

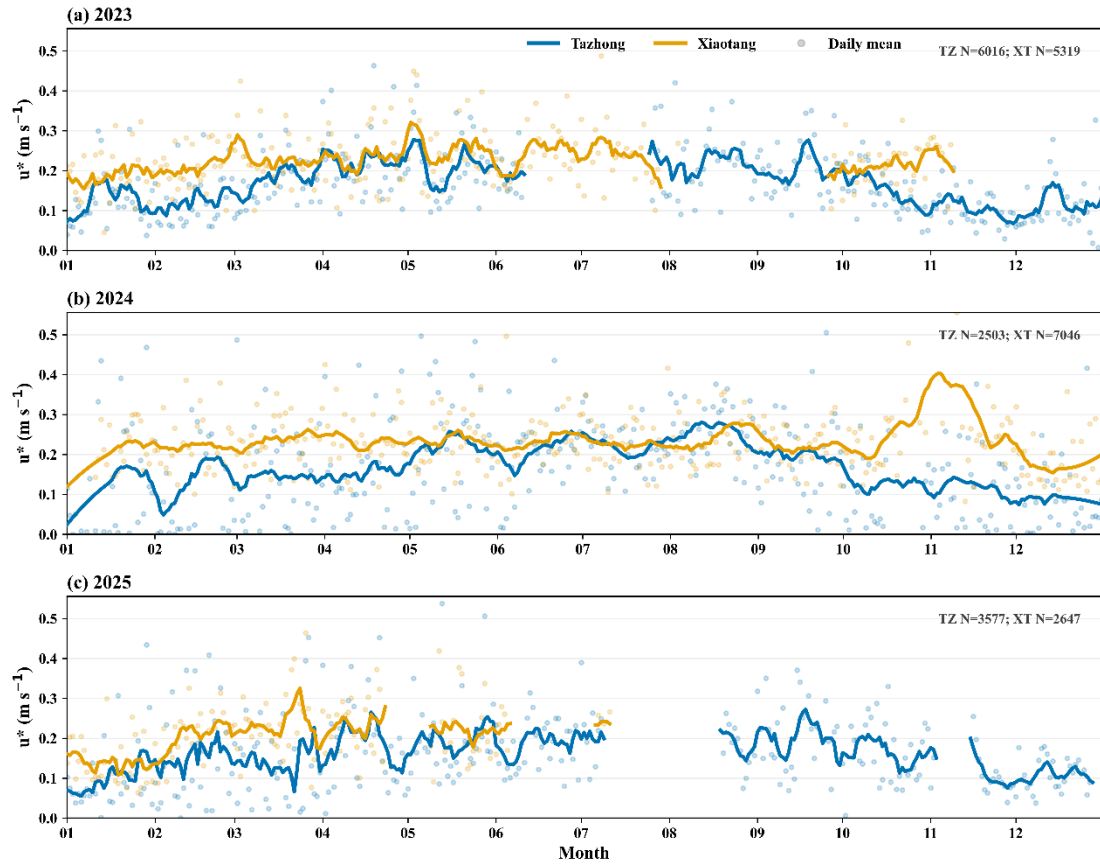


Figure S1. Daily friction-velocity variations at Tazhong (TZ) and Xiaotang (XT), with smoothed seasonal trends, 2023-2025.

H01 fitted roughness length z_0 diagnostics | March–July 2024

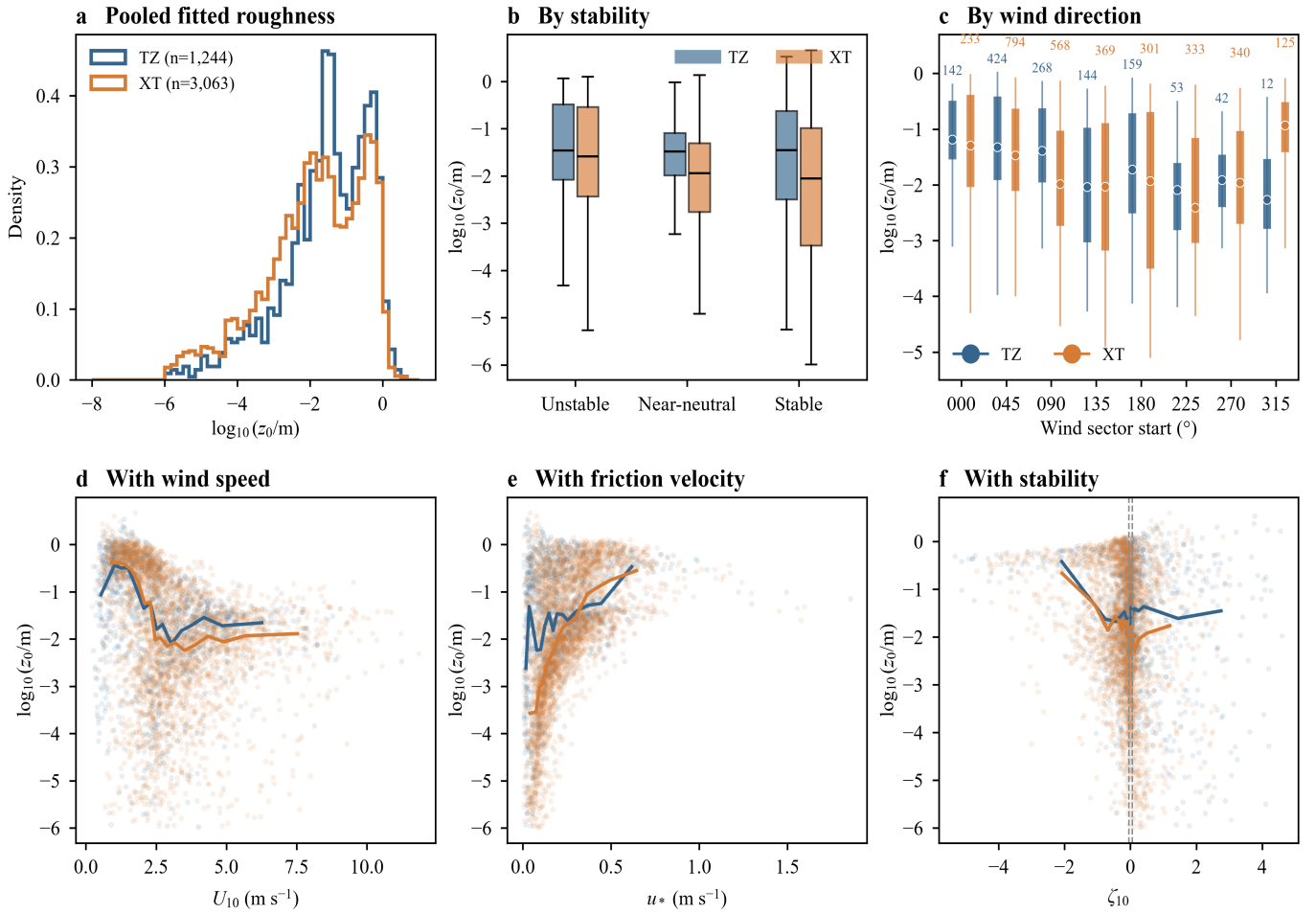


Figure S2. Distribution and diagnostic relationships of the H01 fitted aerodynamic roughness length (z_0) at Tazhong (TZ) and Xiaotang (XT), March–July 2024. H01 uses wind measurements at 1, 2, 4, 10, and 20 m. Blue and orange denote TZ and XT, respectively. (a) Pooled distributions on a $\log_{10}$ scale. (b) Distributions by stability class. (c) Sector medians for 45° wind-direction bins; thick bars show the interquartile range, thin bars the 5th–95th percentile range, and labels the sample count. (d–f) Relationships with 10 m wind speed, profile-derived friction velocity, and the 10 m stability parameter. Lines show medians within quantile-based bins. The stability axis covers the 1st–99th percentiles. Records have positive u^* and z_0 and profile $R^2 \geq 0.7$. These associations are descriptive; z_0 and u^* are jointly retrieved from the same profile and are not independent.

Table S1. Profile-derived friction velocity across height combinations compared with eddy-covariance (EC)-observed friction velocity. Metrics include Pearson's r, Spearman's r, bias, and root-mean-square error (RMSE).

Site	Combination	Heights (m)	Valid h (%)	Pearson r	Spearman r	Bias (m s ⁻¹)	RMSE (m s ⁻¹)
TZ	H01	1-2-4-10-20	14484 (55.27)	0.336	0.457	-0.052	0.210
TZ	H02	2-4-10-20	14336 (54.70)	0.235	0.405	-0.020	0.253
TZ	H03	1-2-4-10-20-32	14659 (55.93)	0.250	0.407	-0.025	0.245
TZ	H04	1-2-4-10-20-32-47-63	14764 (56.33)	0.129	0.316	+0.045	0.334
TZ	H05	32-47-63	13716 (52.34)	-0.048	0.288	+0.570	1.263
TZ	H06	47-63-80	11746 (44.82)	-0.018	0.331	+0.588	1.353
TZ	H07	1-2-4-10-20-32-47-63-80	14743 (56.25)	0.083	0.283	+0.073	0.380
XT	H01	1-2-4-10-20	17331 (69.56)	0.157	0.323	+0.023	0.256
XT	H02	2-4-10-20	17206 (69.06)	0.089	0.284	+0.071	0.335
XT	H03	1-2-4-10-20-32	17359 (69.67)	0.114	0.311	+0.054	0.324
XT	H04	1-2-4-10-20-32-47-63	17353 (69.65)	0.115	0.323	+0.098	0.382
XT	H05	32-47-63	14537 (58.35)	0.129	0.400	+0.459	1.097
XT	H06	47-63-80	13043 (52.35)	0.138	0.404	+0.408	1.076
XT	H07	1-2-4-10-20-32-47-63-80-100	17282 (69.36)	0.136	0.342	+0.112	0.400

Note. H01 denotes the low-level height combination of 1, 2, 4, 10, and 20 m. Metrics were calculated against EC-observed friction velocity. Bias was calculated as profile-derived u^* minus EC-observed u^* . RMSE and Bias are in m s⁻¹. The H01 rows are highlighted because H01 produced the lowest RMSE and the highest Pearson correlation at both stations while maintaining large valid samples and near-surface representativeness.

Table S2. Data availability of profile-derived friction velocity during 2023-2025. The last column reports records rejected by quality control (QC).

Year	Site	Expected h	Existing h (%)	Valid h (%)	No record h	Failed QC h	Missing (%)
2023	TZ	8760	7226 (82.5)	6016 (68.7)	1534	1210	31.3
2023	XT	8760	5879 (67.1)	5319 (60.7)	2881	560	39.3
2024	TZ	8784	8541 (97.2)	7135 (81.2)	243	1172	18.4
2024	XT	8784	8341 (95.0)	7046 (80.2)	443	1295	19.8
2025	TZ	8760	4416 (50.4)	3577 (40.8)	4344	839	59.2
2025	XT	8760	3111 (35.5)	2647 (30.2)	5649	464	69.8

Note. The profile-derived friction velocity refers to the H01 height combination (1, 2, 4, 10, and 20 m). A valid record was defined as a positive u^* value with $r^2 \geq 0.7$. Existing h (%) indicates the number and percentage of hourly records before the r^2 quality control. Failed QC h refers to existing records that did not pass the r^2 criterion or other validity checks. Missing (%) is calculated after quality control.

Table S3. Validation of near-surface variables from the fifth-generation atmospheric reanalysis produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), hereafter ERA5, against tower and EC observations.

Period	Scale	Site	WS ₁₀ R / Bias	T _{2m} R / Bias	ERA5 u* vs EC u*: R / RMSE / Bias
2023–2025	Hourly	TZ	0.603 / +1.306	0.964 / +1.605	0.539 / 0.163 / -0.052
2023–2025	Hourly	XT	0.441 / +0.433	0.979 / +0.879	0.469 / 0.145 / -0.055
2023–2025	Daily	TZ	0.868 / +1.304	0.993 / +1.588	0.698 / 0.097 / -0.027
2023–2025	Daily	XT	0.669 / +0.438	0.994 / +0.854	0.793 / 0.082 / -0.055
2023–2025	Monthly	TZ	0.973 / +1.318	0.997 / +1.665	0.821 / 0.067 / -0.032
2023–2025	Monthly	XT	0.796 / +0.444	0.995 / +0.800	0.941 / 0.070 / -0.058
2024 Jan–Jul	Hourly	TZ	0.586 / +1.303	0.969 / +1.878	0.427 / 0.169 / -0.041
2024 Jan–Jul	Hourly	XT	0.567 / +0.536	0.979 / +1.146	0.458 / 0.155 / -0.065
2024 Jan–Jul	Daily	TZ	0.844 / +1.296	0.993 / +1.838	0.560 / 0.115 / +0.011
2024 Jan–Jul	Daily	XT	0.843 / +0.535	0.996 / +1.108	0.782 / 0.089 / -0.065
2024 Jan–Jul	Monthly	TZ	0.972 / +1.288	1.000 / +1.833	0.719 / 0.055 / +0.006
2024 Jan–Jul	Monthly	XT	0.949 / +0.522	0.999 / +1.036	0.935 / 0.074 / -0.065

Note. WS₁₀ denotes 10 m wind speed, and T_{2m} denotes 2 m air temperature. Bias was calculated as ERA5 minus tower observation for WS₁₀ and T_{2m}, and as ERA5-derived neutral u* minus EC-observed u* for friction velocity. The units of bias are m s⁻¹ for WS₁₀ and u*, and deg C for T_{2m}. RMSE is shown only for the ERA5 u* vs EC u* comparison and is expressed in m s⁻¹. Daily and monthly statistics were calculated from aggregated matched records. Monthly results for 2024 Jan–Jul are provided for reference because only seven monthly samples were available.

Table S4. Comparison of ERA5-derived, EC-observed, and profile-inverted friction velocity.

Period	Scale	Station	ERA5 u* vs EC u* N/R/RMSE/Bias	Profile u* vs EC u* N/R/RMSE/Bias	Profile u* vs ERA5 u* N/R/RMSE/Bias
2023-2025	Hourly	TZ	15687/0.539/0.163/-0.052	14472/0.354/0.205/-0.053	14472/0.400/0.153/-0.001
2023-2025	Hourly	XT	20774/0.469/0.145/-0.055	17270/0.191/0.225/+0.017	17270/0.240/0.209/+0.072
2023-2025	Daily	TZ	625/0.830/0.094/-0.068	594/0.854/0.089/-0.067	594/0.788/0.052/+0.000
2023-2025	Daily	XT	870/0.797/0.081/-0.055	735/0.586/0.082/+0.017	735/0.596/0.093/+0.072
2023-2025	Monthly	TZ	23/0.893/0.076/-0.066	21/0.919/0.069/-0.064	21/0.911/0.022/+0.000
2023-2025	Monthly	XT	29/0.934/0.066/-0.054	25/0.676/0.059/+0.017	25/0.714/0.076/+0.072
2024 Jan-Jul	Hourly	TZ	1564/0.427/0.169/-0.041	1540/0.237/0.222/-0.032	1540/0.251/0.175/+0.011
2024 Jan-Jul	Hourly	XT	5112/0.458/0.155/-0.065	4834/0.208/0.220/+0.001	4834/0.232/0.204/+0.069
2024 Jan-Jul	Daily	TZ	39/0.641/0.121/-0.107	39/0.738/0.096/-0.082	39/0.614/0.057/+0.025
2024 Jan-Jul	Daily	XT	213/0.782/0.089/-0.065	202/0.592/0.077/+0.001	202/0.599/0.091/+0.069
2024 Jan-Jul	Monthly	TZ	2/--/--	2/--/--	2/--/--
2024 Jan-Jul	Monthly	XT	7/0.935/0.074/-0.065	7/0.704/0.059/+0.006	7/0.743/0.076/+0.071

Note. Values are reported as N/R/RMSE/Bias. The profile-inverted friction velocity refers to the low-level H01 height combination of 1, 2, 4, 10, and 20 m. Bias was calculated as estimate minus reference. RMSE and Bias are in m s⁻¹. Daily and monthly results were calculated from aggregated matched records. For TZ during 2024 Jan-Jul at the monthly scale, statistics were not calculated because only two monthly samples were available.

Table S5. Height-combination comparison against the nearest-grid ERA5-derived neutral-profile reference

The study period was March-July 2024. The finite-L profile fits use the Monin-Obukhov length (L) derived from eddy-covariance (EC) observations and are compared with the ERA5 reference. EC-observed u^* was not used as a comparison target or sample filter. N for this group requires a valid finite-L fit and a valid ERA5 reference.

Neutral-only estimates were recalculated from the cleaned tower wind profiles using the logarithmic neutral profile, $U(z) = (u^*/\kappa) \ln(z/z_0)$, with $d = 0$ and $\kappa = 0.4$. For each hourly profile, ordinary least squares (OLS) was applied to U versus $\ln(z)$; the slope and intercept yield $u^* = \kappa a$ and $z_0 = \exp(-b/a)$, respectively. A fit was retained when at least three wind-speed levels were positive, the slope was positive, profile R^2 was at least 0.7, and the ERA5 reference was positive. Neither EC-derived L nor EC-observed u^* entered this calculation or its screening.

At each site, neutral-only statistics use the common timestamps available to all height combinations (H01-H07). Finite-L estimates use their own method-specific valid hours. Because the two groups do not share a common sample, their metrics are not a paired test of the finite-L and neutral fits. The ERA5 reference is calculated from 10 m wind components at the nearest grid point using a neutral log profile; it is neither an in-situ observation nor ERA5's native surface-stress u^* .

Site	Combination	Heights (m)	EC-derived-L profile estimate vs ERA5 reference				Neutral-only common-sample profile estimate vs ERA5 reference			
			N finite-L	r	RMSE (m s ⁻¹)	Bias (m s ⁻¹)	N neutral-only	r	RMSE (m s ⁻¹)	Bias (m s ⁻¹)
TZ	H01	1-2-4-10-20	1313	0.195	0.186	+0.020	1129	0.396	0.118	+0.041
TZ	H02	2-4-10-20	1332	0.143	0.252	+0.060	1129	0.348	0.149	+0.076
TZ	H03	1-2-4-10-20-32	1316	0.161	0.235	+0.050	1129	0.355	0.145	+0.073
TZ	H04	1-2-4-10-20-32-47-63	1325	0.101	0.345	+0.112	1129	0.274	0.205	+0.131
TZ	H05	32-47-63	1320	-0.023	1.157	+0.544	1129	0.046	0.615	+0.434
TZ	H06	47-63-80	765	-0.051	1.258	+0.596	1129	-0.008	0.691	+0.442
TZ	H07	1-2-4-10-20-32-47-63-80	1315	0.084	0.380	+0.129	1129	0.239	0.230	+0.152
XT	H01	1-2-4-10-20	3393	0.261	0.191	+0.060	2494	0.417	0.129	+0.055
XT	H02	2-4-10-20	3378	0.174	0.258	+0.099	2494	0.362	0.157	+0.081
XT	H03	1-2-4-10-20-32	3435	0.199	0.237	+0.084	2494	0.369	0.153	+0.076
XT	H04	1-2-4-10-20-32-47-63	3403	0.169	0.332	+0.136	2494	0.305	0.222	+0.134
XT	H05	32-47-63	3056	0.075	1.198	+0.587	2494	0.181	0.762	+0.490
XT	H06	47-63-80	2771	0.041	1.247	+0.566	2494	0.178	0.734	+0.417
XT	H07	1-2-4-10-20-32-47-63-80-100	3333	0.148	0.398	+0.166	2494	0.283	0.268	+0.166

Table S5b. Height-combination comparison against EC-observed friction velocity

Site	Combination	Heights (m)	Method	N	Pearson r	RMSE (m s ⁻¹)	Bias (m s ⁻¹)
TZ	H01	1-2-4-10-20	finite-L	1442	0.199	0.231	-0.036
TZ	H01	1-2-4-10-20	neutral-only	1313	0.016	0.214	-0.013
TZ	H02	2-4-10-20	finite-L	1442	0.106	0.284	+0.003
TZ	H02	2-4-10-20	neutral-only	1332	-0.073	0.237	+0.034
TZ	H03	1-2-4-10-20-32	finite-L	1446	0.128	0.269	-0.005
TZ	H03	1-2-4-10-20-32	neutral-only	1316	-0.065	0.232	+0.033
TZ	H04	1-2-4-10-20-32-47-63	finite-L	1447	0.037	0.365	+0.058
TZ	H04	1-2-4-10-20-32-47-63	neutral-only	1325	-0.191	0.287	+0.111
TZ	H05	32-47-63	finite-L	1420	-0.162	1.627	+0.653
TZ	H05	32-47-63	neutral-only	1358	-0.372	0.754	+0.543
TZ	H06	47-63-80	finite-L	910	-0.228	2.046	+0.809
TZ	H06	47-63-80	neutral-only	810	-0.420	0.861	+0.586
TZ	H07	1-2-4-10-20-32-47-63-80	finite-L	1448	0.014	0.396	+0.074
TZ	H07	1-2-4-10-20-32-47-63-80	neutral-only	1315	-0.214	0.303	+0.132
XT	H01	1-2-4-10-20	finite-L	3664	0.214	0.215	-0.024
XT	H01	1-2-4-10-20	neutral-only	3393	0.081	0.194	-0.026
XT	H02	2-4-10-20	finite-L	3602	0.148	0.266	+0.012
XT	H02	2-4-10-20	neutral-only	3378	0.010	0.213	+0.005
XT	H03	1-2-4-10-20-32	finite-L	3656	0.182	0.245	-0.003
XT	H03	1-2-4-10-20-32	neutral-only	3435	0.031	0.208	-0.002
XT	H04	1-2-4-10-20-32-47-63	finite-L	3650	0.163	0.317	+0.046
XT	H04	1-2-4-10-20-32-47-63	neutral-only	3403	0.018	0.248	+0.047
XT	H05	32-47-63	finite-L	3360	0.071	1.487	+0.598
XT	H05	32-47-63	neutral-only	3123	-0.011	0.726	+0.391
XT	H06	47-63-80	finite-L	3134	0.074	1.589	+0.594
XT	H06	47-63-80	neutral-only	2851	0.021	0.727	+0.352
XT	H07	1-2-4-10-20-32-47-63-80-100	finite-L	3641	0.163	0.370	+0.073
XT	H07	1-2-4-10-20-32-47-63-80-100	neutral-only	3333	0.028	0.276	+0.075

Note. The period is March–July 2024. EC-observed u^* is the comparison target. Finite-L estimates use EC-derived L and are therefore not independent of EC flux information. Neutral-only estimates use the neutral logarithmic profile and do not use EC-derived L or EC-observed u^* for fitting or screening; profiles are retained when at least three positive wind-speed levels are available, the slope is positive, and profile $R^2 \geq 0.7$.

For each method and height combination, N denotes valid matched hours with positive EC-observed u^* and a valid profile estimate. N can differ among combinations and methods. Pearson r is the linear correlation; Bias is profile-derived u^* minus EC-observed u^* . RMSE and Bias are in m s⁻¹. This table is provided for continuity with the original EC-benchmark analysis and is not a fully independent validation of the finite-L retrieval.

Sensitivity to zero-plane displacement height

Taklimakan Desert tower observations, March–July 2024

Tables S6–S8 assess how profile-derived friction velocity responds to prescribed zero-plane displacement height (d) at Tazhong (TZ) and Xiaotang (XT). Each hourly profile was refitted using the observed Monin–Obukhov length (L). Comparisons use the nearest-grid ERA5-derived neutral-profile estimate; this is a model-derived comparator, not an in-situ measurement. Hourly results are provided in the accompanying machine-readable dataset.

The prescribed d values are sensitivity scenarios, not measurements of the actual displacement height at either site. For combinations that include a 1 m sensor, $d = 1$ m was excluded because it makes $z - d$ equal to zero at the lowest measurement level. Fits were retained when profile R^2 was at least 0.7. Paired statistics use only timestamps that met this criterion for both $d = 0$ and the alternative- d fit.

Table S6. Height-combination sensitivity to zero-plane displacement height

For each site and height combination, the table reports paired agreement with the nearest-grid ERA5-derived neutral-profile u^* and the median percentage change in profile-derived u^* relative to $d = 0$.

Site	Combination	Heights (m)	d (m)	N paired	RMSE (m s^{-1})	Bias (m s^{-1})	Median Δu^* (%)	Median z_0 (m)
TZ	H01	1-2-4-10-20	0.00	1318	0.184	0.013	0.0	0.0329
TZ	H01	1-2-4-10-20	0.25	1297	0.159	-0.010	-8.4	0.0182
TZ	H01	1-2-4-10-20	0.50	1266	0.139	-0.035	-18.3	0.0079
TZ	H02	2-4-10-20	0.00	1343	0.249	0.055	0.0	0.0730
TZ	H02	2-4-10-20	0.25	1339	0.230	0.041	-5.2	0.0538
TZ	H02	2-4-10-20	0.50	1335	0.211	0.026	-10.6	0.0381
TZ	H02	2-4-10-20	1.00	1313	0.173	-0.008	-22.7	0.0151
TZ	H03	1-2-4-10-20-32	0.00	1322	0.231	0.043	0.0	0.0392
TZ	H03	1-2-4-10-20-32	0.25	1299	0.202	0.020	-7.2	0.0249
TZ	H03	1-2-4-10-20-32	0.50	1268	0.167	-0.009	-15.8	0.0123
TZ	H04	1-2-4-10-20-32-47-63	0.00	1309	0.335	0.099	0.0	0.0492
TZ	H04	1-2-4-10-20-32-47-63	0.25	1284	0.293	0.072	-5.8	0.0316
TZ	H04	1-2-4-10-20-32-47-63	0.50	1241	0.231	0.032	-12.6	0.0167
TZ	H05	32-47-63	0.00	1361	1.648	0.728	0.0	1.2610
TZ	H05	32-47-63	0.25	1361	1.636	0.722	-0.6	1.2284
TZ	H05	32-47-63	0.50	1361	1.623	0.716	-1.1	1.2054
TZ	H05	32-47-63	1.00	1361	1.598	0.703	-2.3	1.1381
TZ	H06	47-63-80	0.00	814	2.145	0.964	0.0	1.2549
TZ	H06	47-63-80	0.25	814	2.134	0.958	-0.4	1.2364
TZ	H06	47-63-80	0.50	814	2.122	0.952	-0.8	1.2080
TZ	H06	47-63-80	1.00	814	2.099	0.941	-1.7	1.1563
TZ	H07	1-2-4-10-20-32-47-63-80	0.00	1294	0.364	0.112	0.0	0.0465
TZ	H07	1-2-4-10-20-32-47-63-80	0.25	1267	0.316	0.082	-5.4	0.0311
TZ	H07	1-2-4-10-20-32-47-63-80	0.50	1217	0.250	0.040	-11.3	0.0178

Table S6 continued. XT

Site	Combination	Heights (m)	d (m)	N paired	RMSE (m s ⁻¹)	Bias (m s ⁻¹)	Median Δu^* (%)	Median z_0 (m)
XT	H01	1-2-4-10-20	0.00	3335	0.187	0.056	0.0	0.0140
XT	H01	1-2-4-10-20	0.25	3302	0.160	0.032	-8.8	0.0075
XT	H01	1-2-4-10-20	0.50	3226	0.133	0.002	-19.0	0.0029
XT	H02	2-4-10-20	0.00	3342	0.253	0.095	0.0	0.0244
XT	H02	2-4-10-20	0.25	3337	0.233	0.079	-5.3	0.0173
XT	H02	2-4-10-20	0.50	3319	0.211	0.061	-10.9	0.0116
XT	H02	2-4-10-20	1.00	3284	0.168	0.023	-23.1	0.0041
XT	H03	1-2-4-10-20-32	0.00	3361	0.232	0.081	0.0	0.0149
XT	H03	1-2-4-10-20-32	0.25	3331	0.201	0.057	-7.7	0.0085
XT	H03	1-2-4-10-20-32	0.50	3262	0.166	0.026	-16.7	0.0038
XT	H04	1-2-4-10-20-32-47-63	0.00	3250	0.319	0.130	0.0	0.0159
XT	H04	1-2-4-10-20-32-47-63	0.25	3204	0.278	0.101	-6.3	0.0098
XT	H04	1-2-4-10-20-32-47-63	0.50	3109	0.223	0.063	-13.8	0.0047
XT	H05	32-47-63	0.00	3113	1.575	0.725	0.0	0.3618
XT	H05	32-47-63	0.25	3113	1.563	0.719	-0.7	0.3509
XT	H05	32-47-63	0.50	3113	1.551	0.712	-1.3	0.3440
XT	H05	32-47-63	1.00	3112	1.528	0.700	-2.7	0.3248
XT	H06	47-63-80	0.00	2836	1.704	0.746	0.0	0.3331
XT	H06	47-63-80	0.25	2836	1.695	0.741	-0.5	0.3272
XT	H06	47-63-80	0.50	2836	1.686	0.736	-1.0	0.3201
XT	H06	47-63-80	1.00	2836	1.667	0.727	-2.0	0.3052
XT	H07	1-2-4-10-20-32-47-63-80-100	0.00	3083	0.393	0.171	0.0	0.0140
XT	H07	1-2-4-10-20-32-47-63-80-100	0.25	3036	0.345	0.140	-5.7	0.0082
XT	H07	1-2-4-10-20-32-47-63-80-100	0.50	2961	0.285	0.100	-12.3	0.0037

Note. Bias is profile-derived u^* minus the ERA5-derived reference. Median Δu^* is the paired percentage change from the $d = 0$ fit. N paired is the number of timestamps meeting $R^2 \geq 0.7$ in both fits. For $d = 1$ m, only H02, H05, and H06 are shown because their lowest measurement heights exceed 1 m. z_0 is reported for successfully resolved fits; its sample may be smaller than N paired.

Table S7. Wind-direction dependence of H01 displacement-height sensitivity

Wind-direction sectors are 45° bins based on the 10-m wind direction. The table compares paired hourly H01 u^* estimates at $d = 0.25$ and 0.5 m with the $d = 0$ baseline.

Site	Wind sector (°)	N at $d = 0.5$	Median Δu^* at $d = 0.25$ (%)	Median Δu^* at $d = 0.5$ (%)	Median z_0 at $d = 0$ (m)	Median z_0 at $d = 0.5$ (m)
TZ	000-045	146	-6.8	-15.0	0.0593	0.0193
TZ	045-090	436	-6.5	-14.1	0.0416	0.0113
TZ	090-135	262	-8.8	-18.8	0.0428	0.0091
TZ	135-180	152	-8.2	-17.6	0.0088	0.0015
TZ	180-225	160	-9.2	-20.0	0.0143	0.0024
TZ	225-270	53	-8.9	-19.4	0.0066	0.0012
TZ	270-315	44	-8.6	-18.8	0.0101	0.0019
TZ	315-000	13	-8.4	-18.3	0.0053	0.0007
XT	000-045	239	-6.6	-14.7	0.0422	0.0102
XT	045-090	802	-8.6	-18.7	0.0265	0.0057
XT	090-135	587	-9.3	-20.0	0.0086	0.0014
XT	135-180	395	-9.2	-19.7	0.0068	0.0013
XT	180-225	328	-9.1	-19.6	0.0082	0.0014
XT	225-270	370	-9.3	-20.0	0.0030	0.0004
XT	270-315	382	-7.9	-17.3	0.0105	0.0020
XT	315-000	123	-7.5	-16.3	0.1045	0.0360

Note. Δu^* is the median paired percentage change relative to $d = 0$. Sector counts vary because the profile-fit quality criterion is applied separately to each d scenario. Sector-specific estimates with small N should be interpreted cautiously; the table is descriptive and does not imply statistical significance or identify dune-facing directions.

Table S8. Stability dependence of H01 displacement-height sensitivity and fitted z_0

The table summarizes H01 profile-fit statistics by EC-observed stability class for $d = 0$ and 0.5 m.

Site	Stability	d (m)	N profiles	N resolved z_0	Median Δu^* (%)	z_0 5th pct (m)	z_0 median (m)	z_0 95th pct (m)
TZ	Near-neutral	0.0	219	219	0.0	0.00050	0.0402	0.480
TZ	Near-neutral	0.5	217	216	-18.7	0.00006	0.0106	0.182
TZ	stable	0.0	560	505	0.0	0.00000	0.0329	0.654
TZ	stable	0.5	558	492	-6.1	0.00000	0.0113	0.328
TZ	unstable	0.0	504	479	0.0	0.00026	0.0258	0.876
TZ	unstable	0.5	460	441	-22.6	0.00001	0.0044	0.347
XT	Near-neutral	0.0	466	463	0.0	0.00006	0.0118	0.476
XT	Near-neutral	0.5	465	458	-17.7	0.00001	0.0026	0.214
XT	stable	0.0	1139	956	0.0	0.00000	0.0068	0.558
XT	stable	0.5	1135	932	-7.2	0.00000	0.0021	0.268
XT	unstable	0.0	1674	1603	0.0	0.00008	0.0190	0.784
XT	unstable	0.5	1575	1522	-22.7	0.00001	0.0033	0.333

Note. For $d = 0$, Δu^* is zero by definition; for $d = 0.5$ m it is calculated on timestamps passing the R^2 criterion for both d scenarios. z_0 percentiles use only successfully resolved z_0 fits. Wide percentile ranges indicate strong temporal variability in the retrieved diagnostic z_0 and should not be interpreted as direct measurements of a fixed surface roughness length.

Sensitivity to fixed versus hourly fitted roughness length

This analysis compares the original hourly joint retrieval of u^* and z_0 with a fit that fixes z_0 and estimates only u^* . Both fits use the same measured wind profiles, $d = 0$, the same EC-derived Monin–Obukhov length (L), and the same stability corrections. Performance is assessed against the ERA5-derived neutral-profile reference, not against EC-observed u^* or an in-situ measurement.

The effect of fixing z_0 differed between sites and scenarios. At XT, H01 had the lowest RMSE in both fixed- z_0 scenarios. At TZ, H02 had a slightly lower RMSE than H01 under the H01-median scenario (0.1347 versus 0.1354 m s^{-1}). Under the literature-value scenario, H06 had the numerically lowest RMSE, but it was based on 292 paired records, compared with 874 for H01. The results do not establish a clear alternative to H01 at TZ, although its RMSE ranking was not invariant to the z_0 constraint. Directional differences varied by sector and scenario and remain descriptive. Thus, fixing z_0 changed some height-combination rankings and directional estimates.

Table S9a. Height-combination skill under hourly and fixed z_0

Site	Fixed- z_0 scenario	Combo	Paired N	r free	RMSE free (m s^{-1})	Bias free (m s^{-1})	r fixed	RMSE fixed (m s^{-1})	Bias fixed (m s^{-1})	Fixed RMSE rank
TZ	Literature fixed	H01	874	0.431	0.127	-0.021	0.445	0.116	-0.060	2
TZ	Literature fixed	H02	821	0.435	0.138	-0.009	0.455	0.116	-0.060	5
TZ	Literature fixed	H03	853	0.404	0.141	-0.012	0.428	0.119	-0.060	7
TZ	Literature fixed	H04	807	0.450	0.154	0.002	0.470	0.116	-0.055	3
TZ	Literature fixed	H05	486	0.450	0.179	0.004	0.486	0.117	-0.059	6
TZ	Literature fixed	H06	292	0.445	0.204	0.048	0.513	0.112	-0.026	1
TZ	Literature fixed	H07	779	0.451	0.157	0.004	0.476	0.116	-0.054	4
TZ	H01 median fixed	H01	868	0.377	0.135	-0.007	0.420	0.135	-0.006	2
TZ	H01 median fixed	H02	844	0.383	0.150	0.008	0.433	0.135	-0.008	1
TZ	H01 median fixed	H03	861	0.392	0.146	0.006	0.432	0.136	-0.004	3
TZ	H01 median fixed	H04	836	0.397	0.172	0.027	0.432	0.141	0.004	5
TZ	H01 median fixed	H05	602	0.424	0.278	0.108	0.483	0.139	0.012	4
TZ	H01 median fixed	H06	313	0.355	0.281	0.127	0.454	0.159	0.052	7
TZ	H01 median fixed	H07	813	0.405	0.178	0.032	0.444	0.142	0.006	6

Table S9a continued. XT

Site	Fixed-z0 scenario	Combo	Paired N	r free	RMSE free (m s ⁻¹)	Bias free (m s ⁻¹)	r fixed	RMSE fixed (m s ⁻¹)	Bias fixed (m s ⁻¹)	Fixed RMSE rank
XT	Literature fixed	H01	2038	0.484	0.131	0.027	0.493	0.106	0.002	1
XT	Literature fixed	H02	1919	0.459	0.146	0.039	0.494	0.108	0.003	2
XT	Literature fixed	H03	1943	0.467	0.139	0.033	0.487	0.109	0.004	3
XT	Literature fixed	H04	1787	0.459	0.155	0.045	0.494	0.111	0.010	4
XT	Literature fixed	H05	1183	0.413	0.225	0.109	0.496	0.115	0.020	6
XT	Literature fixed	H06	951	0.368	0.214	0.103	0.471	0.122	0.037	7
XT	Literature fixed	H07	1598	0.458	0.163	0.055	0.500	0.113	0.018	5
XT	H01 median fixed	H01	1946	0.458	0.139	0.038	0.481	0.122	0.028	1
XT	H01 median fixed	H02	1847	0.455	0.152	0.049	0.487	0.124	0.029	2
XT	H01 median fixed	H03	1863	0.440	0.148	0.044	0.467	0.126	0.030	3
XT	H01 median fixed	H04	1730	0.436	0.169	0.061	0.474	0.131	0.040	4
XT	H01 median fixed	H05	1260	0.368	0.268	0.146	0.468	0.136	0.051	6
XT	H01 median fixed	H06	953	0.353	0.236	0.127	0.460	0.145	0.067	7
XT	H01 median fixed	H07	1554	0.407	0.184	0.073	0.461	0.136	0.049	5

Notes. ‘Literature fixed’ uses $z_0 = 0.003265$ m at TZ and 0.005858 m at XT, representative values reported by Jin et al. (2020); these are point estimates, not universal bounds. ‘H01 median fixed’ uses the station-specific median of valid, $R_2 \geq 0.70$, hourly H01 z_0 fits in March–July 2024 (TZ: 0.03294 m; XT: 0.01400 m); it is an internal sensitivity value, not independent validation. For each site–combination–scenario, N is the number of timestamps for which both methods pass the positive- u^* and $R_2 \geq 0.70$ criteria and the ERA5 reference is present. N can differ among combinations. Pearson r is linear association; Bias = profile-derived u^* minus ERA5 reference. The ERA5 reference is a neutral-profile-derived estimate and is not native ERA5 surface stress.

Table S9b. Directional H01 response to fixing z₀

Site	Fixed-z ₀ scenario	Wind sector (°)	Paired N	Median u* free (m s ⁻¹)	Median u* fixed (m s ⁻¹)	Change (%)
TZ	H01 median fixed	000-045	115	0.184	0.199	7.7
TZ	H01 median fixed	045-090	314	0.190	0.186	-2.2
TZ	H01 median fixed	090-135	196	0.179	0.168	-6.4
TZ	H01 median fixed	135-180	84	0.117	0.100	-14.7
TZ	H01 median fixed	180-225	87	0.200	0.184	-7.8
TZ	H01 median fixed	225-270	32	0.216	0.233	7.8
TZ	H01 median fixed	270-315	34	0.256	0.327	27.5
TZ	H01 median fixed	315-000	6	0.393	0.505	28.3
TZ	Literature fixed	000-045	102	0.181	0.148	-17.9
TZ	Literature fixed	045-090	292	0.183	0.147	-19.8
TZ	Literature fixed	090-135	189	0.164	0.136	-16.7
TZ	Literature fixed	135-180	102	0.106	0.106	-0.2
TZ	Literature fixed	180-225	100	0.147	0.152	3.0
TZ	Literature fixed	225-270	42	0.167	0.154	-8.1
TZ	Literature fixed	270-315	38	0.247	0.219	-11.1
TZ	Literature fixed	315-000	9	0.300	0.287	-4.3

Table S9b continued. XT

Site	Fixed-z0 scenario	Wind sector (°)	Paired N	Median u* free (m s ⁻¹)	Median u* fixed (m s ⁻¹)	Change (%)
XT	H01 median fixed	000-045	161	0.204	0.207	1.6
XT	H01 median fixed	045-090	560	0.229	0.220	-3.9
XT	H01 median fixed	090-135	382	0.209	0.223	6.7
XT	H01 median fixed	135-180	208	0.193	0.183	-5.2
XT	H01 median fixed	180-225	135	0.186	0.177	-4.6
XT	H01 median fixed	225-270	194	0.175	0.211	20.4
XT	H01 median fixed	270-315	221	0.221	0.239	8.3
XT	H01 median fixed	315-000	85	0.268	0.199	-25.7
XT	Literature fixed	000-045	152	0.190	0.181	-4.9
XT	Literature fixed	045-090	558	0.216	0.193	-10.8
XT	Literature fixed	090-135	404	0.193	0.190	-1.7
XT	Literature fixed	135-180	236	0.159	0.162	2.4
XT	Literature fixed	180-225	150	0.163	0.163	-0.1
XT	Literature fixed	225-270	222	0.159	0.175	10.6
XT	Literature fixed	270-315	235	0.210	0.207	-1.3
XT	Literature fixed	315-000	81	0.267	0.188	-29.7

Notes. Wind sectors are 45° clockwise from north using the 10-m wind direction. Directional medians use H01 timestamps paired between the two z0 treatments and meeting the stated profile-fit criteria. Percentage change is $100 \times (\text{fixed-z0 median } u^* - \text{hourly-fitted-z0 median } u^*) / \text{hourly-fitted-z0 median } u^*$. Sector sample sizes are shown because sparsely sampled directions, especially at TZ, should not be over-interpreted. The finite-L analysis still uses EC-derived L; it tests the effect of fixing z0 only and does not address dependence on EC-L.

Reference. Jin, L. et al. (2020). Unmanned Aerial Vehicle Observations of the Vertical Distribution of Particulate Matter in the Surface Layer of the Taklimakan Desert in China. *Atmosphere*, 11, 980. <https://doi.org/10.3390/atmos11090980>.

Table S10. Distribution statistics of H01 fitted roughness length z_0

Tazhong (TZ) and Xiaotang (XT), March–July 2024

Site	Accepted n / 3672	Below / within / above published interval (%)	$z_0 \geq 1 \text{ m}$ n (%)	Minimum (m)	P05 (m)	P25 (m)	Median (m)	P75 (m)	P95 (m)	Maximum (m)
TZ	1,244 (33.88%)	12.38 / 15.92 / 71.70	36 (2.89%)	1.10×10^{-6}	1.02×10^{-4}	0.00618	0.0356	0.2354	0.8363	3.403
XT	3,063 (83.42%)	20.05 / 19.26 / 60.69	63 (2.06%)	1.03×10^{-6}	2.58×10^{-5}	0.00200	0.0179	0.1767	0.7635	4.620

Accepted records are original H01 fits with status ok, positive u^* and z_0 , and profile $R^2 \geq 0.7$. Percentiles are calculated from these records. The accepted sample comprises 1,244 of 3,672 input hours at TZ and 3,063 of 3,672 at XT.

The published interval (0.0011–0.0084 m) is the range of diurnal-mean z_0 reported from 2010 observations at a northern-margin Taklimakan site (Jin et al., 2018). The below/within/above percentages compare hourly fitted values with this contextual interval; it is not a universal acceptance range or a like-for-like hourly benchmark. The $z_0 \geq 1 \text{ m}$ column flags estimates at or above the lowest H01 anemometer height. This is a profile-geometry diagnostic, not a general roughness threshold. The retrieved z_0 is an effective fitted parameter. It may reflect flow distortion or departures from Monin-Obukhov similarity theory (MOST), as well as surface roughness.

Reference: Jin, L., Li, Z., He, Q., Liu, Y., Mamtimin, A., Liu, X., Huo, W., Xin, Y., Zhang, J., and Zhou, C. (2018). Observed key surface parameters for characterizing land–atmospheric interactions in the northern marginal zone of the Taklimakan Desert, China. *Atmosphere*, 9(12), 458. <https://doi.org/10.3390/atmos9120458>.