

Supplementary material

Influence of atmospheric stability on the *wind speed–energy–revenue* forecasting chain

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A Validation of SoDAR measurements

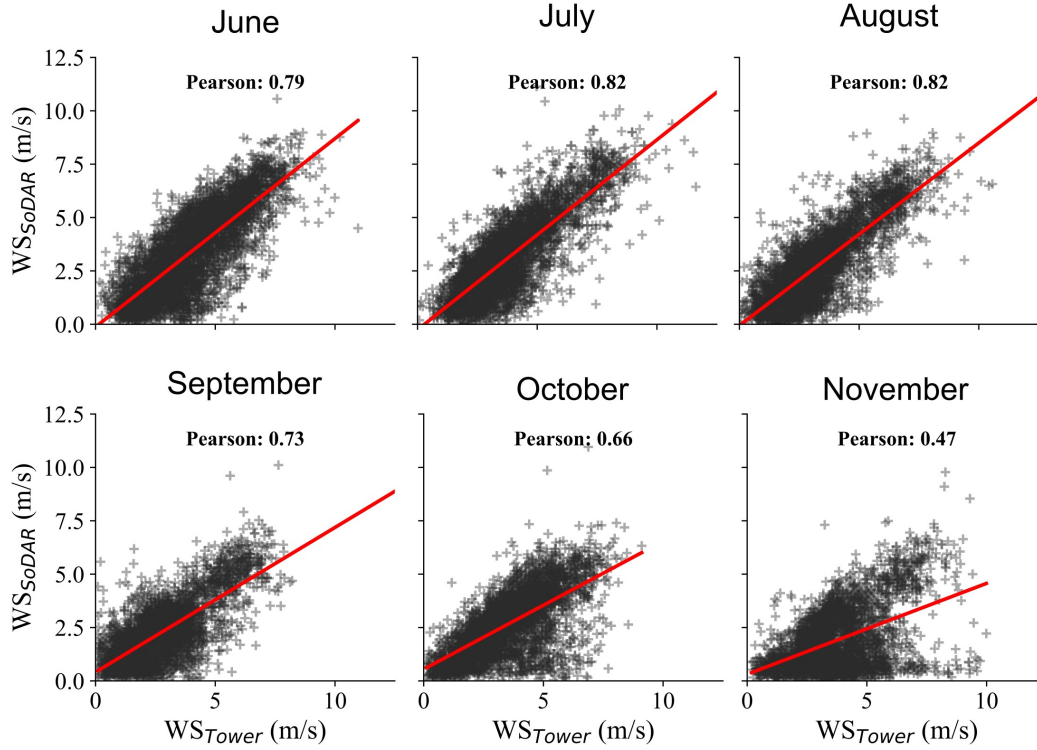


Figure S1: Scatter plot with linear correlation fit between monthly WS measurements obtained by the SoDAR and the 30 m tower-mounted 3D sonic anemometer (CSAT3B). Each month indicates the associated Pearson correlation coefficient.

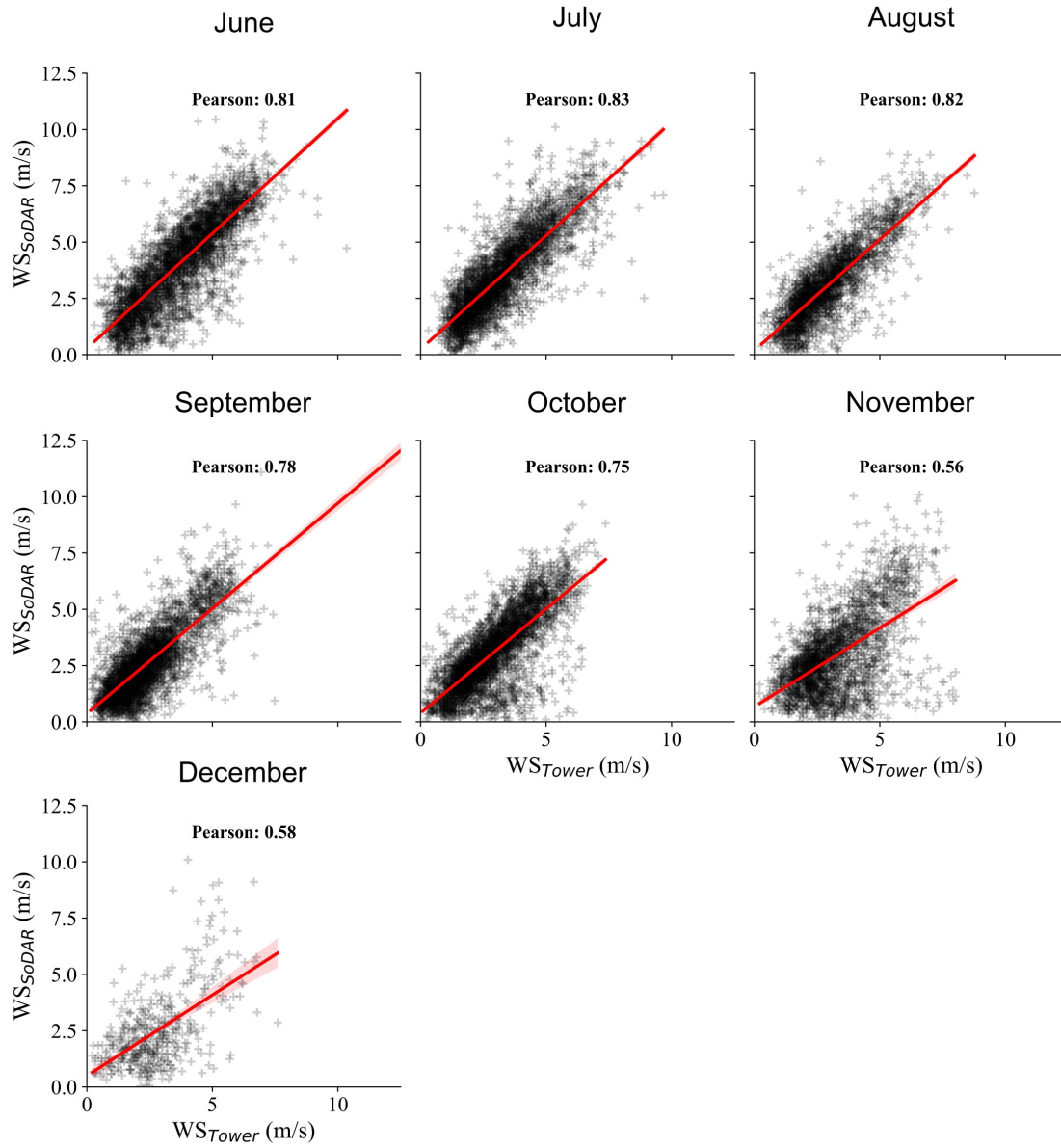


Figure S2: Scatter plot with linear correlation fit between monthly WS measurements obtained by the SoDAR and the 20 m tower-mounted 2D ultrasonic anemometer (Gill WindSonic). Each month indicates the associated Pearson correlation coefficient.

B Supplementary figures

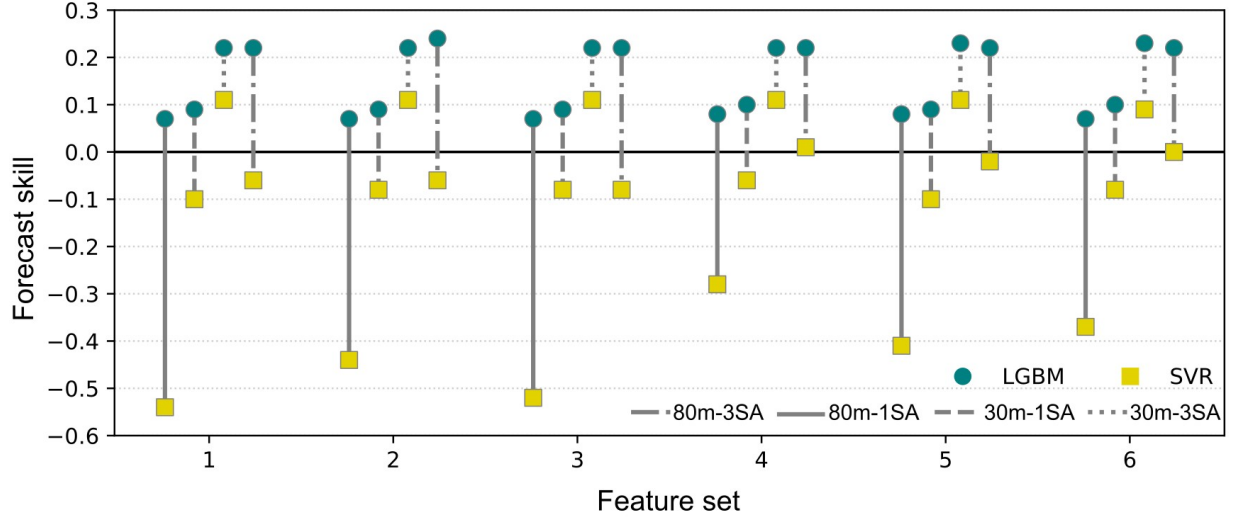


Figure S3: Forecast skill for a lag of 6. Each color indicates an algorithm (green = LGBM, yellow = SVR) and each type of bar represents a combination of height and horizon (1SA = one-step-ahead, 3SA = three-step-ahead).

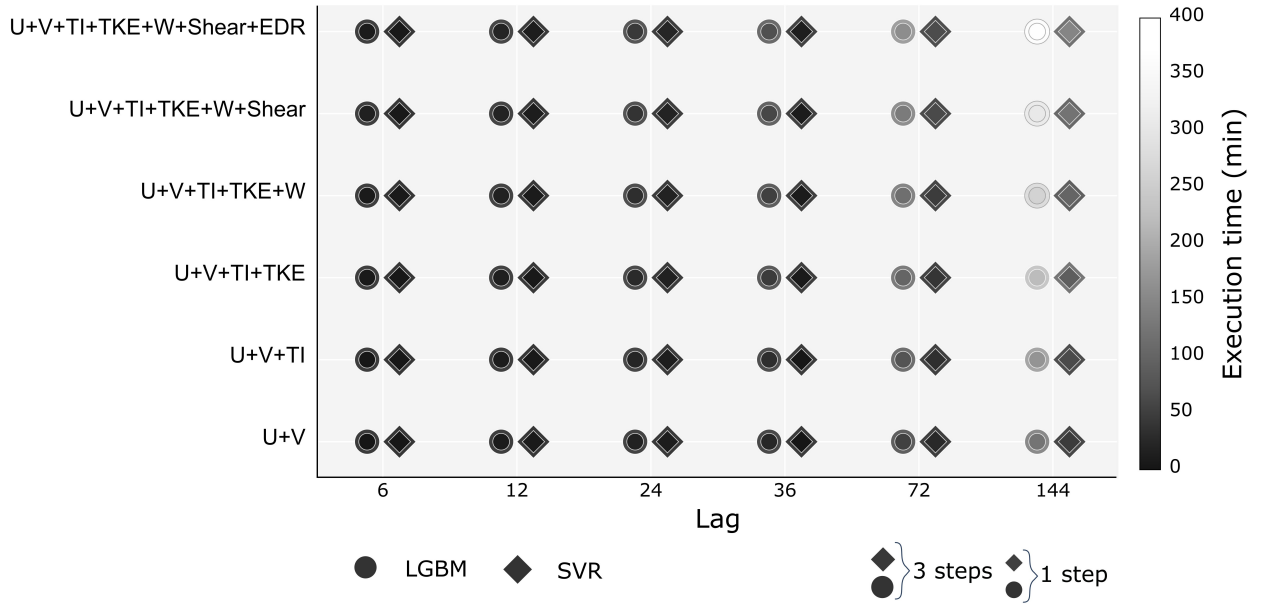


Figure S4: Execution time comparison of algorithms across configurations.

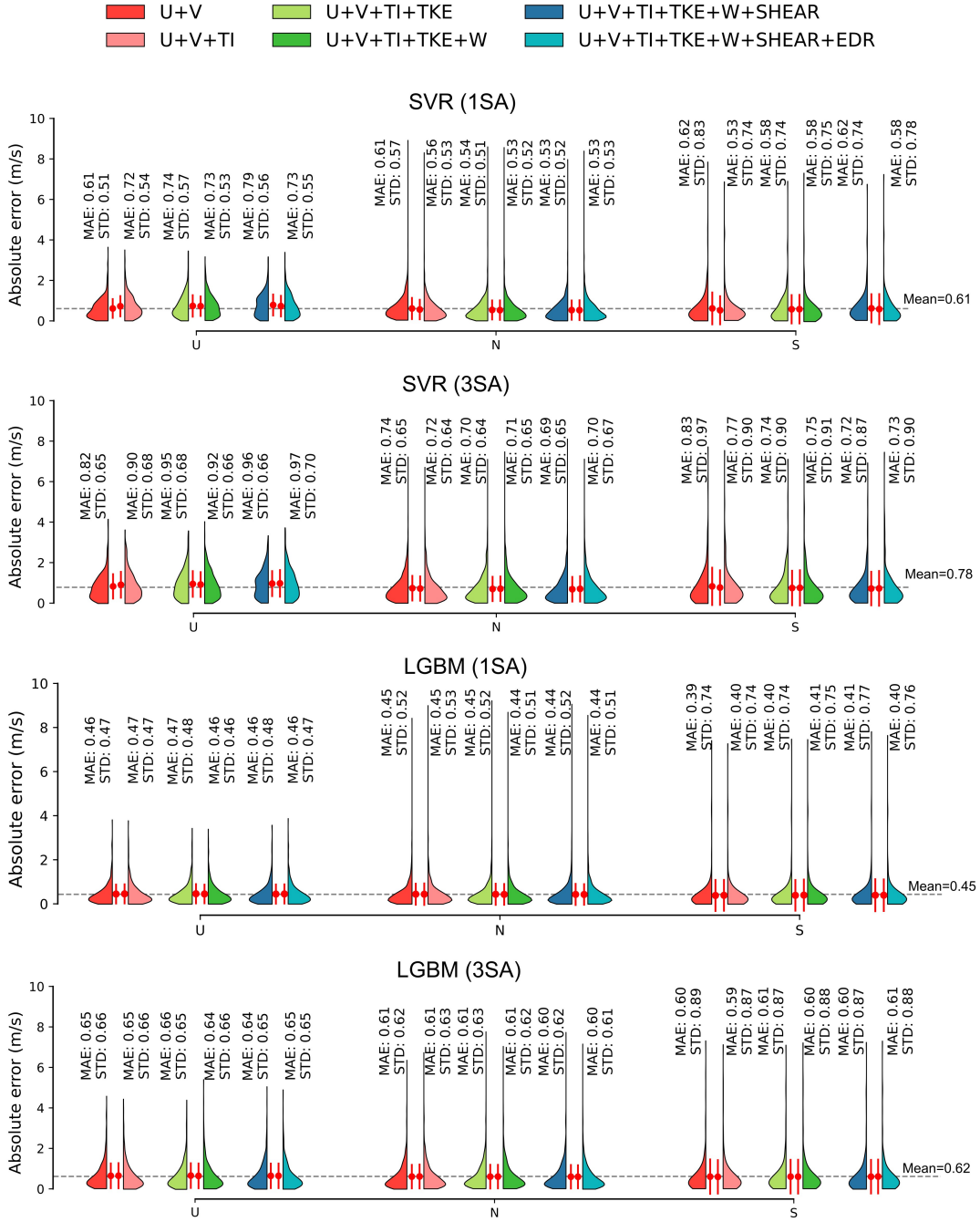


Figure S5: Violin plots of absolute error at 30 m for each configuration, with mean and standard deviation (red circle, vertical bar). The dotted line represents the average of the mean error values.

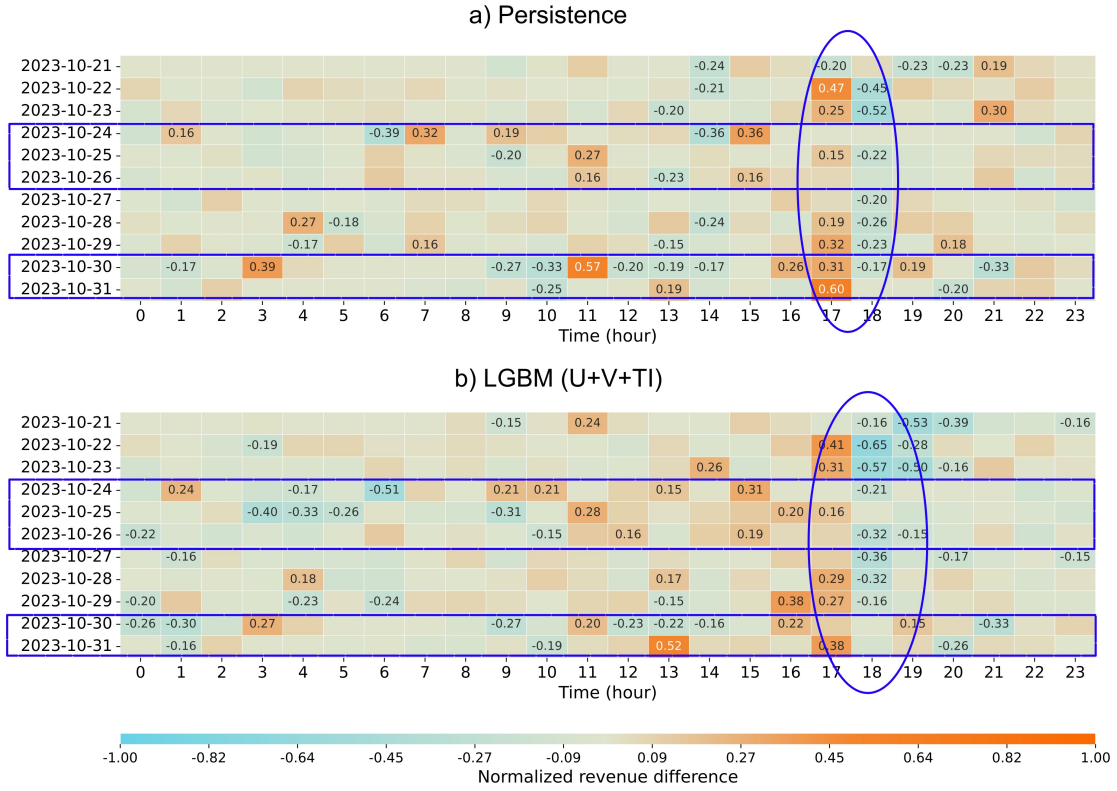


Figure S6: Heatmap of differences between baseline estimated revenue for a) persistence and b) LGBM, normalized by baseline daily revenue for **one-step-ahead forecasts**. The Y axis shows the eleven test days; the X axis shows the hours. The blue boxes highlight a mostly positive bias (orange tones), indicating over-estimation. The blue oval shows the time lapse with the higher transition in error (over- to underestimation).

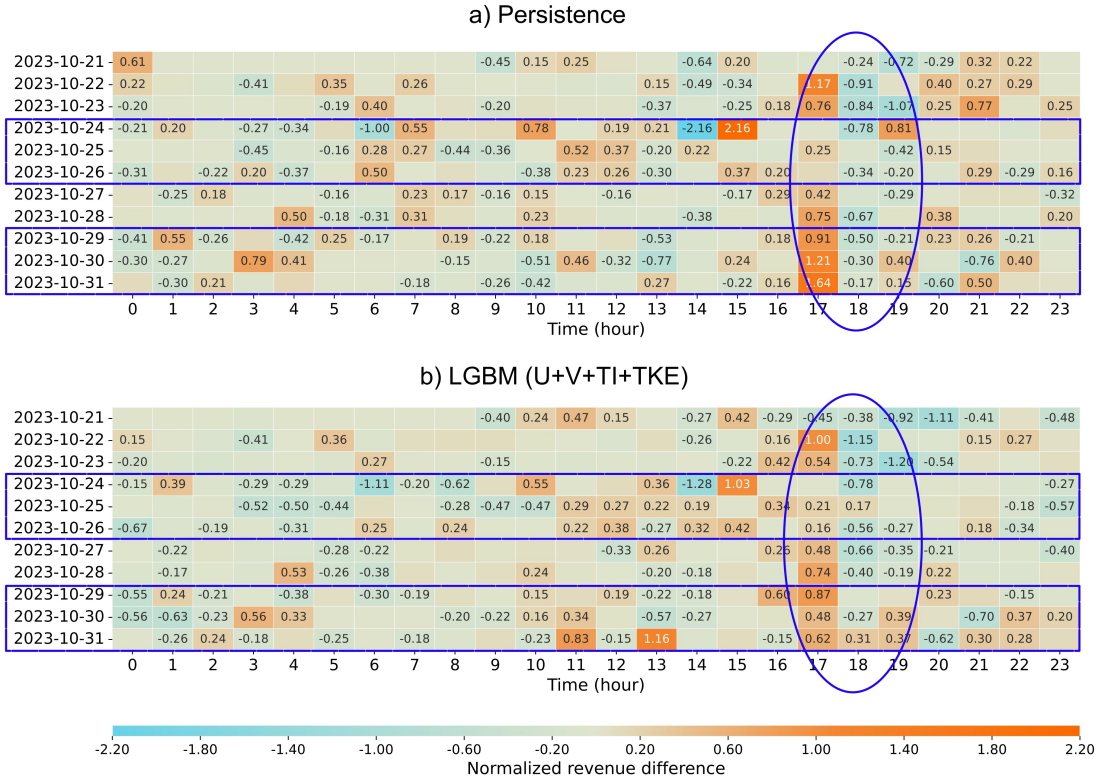


Figure S7: Heatmap of differences between baseline estimated revenue for a) persistence and b) LGBM, normalized by baseline daily revenue for **three-step-ahead forecasts**. The Y axis shows the eleven test days; the X axis shows the hours. The blue boxes highlight a mostly positive bias (orange tones), indicating overestimation. The blue oval shows the time lapse with the higher transition in error (over- to underestimation).

C Supplementary tables

Table S1: Forecast error results for the different one-step-ahead configurations. Bold numbers indicate the lowest error values.

Algorithm-Metric	30 m			80 m			Lag	Feature set
	RMSE	NRMSE	MAE	RMSE	NRMSE	MAE		
SVR	0.847	0.078	0.613	1.329	0.143	1.112	6	1
	0.811	0.074	0.576	1.256	0.135	1.033	12	
	0.838	0.077	0.612	1.161	0.125	0.924	24	
	0.849	0.078	0.619	1.213	0.131	0.972	36	
	0.902	0.083	0.672	1.257	0.135	1.007	72	
	0.991	0.091	0.745	1.274	0.137	1.019	144	
	0.829	0.076	0.608	1.244	0.134	1.027	6	2
	0.837	0.077	0.596	1.172	0.126	0.954	12	
	0.828	0.076	0.593	1.186	0.128	0.947	24	
	0.824	0.075	0.601	1.147	0.123	0.907	36	
	0.871	0.080	0.638	1.188	0.128	0.943	72	
	0.940	0.086	0.715	1.252	0.135	0.998	144	
	0.829	0.076	0.603	1.314	0.141	1.080	6	3
	0.861	0.079	0.632	1.241	0.134	1.003	12	
	0.870	0.080	0.638	1.324	0.143	1.058	24	
	0.880	0.081	0.656	1.162	0.125	0.916	36	
	0.933	0.085	0.700	1.267	0.136	1.009	72	
	0.947	0.087	0.714	1.317	0.142	1.066	144	
	0.818	0.075	0.595	1.107	0.119	0.870	6	4
	0.860	0.079	0.639	1.141	0.123	0.912	12	
	0.844	0.077	0.617	1.163	0.125	0.920	24	
	0.889	0.081	0.659	1.205	0.130	0.960	36	
	0.908	0.083	0.673	1.284	0.138	1.034	72	
	0.991	0.091	0.755	1.361	0.147	1.097	144	
	0.844	0.077	0.621	1.213	0.131	0.977	6	5
	0.871	0.080	0.650	1.077	0.116	0.829	12	
	0.850	0.078	0.618	1.192	0.128	0.938	24	
	0.911	0.083	0.669	1.181	0.127	0.943	36	
	0.951	0.087	0.719	1.299	0.140	1.043	72	
	0.958	0.088	0.728	1.346	0.145	1.076	144	
	0.832	0.076	0.598	1.184	0.127	0.943	6	6
	0.847	0.078	0.621	1.201	0.129	0.955	12	
	0.898	0.082	0.676	1.212	0.130	0.963	24	
	0.911	0.083	0.676	1.241	0.134	0.995	36	
	0.974	0.089	0.736	1.325	0.143	1.066	72	
	1.010	0.092	0.781	1.376	0.148	1.117	144	

Table S1: **(continued)** Forecast error results for the different one-step-ahead configurations. Bold numbers indicate the lowest error values.

Algorithm-Metric	30 m			80 m			Lag	Feature set
	RMSE	NRMSE	MAE	RMSE	NRMSE	MAE		
LGBM	0.697	0.064	0.447	0.801	0.086	0.545	6	1
	0.692	0.063	0.446	0.798	0.086	0.545	12	
	0.699	0.064	0.450	0.802	0.086	0.549	24	
	0.696	0.064	0.450	0.803	0.086	0.551	36	
	0.699	0.064	0.449	0.803	0.086	0.550	72	
	0.699	0.064	0.456	0.805	0.087	0.554	144	
	0.703	0.064	0.450	0.802	0.086	0.546	6	2
	0.696	0.064	0.446	0.799	0.086	0.544	12	
	0.699	0.064	0.448	0.800	0.086	0.545	24	
	0.701	0.064	0.455	0.805	0.087	0.547	36	
	0.703	0.064	0.452	0.805	0.087	0.553	72	
	0.704	0.064	0.455	0.798	0.086	0.547	144	
	0.700	0.064	0.450	0.802	0.086	0.546	6	3
	0.700	0.064	0.449	0.804	0.087	0.544	12	
	0.698	0.064	0.448	0.801	0.086	0.549	24	
	0.704	0.065	0.455	0.801	0.086	0.547	36	
	0.696	0.064	0.450	0.802	0.086	0.553	72	
	0.702	0.064	0.454	0.808	0.087	0.557	144	
	0.691	0.063	0.445	0.795	0.086	0.543	6	4
	0.700	0.064	0.445	0.798	0.086	0.546	12	
	0.690	0.063	0.447	0.801	0.086	0.544	24	
	0.691	0.063	0.447	0.798	0.086	0.544	36	
	0.690	0.063	0.449	0.804	0.087	0.552	72	
	0.700	0.064	0.450	0.803	0.086	0.552	144	
	0.697	0.064	0.442	0.796	0.086	0.547	6	5
	0.700	0.064	0.448	0.796	0.086	0.544	12	
	0.691	0.063	0.446	0.792	0.085	0.542	24	
	0.692	0.063	0.446	0.796	0.086	0.544	36	
	0.694	0.064	0.448	0.801	0.086	0.548	72	
	0.699	0.064	0.449	0.798	0.086	0.550	144	
	0.691	0.063	0.443	0.798	0.086	0.544	6	6
	0.697	0.064	0.446	0.801	0.086	0.550	12	
	0.695	0.064	0.448	0.795	0.086	0.543	24	
	0.697	0.064	0.446	0.797	0.086	0.544	36	
	0.702	0.064	0.450	0.795	0.086	0.545	72	
	0.696	0.064	0.449	0.805	0.087	0.552	144	
Persistence	0.769	0.070	0.484	0.862	0.093	0.569	1	speed

Table S2: Forecast error results for the different three-step-ahead configurations. Bold numbers indicate the lowest error values.

Algorithm-Metric	30 m			80 m			Lag	Feature set
	RMSE	NRMSE	MAE	RMSE	NRMSE	MAE		
SVR	1.039	0.095	0.774	1.425	0.153	1.155	6	1
	0.995	0.091	0.742	1.397	0.150	1.131	12	
	1.040	0.095	0.790	1.410	0.152	1.137	24	
	1.027	0.094	0.765	1.421	0.153	1.150	36	
	1.068	0.098	0.812	1.403	0.151	1.129	72	
	1.093	0.100	0.843	1.413	0.152	1.127	144	
	1.044	0.096	0.781	1.429	0.154	1.167	6	2
	1.027	0.094	0.764	1.417	0.153	1.145	12	
	1.020	0.093	0.754	1.434	0.154	1.162	24	
	1.014	0.093	0.754	1.391	0.150	1.118	36	
	1.063	0.097	0.798	1.407	0.151	1.115	72	
	1.054	0.097	0.807	1.408	0.152	1.117	144	
	1.046	0.096	0.781	1.459	0.157	1.188	6	3
	1.036	0.095	0.782	1.447	0.156	1.174	12	
	1.050	0.096	0.790	1.455	0.157	1.168	24	
	1.051	0.096	0.788	1.399	0.151	1.126	36	
	1.055	0.097	0.792	1.434	0.154	1.146	72	
	1.046	0.096	0.788	1.449	0.156	1.158	144	
	1.042	0.095	0.779	1.340	0.144	1.057	6	4
	1.053	0.096	0.798	1.336	0.144	1.068	12	
	1.043	0.096	0.778	1.395	0.150	1.122	24	
	1.070	0.098	0.800	1.400	0.151	1.126	36	
	1.068	0.098	0.805	1.442	0.155	1.158	72	
	1.070	0.098	0.817	1.481	0.159	1.185	144	
	1.041	0.095	0.776	1.372	0.148	1.095	6	5
	1.062	0.097	0.801	1.286	0.138	1.005	12	
	1.041	0.095	0.789	1.355	0.146	1.073	24	
	1.072	0.098	0.797	1.379	0.148	1.097	36	
	1.089	0.100	0.822	1.461	0.157	1.170	72	
	1.078	0.099	0.824	1.460	0.157	1.167	144	
	1.068	0.098	0.791	1.349	0.145	1.062	6	6
	1.039	0.095	0.783	1.318	0.142	1.045	12	
	1.057	0.097	0.795	1.386	0.149	1.112	24	
	1.091	0.100	0.826	1.389	0.150	1.115	36	
	1.100	0.101	0.831	1.457	0.157	1.172	72	
	1.102	0.101	0.852	1.486	0.160	1.192	144	

Table S2: **(continued)** Forecast error results for the different three-step-ahead configurations. Bold numbers indicate the lowest error values.

Algorithm-Metric	30 m			80 m			Lag	Feature set
	RMSE	NRMSE	MAE	RMSE	NRMSE	MAE		
LGBM	0.911	0.083	0.618	1.051	0.113	0.750	6	1
	0.900	0.082	0.618	1.048	0.113	0.754	12	
	0.912	0.083	0.618	1.047	0.113	0.757	24	
	0.905	0.083	0.616	1.050	0.113	0.763	36	
	0.904	0.083	0.614	1.060	0.114	0.764	72	
	0.897	0.082	0.611	1.034	0.111	0.742	144	
	0.917	0.084	0.623	1.027	0.111	0.734	6	2
	0.906	0.083	0.621	1.039	0.112	0.745	12	
	0.898	0.082	0.615	1.043	0.112	0.749	24	
	0.906	0.083	0.617	1.046	0.113	0.758	36	
	0.913	0.084	0.619	1.044	0.112	0.752	72	
	0.890	0.082	0.610	1.036	0.112	0.745	144	
	0.912	0.084	0.621	1.051	0.113	0.746	6	3
	0.907	0.083	0.616	1.049	0.113	0.747	12	
	0.899	0.082	0.612	1.046	0.113	0.745	24	
	0.904	0.083	0.617	1.060	0.114	0.763	36	
	0.899	0.082	0.618	1.060	0.114	0.759	72	
	0.889	0.081	0.609	1.045	0.112	0.752	144	
	0.908	0.083	0.618	1.052	0.113	0.748	6	4
	0.896	0.082	0.613	1.037	0.112	0.745	12	
	0.886	0.081	0.607	1.040	0.112	0.745	24	
	0.893	0.082	0.609	1.050	0.113	0.752	36	
	0.903	0.083	0.617	1.046	0.113	0.747	72	
	0.886	0.081	0.610	1.046	0.113	0.755	144	
	0.904	0.083	0.614	1.052	0.113	0.752	6	5
	0.897	0.082	0.609	1.040	0.112	0.744	12	
	0.893	0.082	0.611	1.044	0.112	0.745	24	
	0.902	0.083	0.612	1.046	0.113	0.752	36	
	0.896	0.082	0.613	1.043	0.112	0.742	72	
	0.884	0.081	0.608	1.048	0.113	0.754	144	
	0.901	0.082	0.615	1.046	0.113	0.746	6	6
	0.896	0.082	0.608	1.036	0.112	0.740	12	
	0.898	0.082	0.610	1.043	0.112	0.750	24	
	0.904	0.083	0.611	1.052	0.113	0.755	36	
	0.898	0.082	0.614	1.043	0.112	0.747	72	
	0.888	0.081	0.611	1.039	0.112	0.751	144	
Persistence	1.17	0.107	0.8	1.349	0.145	0.970	3	speed

Table S3: Results of the DM test with MSE as the loss function. Each set of predictors is compared with the baseline model, reporting the DM statistic (S) and its p -value (P). A positive value of S indicates that the first model (alternative configurations) outperforms the baseline model ($U+V$). A negative value indicates that the baseline model has better performance. Bold entries indicate statistically significant results. Green values mark cases where the alternative model was significant and outperformed the baseline.

Alternative model (A):	Baseline model (B): U+V					
	6	12	24	36	72	144
SVR (one-step-ahead horizon)						
U+V+TI	S=-6.0679 P=1.62E-09*	S=-5.8596 P=5.63E-09*	S=1.7999 P=7.21E-02	S=-4.5845 P=5.00E-06*	S=-5.4549 P=5.68E-08*	S=-1.797764 P=7.24E-02
U+V+TI+TKE	S=-0.89 P=3.74E-01	S=-0.9457 P=3.44E-01	S=9.2773 P=5.52E-20*	S=-3.3144 P=9.39E-04*	S=0.6327 P=5.27E-01	S=3.319745 P=9.21E-04*
U+V+TI+TKE+W	S=-13.3332 P=1.63E-38*	S=-7.4647 P=1.37E-13*	S=0.1211 P=9.04E-01	S=-0.61254 P=5.40E-01	S=1.7754 P=7.60E-02	S=6.126844 P=1.13E-09*
U+V+TI+TKE+W+SHEAR	S=-6.6769 P=3.37E-11*	S=-10.3908 P=1.64E-24*	S=1.9826 P=4.76E-02**	S=-2.1952 P=2.83E-02**	S=2.8459 P=4.49E-03*	S=4.59279 P=4.72E-06*
U+V+TI+TKE+W+SHEAR+EDR	S=-7.8301 P=8.86E-15*	S=-3.2637 P=1.12E-03*	S=2.9316 P=3.42E-03*	S=1.8385 P=6.62E-02	S=4.351205 P=1.44E-05*	S=6.673924 P=3.43E-11*
LGBM (one-step-ahead horizon)						
U+V+TI	S=0.1881 P=8.51E-01	S=0.3160 P=7.52E-01	S=-0.3387 P=7.35E-01	S=0.4561 P=6.48E-01	S=0.3416 P=7.33E-01	S=-1.3836 P=1.67E-01
U+V+TI+TKE	S=0.1257 P=9.00E-01	S=1.0713 P=2.84E-01	S=0.2007 P=8.41E-01	S=-0.3057 P=7.60E-01	S=-0.1550 P=8.77E-01	S=0.3953 P=6.93E-01
U+V+TI+TKE+W	S=-0.9755 P=3.29E-01	S=0.1252 P=9.00E-01	S=0.2746 P=7.84E-01	S=-0.8703 P=3.84E-01	S=0.0832 P=9.34E-01	S=-0.3438 P=7.31E-01
U+V+TI+TKE+W+SHEAR	S=-0.7710 P=4.41E-01	S=-0.3032 P=0.7710	S=1.6267 P=1.62E-01	S=-1.0946 P=2.74E-01	S=-0.2899 P=7.72E-01	S=-1.1677 P=2.43E-01
U+V+TI+TKE+W+SHEAR+EDR	S=-0.4895 P=6.25E-01	S=0.4550 P=6.49E-01	S=1.0722 P=2.84E-01	S=-0.9961 P=3.19E-01	S=-1.2546 P=2.10E-01	S=-0.0549 P=9.56E-01
SVR (three-step-ahead horizon)						
U+V+TI	S=0.2785 P=7.81E-01	S=1.3850 P=1.66E-01	S=1.7114 P=8.72E-02	S=-1.8934 P=5.85E-02	S=0.2948 P=7.68E-01	S=-0.3996 P=6.89E-01
U+V+TI+TKE	S=1.6253 P=1.04E-01	S=2.8543 P=4.37E-03*	S=2.5700 P=1.03E-02**	S=-1.2435 P=2.14E-01	S=1.8340 P=6.68E-02	S=2.4469 P=1.45E-02**
U+V+TI+TKE+W	S=-4.0544 P=5.30E-05*	S=3.3464 P=8.38E-04*	S=0.8118 P=4.17E-01	S=-1.2492 P=2.12E-01	S=2.3776 P=1.75E-02**	S=4.2427 P=2.30E-05*
U+V+TI+TKE+W+SHEAR	S=-2.2412 P=2.52E-02**	S=-5.2825 P=1.45E-07*	S=-2.6355 P=8.48E-03*	S=-2.0485 P=4.07E-02**	S=3.0471 P=2.35E-03*	S=2.9502 P=3.22E-03*
U+V+TI+TKE+W+SHEAR+EDR	S=-3.1393 P=1.73E-03*	S=-3.9193 P=9.26E-05*	S=-1.1346 P=2.57E-01	S=-1.6023 P=1.09E-01	S=3.1687 P=1.56E-03*	S=3.9812 P=7.20E-05*
LGBM (three-step-ahead horizon)						
U+V+TI	S=-2.8905 P=3.90E-03*	S=-1.4212 P=1.55E-01	S=-0.6281 P=5.30E-01	S=-0.6530 P=5.14E-01	S=-2.1974 P=2.81E-02**	S=0.2978 P=7.66E-01
U+V+TI+TKE	S=0.0068 P=9.95E-01	S=0.1242 P=9.01E-01	S=-0.1544 P=8.77E-01	S=1.2442 P=2.14E-01	S=0.0233 P=9.81E-01	S=1.0594 P=2.90E-01
U+V+TI+TKE+W	S=0.1552 P=8.77E-01	S=-1.3707 P=1.71E-01	S=-0.8895 P=3.74E-01	S=-0.0213 P=9.83E-01	S=-1.4904 P=1.36E-01	S=1.2278 P=2.20E-01
U+V+TI+TKE+W+SHEAR	S=0.1066 P=9.15E-01	S=-1.0257 P=3.05E-01	S=-0.3527 P=7.24E-01	S=-0.5101 P=6.10E-01	S=-1.6844 P=9.23E-02	S=1.4070 P=1.60E-01
U+V+TI+TKE+W+SHEAR+EDR	S=-0.5595 P=5.76E-01	S=-1.3580 P=1.75E-01	S=-0.4432 P=6.58E-01	S=0.2076 P=8.36E-01	S=-1.5407 P=1.24E-01	S=0.4947 P=6.21E-01

Note: *1% significance, ** 5% significance, *** 10% significance

Table S4: Wind forecast errors by atmospheric stability condition for the LGBM model. The bolded numbers highlight the minimum error values.

one-step-ahead			three-step-ahead			Class	Height	Feature Set
MAE	NRMSE	STD	MAE	NRMSE	STD			
0.452	0.064	1.253	0.607	0.082	1.261	N	30	1
0.394	0.102	0.882	0.602	0.130	0.761	S		
0.459	0.128	0.916	0.646	0.180	0.924	U		
0.637	0.105	1.477	0.804	0.125	1.433	N	80	
0.407	0.078	1.032	0.63	0.118	0.933	S		
0.591	0.099	1.477	0.837	0.139	1.516	U		
0.451	0.065	1.251	0.613	0.083	1.256	N	30	2
0.4	0.102	0.876	0.593	0.127	0.757	S		
0.467	0.130	0.924	0.651	0.181	0.930	U		
0.636	0.105	1.471	0.783	0.123	1.411	N	80	
0.407	0.078	1.064	0.62	0.114	0.962	S		
0.595	0.100	1.475	0.822	0.136	1.490	U		
0.448	0.064	1.255	0.605	0.082	1.270	N	30	3
0.4	0.101	0.865	0.605	0.129	0.748	S		
0.472	0.131	0.931	0.656	0.181	0.916	U		
0.639	0.106	1.488	0.796	0.125	1.435	N	80	
0.404	0.077	1.056	0.619	0.115	0.938	S		
0.595	0.100	1.481	0.852	0.142	1.534	U		
0.442	0.063	1.233	0.608	0.082	1.255	N	30	4
0.408	0.103	0.845	0.601	0.129	0.733	S		
0.462	0.128	0.926	0.642	0.179	0.921	U		
0.633	0.104	1.458	0.799	0.125	1.389	N	80	
0.407	0.078	1.043	0.629	0.118	0.927	S		
0.587	0.098	1.484	0.839	0.140	1.505	U		
0.441	0.064	1.238	0.6	0.081	1.255	N	30	5
0.405	0.105	0.844	0.603	0.128	0.729	S		
0.457	0.129	0.932	0.644	0.179	0.910	U		
0.641	0.104	1.458	0.809	0.126	1.392	N	80	
0.405	0.078	1.055	0.621	0.115	0.956	S		
0.593	0.098	1.477	0.852	0.140	1.490	U		
0.439	0.063	1.232	0.599	0.080	1.250	N	30	6
0.404	0.104	0.843	0.614	0.130	0.733	S		
0.463	0.129	0.927	0.645	0.179	0.916	U		
0.637	0.105	1.449	0.8	0.125	1.387	N	80	
0.399	0.076	1.042	0.621	0.116	0.949	S		
0.598	0.100	1.479	0.839	0.139	1.487	U		

Table S5: Wind forecast errors by atmospheric stability condition for the SVR model. The bolded numbers highlight the minimum error values.

one-step-ahead			three-step-ahead			Class	Height	Feature Set
MAE	NRMSE	STD	MAE	NRMSE	STD			
0.613	0.078	1.230	0.737	0.092	1.150	N	30	1
0.617	0.125	0.965	0.828	0.154	0.834	S		
0.614	0.156	0.814	0.822	0.204	0.807	U		
1.132	0.155	1.468	1.126	0.158	1.341	N	80	
1.193	0.184	1.023	1.274	0.201	0.930	S		
0.951	0.137	1.055	1.022	0.157	1.139	U		
0.562	0.072	1.147	0.719	0.091	1.051	N	30	2
0.526	0.110	0.848	0.768	0.143	0.687	S		
0.723	0.177	0.740	0.901	0.221	0.781	U		
1.005	0.141	1.391	1.077	0.153	1.278	N	80	
1.093	0.171	0.912	1.314	0.205	0.921	S		
0.963	0.139	0.983	1.103	0.164	1.003	U		
0.535	0.070	1.273	0.699	0.089	1.118	N	30	3
0.575	0.114	0.898	0.744	0.141	0.743	S		
0.739	0.183	0.787	0.946	0.227	0.766	U		
1.06	0.150	1.672	1.096	0.156	1.456	N	80	
1.234	0.189	0.989	1.395	0.216	0.924	S		
0.876	0.130	1.218	1.034	0.156	1.205	U		
0.526	0.070	1.152	0.710	0.090	1.128	N	30	4
0.58	0.114	0.751	0.751	0.143	0.697	S		
0.728	0.175	0.805	0.918	0.220	0.783	U		
0.888	0.130	1.317	0.989	0.145	1.245	N	80	
0.856	0.141	0.910	1.151	0.187	0.913	S		
0.859	0.129	1.274	1.035	0.157	1.197	U		
0.533	0.070	1.158	0.686	0.089	1.048	N	30	5
0.617	0.117	0.856	0.719	0.137	0.725	S		
0.785	0.188	0.756	0.964	0.228	0.730	U		
0.925	0.133	1.326	0.980	0.142	1.215	N	80	
1.063	0.169	0.837	1.157	0.187	0.854	S		
0.936	0.140	1.213	1.211	0.179	1.142	U		
0.53	0.070	1.158	0.704	0.091	1.060	N	30	6
0.578	0.118	0.736	0.728	0.140	0.613	S		
0.731	0.179	0.807	0.975	0.234	0.767	U		
0.943	0.137	1.298	1.003	0.147	1.226	N	80	
0.985	0.158	0.883	1.101	0.181	0.876	S		
0.876	0.134	1.235	1.109	0.168	1.130	U		