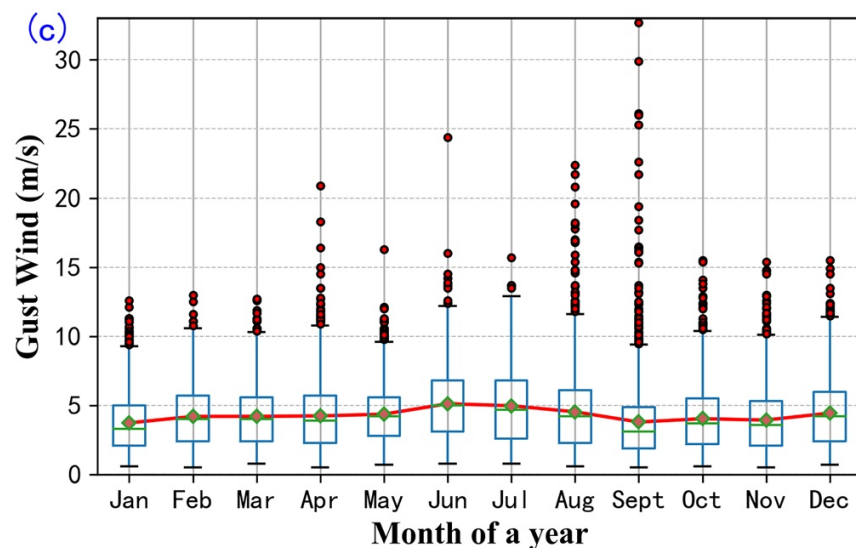
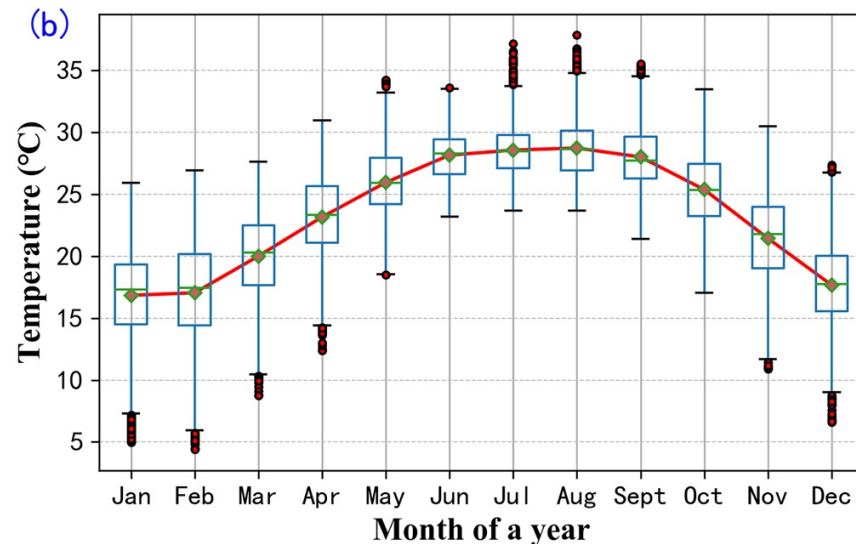
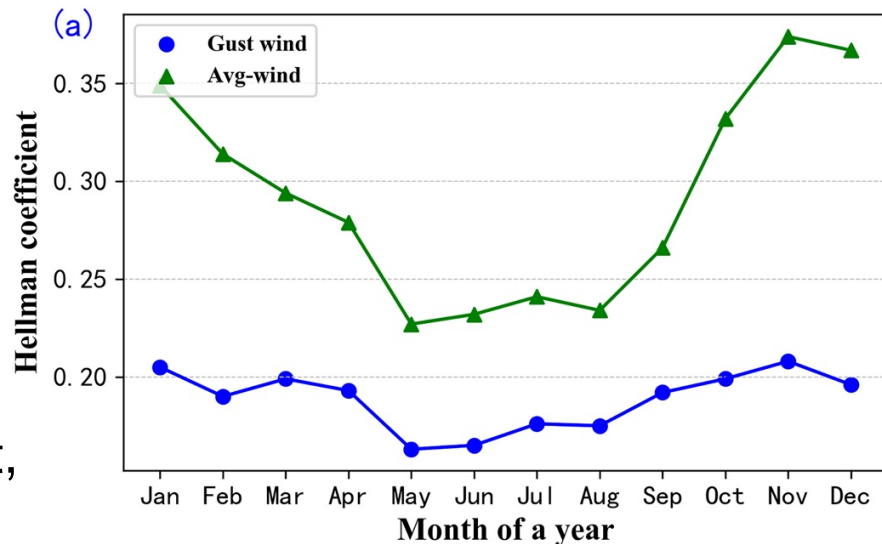
The diurnal variation of the Hellman coefficient values is almost opposite to the diurnal temperature change. The correlation between the two variables is -0.980 for the gust wind and -0.985 for the avg-wind.





Results and Discussions (rural area)

Monthly mean of the vertical variation characteristics of the wind speeds over the rural area (a) the mean Hellman coefficient, (b) 10 m Temperature, (c) gust wind speeds at the G1101 station, and (d) avg-wind speeds at the G1101 station.





Results and Discussions (urban area)

Approximate Percentile range	Gust wind				Avg-wind			
	Wind speed ranges (ms ⁻¹)	Sample size for different ranges			Wind speed ranges (ms ⁻¹)	Sample size for different ranges		
		Sub-total	Apr-Aug	Sep-Mar		Sub-total	Apr-Aug	Sep-Mar
0%-5%	[0.3, 1.0]	1267	422	845	[0.2, 0.4]	1311	477	834
5%-10%	(1.0, 1.3]	903	383	520	(0.4, 0.5]	921	406	515
10%-15%	(1.3, 1.6]	1016	495	521	(0.5, 0.6]	1112	570	542
15%-20%	(1.6, 1.9]	1137	567	570	(0.6, 0.7]	1111	576	535
20%-25%	(1.9, 2.2]	1367	664	703	(0.7, 0.8]	1358	765	593
25%-30%	(2.2, 2.4]	1027	493	534	(0.8, 0.9]	1414	715	699
30%-35%	(2.4, 2.6]	1080	451	629	(0.9, 1.0]	1576	733	843
35%-40%	(2.6, 2.8]	1154	490	664	(1.0, 1.0]	0	0	0
40%-45%	(2.8, 3.0]	1146	497	649	(1.0, 1.1]	1631	705	926
45%-50%	(3.0, 3.1]	590	265	325	(1.1, 1.2]	1546	634	912
50%-55%	(3.1, 3.3]	1159	449	710	(1.2, 1.3]	0	0	0
55%-60%	(3.3, 3.5]	1157	399	758	(1.3, 1.3]	1654	592	1062
60%-65%	(3.5, 3.7]	1064	404	660	(1.3, 1.4]	1504	514	990
65%-70%	(3.7, 3.9]	990	334	656	(1.4, 1.5]	1218	377	841
70%-75%	(3.9, 4.1]	916	280	636	(1.5, 1.5]	0	0	0
75%-80%	(4.1, 4.4]	1224	378	846	(1.5, 1.6]	1121	326	795
80%-85%	(4.4, 4.7]	1008	295	713	(1.6, 1.8]	1626	345	1281
85%-90%	(4.7, 5.1]	994	288	706	(1.8, 1.9]	649	128	521
90%-95%	(5.1, 5.8]	1028	278	750	(1.9, 2.1]	1167	234	933
95%-100%	(5.8, 20.8]	941	239	702	(2.1, 6.8]	819	140	679
Total Range	[0.3, 20.8]	21168	8071	13097	[0.2, 6.8]	21738	8237	13501

Information of Sample Numbers in Different Percentile Groups of Wind Speeds and for Different Seasons Based at the ground Station



Results and Discussions (urban area)

The Fitted Hellman Coefficients for the Different Wind Ranges' Conditions Based on the Wind Observations at the Central Park

Approximate Percentile range	Gust wind				Avg-wind			
	Wind speed ranges (ms ⁻¹)	α for different speed ranges			Wind speed ranges (ms ⁻¹)	α for different speed ranges		
		Sub-group	Apr-Aug	Sep-Mar		Sub-group	Apr-Aug	Sep-Mar
0%-5%	[0.3, 1.0]	0.487	0.466	0.498	[0.2, 0.4]	0.640	0.606	0.660
5%-10%	(1.0, 1.3]	0.385	0.381	0.389	(0.4, 0.5]	0.550	0.543	0.556
10%-15%	(1.3, 1.6]	0.342	0.334	0.350	(0.5, 0.6]	0.532	0.519	0.546
15%-20%	(1.6, 1.9]	0.294	0.298	0.291	(0.6, 0.7]	0.489	0.489	0.489
20%-25%	(1.9, 2.2]	0.258	0.262	0.254	(0.7, 0.8]	0.459	0.452	0.468
25%-30%	(2.2, 2.4]	0.236	0.242	0.230	(0.8, 0.9]	0.427	0.418	0.435
30%-35%	(2.4, 2.6]	0.22	0.210	0.227	(0.9, 1.0]	0.396	0.386	0.405
35%-40%	(2.6, 2.8]	0.211	0.216	0.208	(1.0, 1.0]	0.388	0.374	0.403
40%-45%	(2.8, 3.0]	0.196	0.194	0.197	(1.0, 1.1]	0.382	0.362	0.398
45%-50%	(3.0, 3.1]	0.191	0.178	0.195	(1.1, 1.2]	0.365	0.349	0.376
50%-55%	(3.1, 3.3]	0.178	0.176	0.179	(1.2, 1.3]	0.352	0.345	0.367
55%-60%	(3.3, 3.5]	0.177	0.167	0.178	(1.3, 1.3]	0.349	0.341	0.358
60%-65%	(3.5, 3.7]	0.168	0.165	0.173	(1.3, 1.4]	0.345	0.339	0.348
65%-70%	(3.7, 3.9]	0.166	0.169	0.165	(1.4, 1.5]	0.324	0.311	0.330
70%-75%	(3.9, 4.1]	0.164	0.165	0.160	(1.5, 1.5]	0.319	0.310	0.327
75%-80%	(4.1, 4.4]	0.176	0.176	0.177	(1.5, 1.6]	0.316	0.305	0.324
80%-85%	(4.4, 4.7]	0.171	0.165	0.174	(1.6, 1.8]	0.324	0.320	0.326
85%-90%	(4.7, 5.1]	0.167	0.168	0.167	(1.8, 1.9]	0.330	0.347	0.325
90%-95%	(5.1, 5.8]	0.169	0.164	0.171	(1.9, 2.1]	0.324	0.333	0.322
95%-100%	(5.8, 20.8]	0.170	0.169	0.170	(2.1, 6.8]	0.329	0.352	0.324

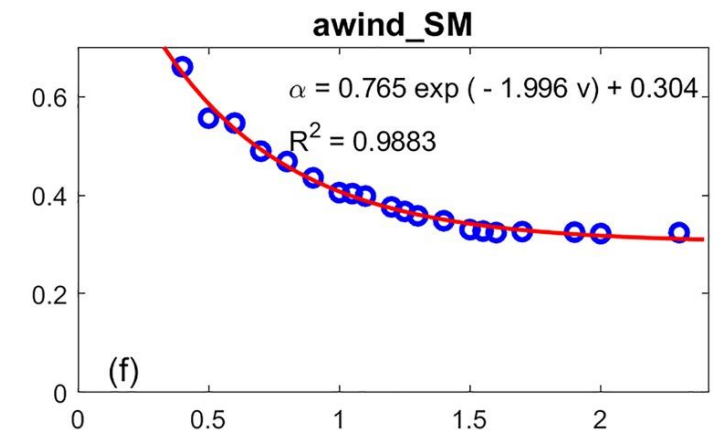
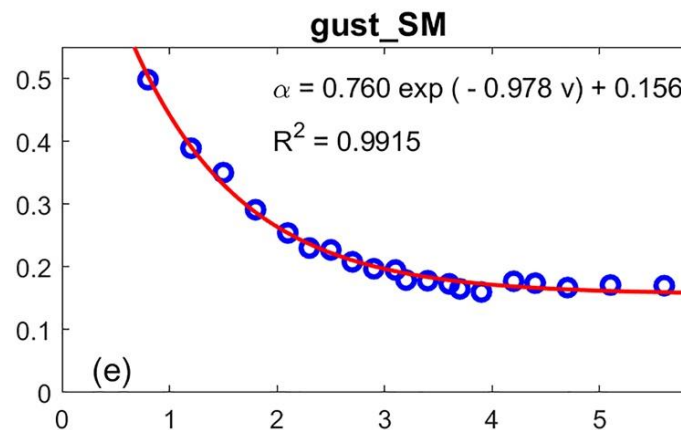
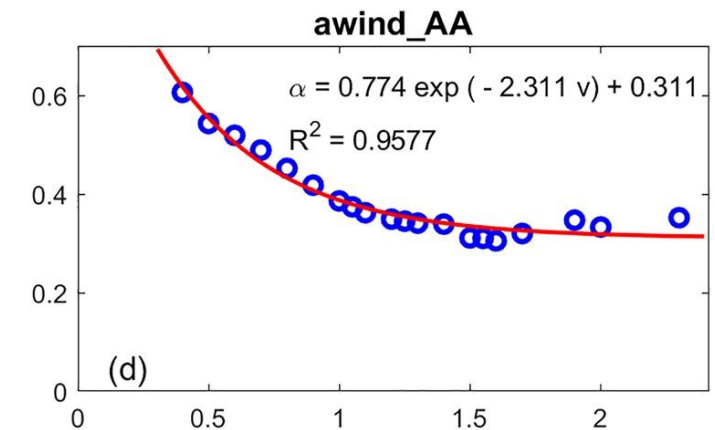
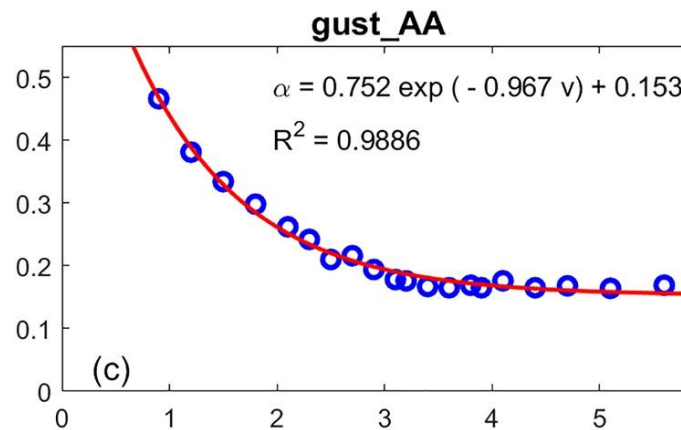
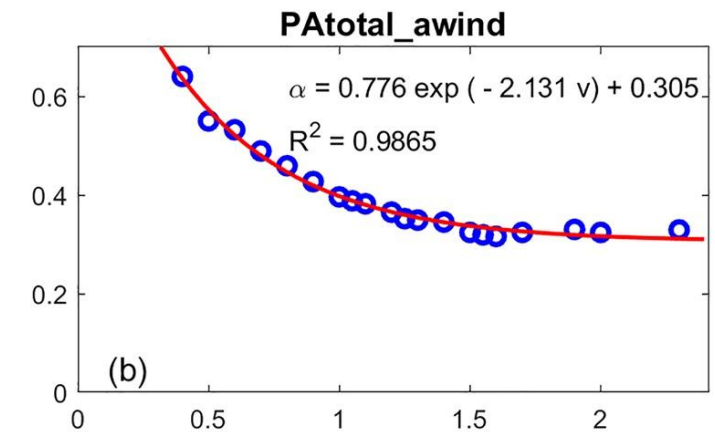
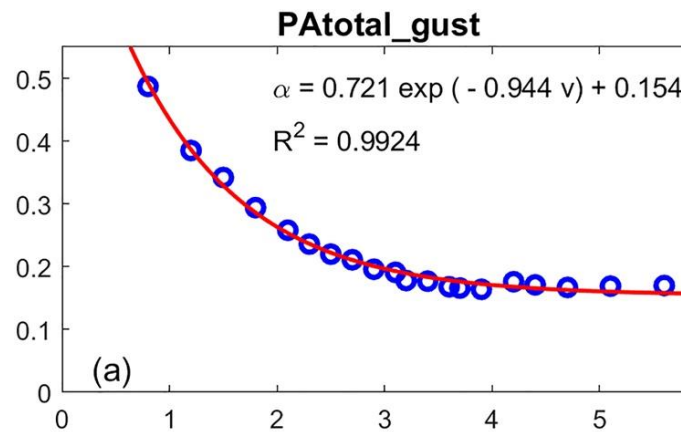


Results and Discussions

(urban area)

Fitting curve between the Hellman coefficients and the wind speeds based on the Central Park station and Ping An Building Station from August 2018 to January 2021

Vertical variation characteristics of Wind Speed in urban areas



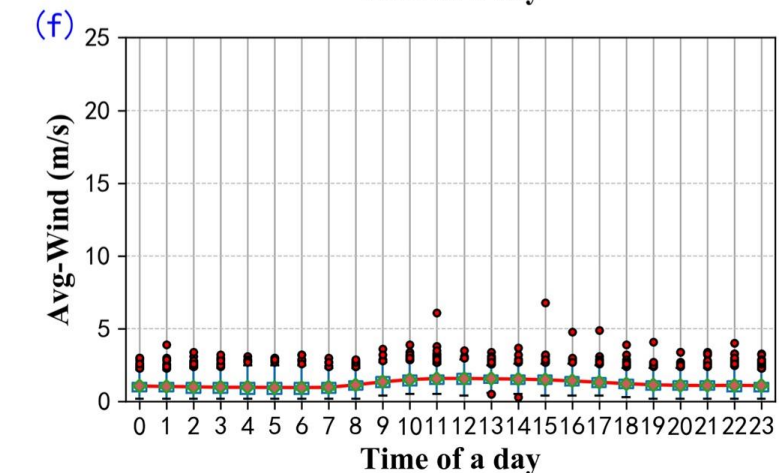
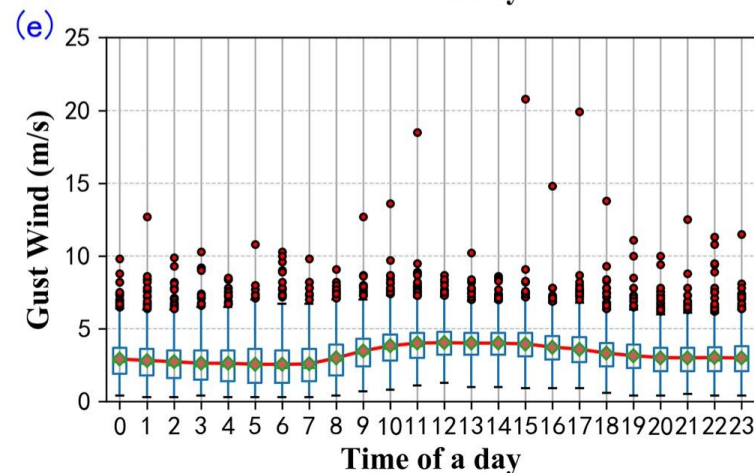
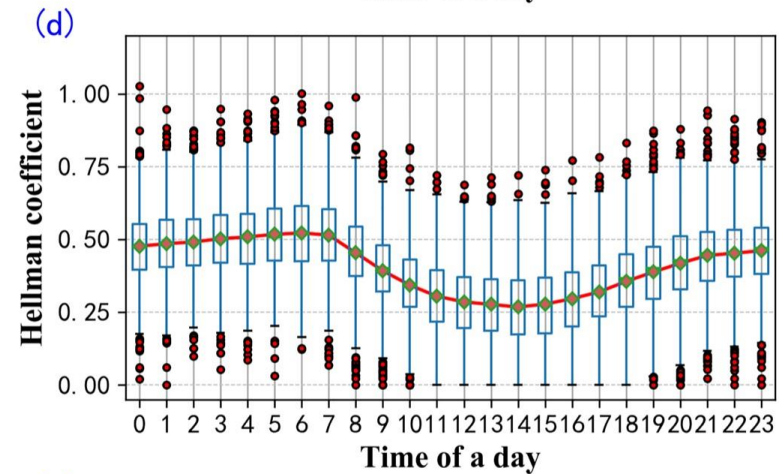
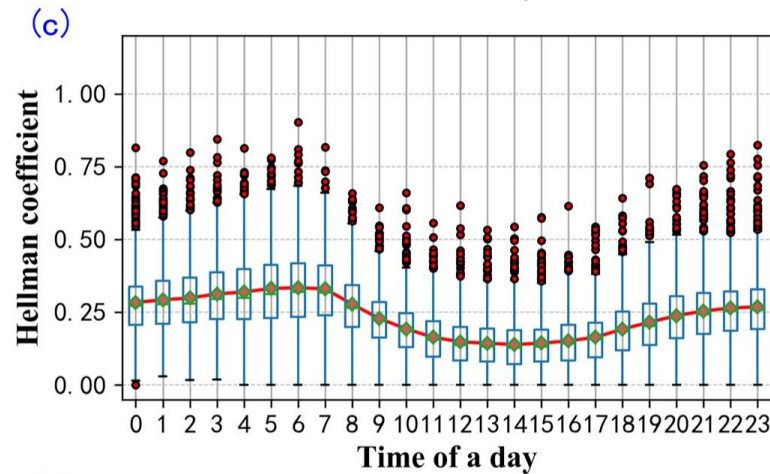
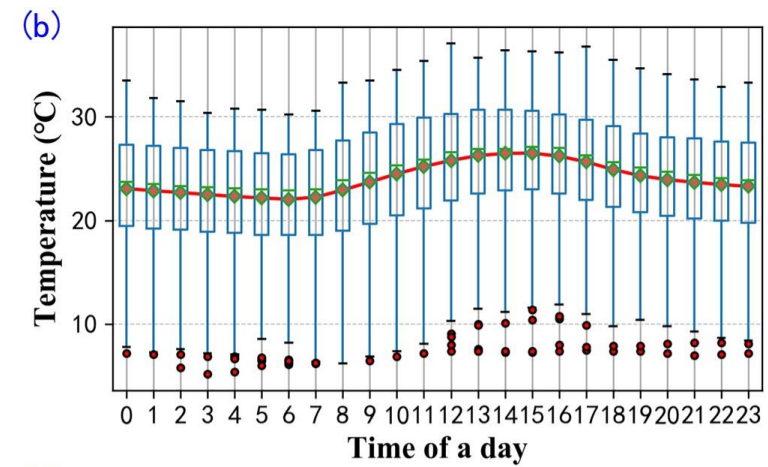
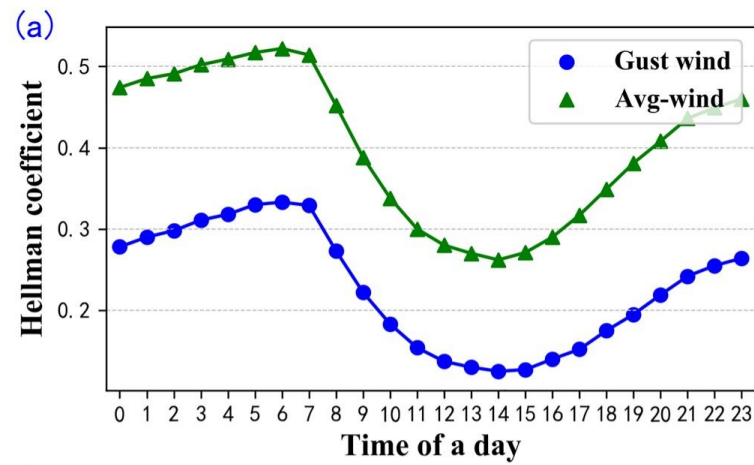


Results and Discussions

(urban area)

Diurnal variation characteristics of the vertical wind speeds over the urban area (a) the mean Hellman coefficient, (b) 14 m Temperature, (c) detailed Hellman coefficients for gust wind, (d) detailed Hellman coefficients for avg-wind (e) gust wind speeds at the G3773 station, and (d) avg-wind speeds at the G3773 station.

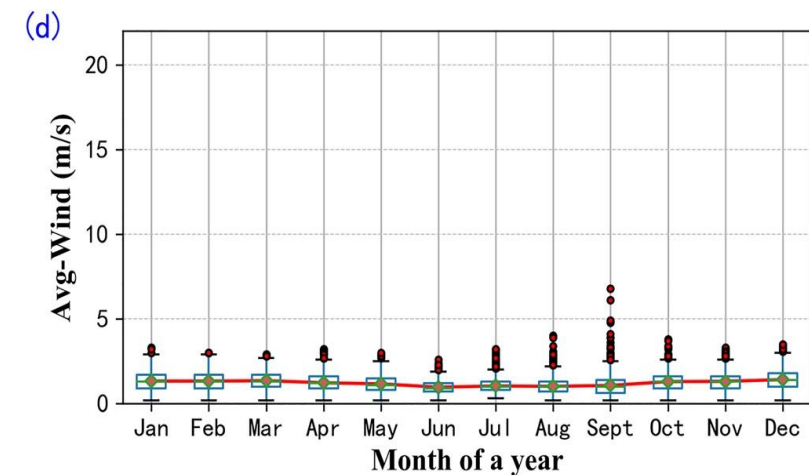
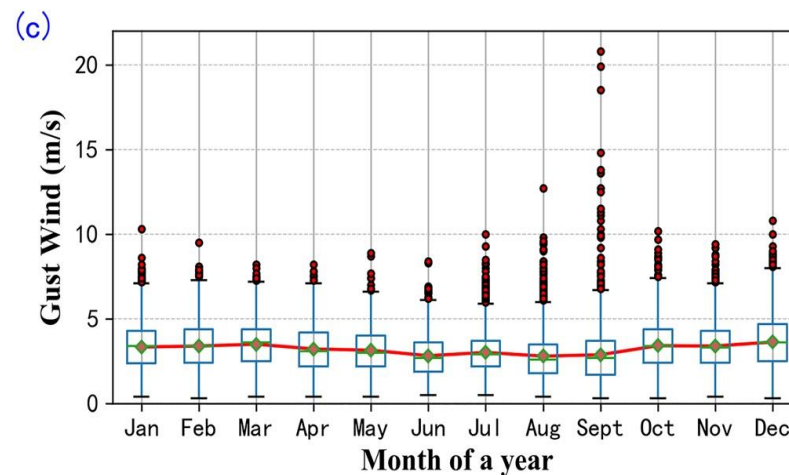
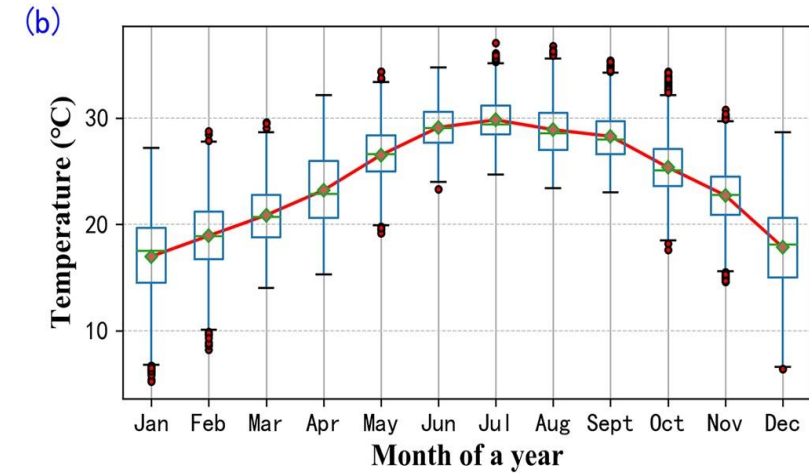
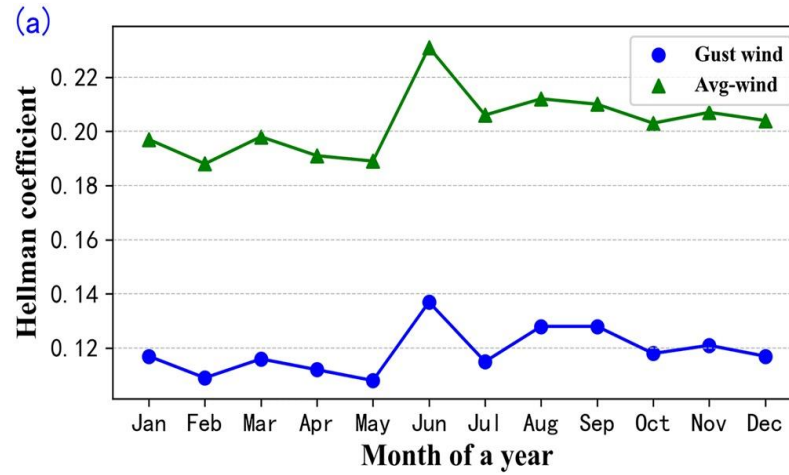
Similar to the rural open flat area, the winds tend to be larger during the daytime than the winds during the nighttime, corresponding to a lower Hellman coefficient during the daytime and a higher Hellman coefficient during the nighttime.





Results and Discussions (urban area)

Monthly variation characteristics of the vertical wind speeds over the urban area (a) Hellman coefficient, (b) 14 m Temperature, (c) gust wind speeds at the G3773 station, and (d) avg-wind speeds at the G3773 station.



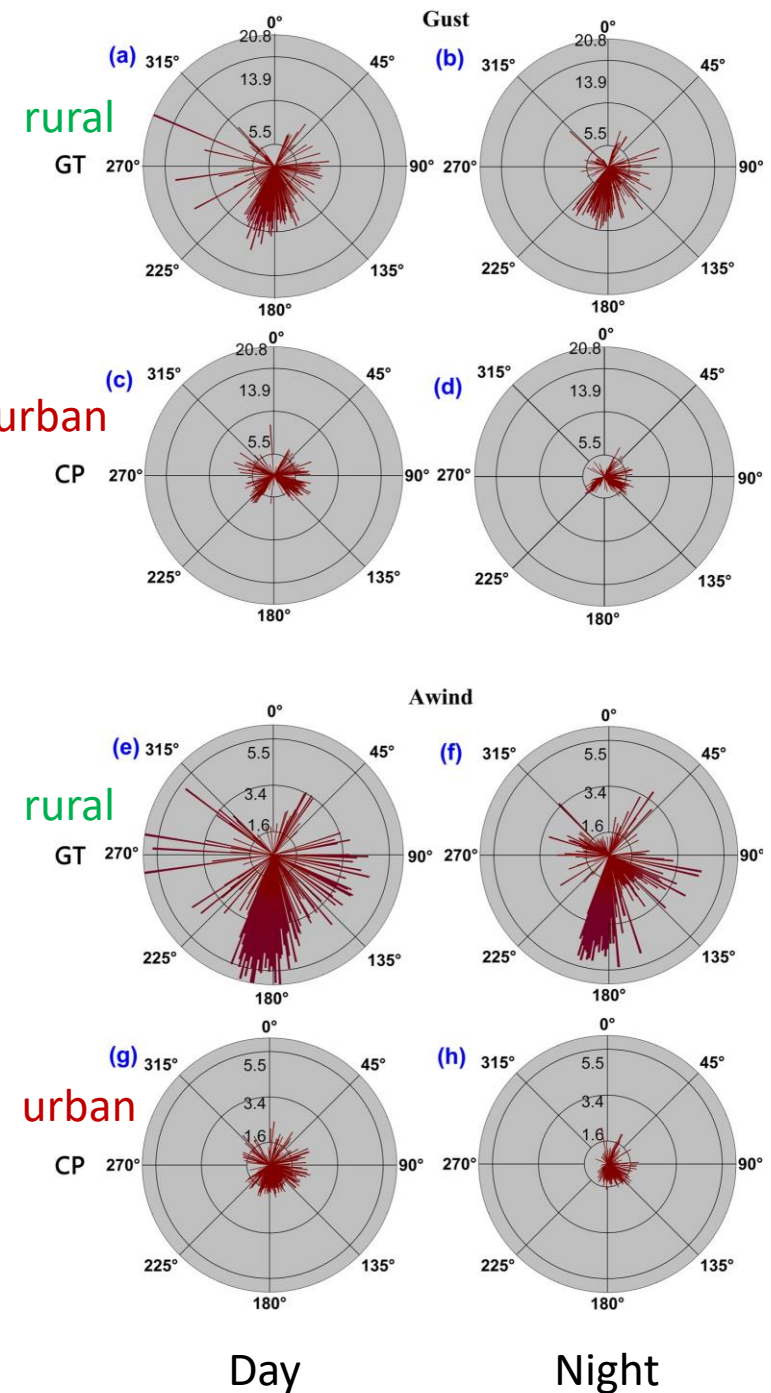


Results and Discussions

The Statistics Properties of the Monthly Gust Wind and Avg-Wind at G1101 (GT) and G3773 (CP) During the Daytime and Nighttime in June

Station	Item	Gust_day	Gust_night	Awind_day	Awind_night
Gradient Tower (rural)	Mean Wind	6.418	4.301	4.004	2.696
	Southerly	86.50%	78.48%	87.84%	80.55%
	Northerly	13.50%	21.52%	12.16%	19.45%
Central Park (urban)	Mean Wind	3.482	2.211	1.225	0.785
	Southerly	75.08%	78.72%	78.66%	82.12%
	Northerly	24.92%	21.28%	21.34%	17.88%
	Wind _{CP} / Wind _{GT}	0.543	0.514	0.306	0.291

The wind rose diagrams for the gust wind (a–d) and avg-wind (e–h) observed at the Gradient Tower (GT, G1101) station and Central Park (CP, G3773) station during the daytime and nighttime in June.

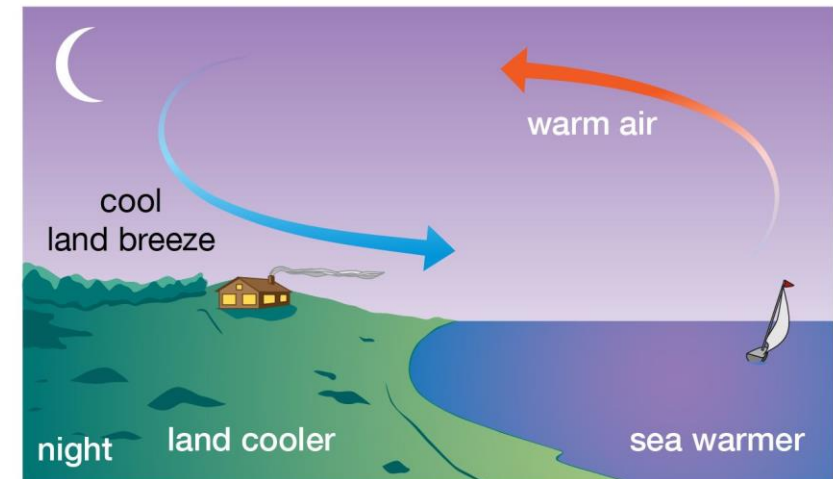
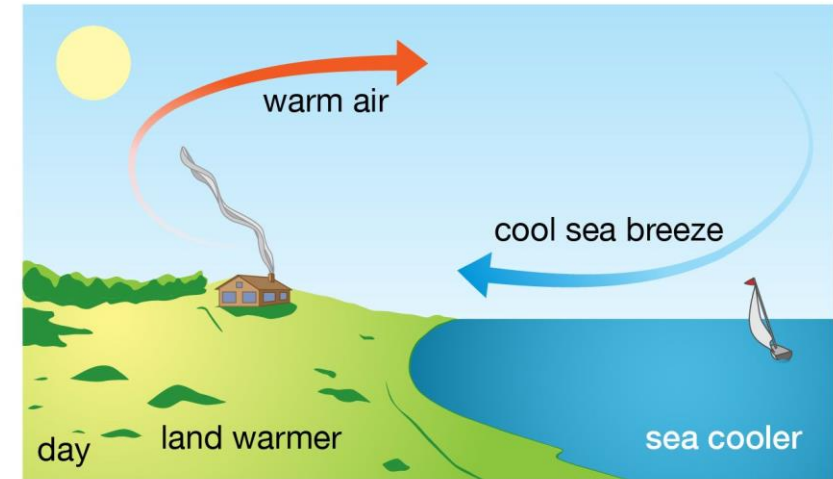




Results and Discussions

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Conclusions

- 风速通常随着高度的增加而增加，遵循**power law function**.
- 阵风和平均风的**Hellman**系数值随着风速的增加而减小，服从相对于风速的**exponential decay function**
- 当风达到高百分位水平（即 80% 左右）时，**Hellman**系数几乎保持恒定。
- 城市地区**Hellman**系数大于郊区，平均风速大于阵风风速。
- 郊区和城市地区的**Hellman**系数存在明显的日变化。通常在下午 2 点至 3 点左右达到最低值，此时是每日最高气温，并在早上 6 点至 7 点达到最高值，此时是每日最低气温。
- **Hellman**系数的月变化在深圳城市区域不明显，这可能与深圳的城市热岛效应有关。



中国科学院深圳先进技术研究院
SHENZHEN INSTITUTES OF ADVANCED TECHNOLOGY
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Wu, Y., Li, Q.*, Li, G., He, B., Dong, L., Lan, H., et al. (2022). Vertical wind speed variation in a metropolitan city in South China. *Earth and Space Science*, 9, e2021EA002095. <https://doi.org/10.1029/2021EA002095>

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