

An Experimental Study on Decomposition-Based Deep Ensemble Learning for Traffic Flow Forecasting (Supplementary Material)

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1 Introduction

This is the full experimental results for bagging, time domain multi-resolution ensemble, Empirical Mode Decomposition (EMD), Ensemble Empirical Mode Decomposition (EEMD), and Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) in three test datasets for AJCAI submission "An Experimental Study on Decomposition-Based Deep Ensemble Learning for Traffic Flow Forecasting".

Mean aggregation is the baseline strategy for time domain multi-resolution ensemble and conventional bagging. Due to the nature of decomposition, sum aggregation is the baseline strategy for decomposition-based methods. We further apply linear regression and MLP as the optimised final learners to utilise the predictions generated from base learners. A standalone LSTM model, trained on the aggregated time-series data with an equal time interval and forecasting horizon, was also compared with the aforementioned methods as an additional baseline.

2 Supplementary section

Table S1. Results of the ensemble learning methods using optimised aggregation against baselines methods in Melbourne data in 10 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site14005	site14049	site14059	site14061	site14063
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	59.571	90.093	57.492	56.638	47.474
Bagging + mean	48.641	61.146	45.595	47.933	36.349
Bagging + linear	42.536	42.830	38.905	42.932	33.923
Bagging + MLP	47.573	60.660	45.151	46.321	35.760
Multi-reso + mean	49.031	65.619	51.342	53.779	39.157
Multi-reso + linear	40.921	43.860	37.984	39.806	32.725
Multi-reso + MLP	47.728	61.204	49.164	51.700	38.329
EMD + sum	25.495	41.054	36.986	35.786	33.445
EMD + linear	24.207	33.555	31.979	31.470	28.858
EMD + MLP	27.685	38.204	34.679	36.811	35.994
EEMD + sum	34.242	30.374	33.360	46.221	27.455
EEMD + linear	22.142	26.747	22.730	21.193	17.567
EEMD + MLP	23.975	27.544	23.122	24.551	22.321
CEEMDAN + sum	28.040	37.329	44.193	35.428	29.592
CEEMDAN + linear	26.990	31.893	35.267	33.211	27.943
CEEMDAN + MLP	27.632	29.299	40.161	32.815	28.029
I = 240 minutes					
LSTM	54.201	72.146	55.417	55.770	39.333
Bagging + mean	49.042	55.783	47.451	49.639	36.745
Bagging + linear	41.615	42.843	38.320	41.479	34.100
Bagging + MLP	47.317	54.854	46.411	48.515	36.542
Multi-reso + mean	47.799	60.911	49.050	49.571	37.377
Multi-reso + linear	40.917	43.729	38.918	39.899	32.722
Multi-reso + MLP	47.111	58.468	48.014	47.639	36.715
EMD + sum	32.267	46.931	36.186	33.227	31.250
EMD + linear	26.184	31.717	31.878	29.021	30.491
EMD + MLP	37.696	33.864	35.806	33.640	31.292
EEMD + sum	31.110	29.354	22.904	30.757	15.993
EEMD + linear	20.579	25.382	21.272	22.127	15.363
EEMD + MLP	23.927	25.726	21.505	23.093	25.374
CEEMDAN + sum	31.853	40.098	38.695	30.779	27.626
CEEMDAN + linear	28.842	31.542	30.484	29.071	23.270
CEEMDAN + MLP	30.957	35.395	29.155	37.400	30.473
I = 360 minutes					
LSTM	58.276	76.819	54.426	54.874	44.023
Bagging + mean	49.079	56.300	46.259	48.500	37.524
Bagging + linear	41.193	42.562	39.512	42.233	34.382
Bagging + MLP	48.326	55.093	46.016	46.717	37.167
Multi-reso + mean	49.396	60.222	46.547	50.556	38.976
Multi-reso + linear	40.547	44.325	38.253	40.455	31.959
Multi-reso + MLP	48.223	57.618	45.247	49.195	38.320
EMD + sum	23.204	48.403	35.376	31.975	24.332
EMD + linear	19.965	33.480	28.697	30.292	22.381
EMD + MLP	24.914	43.897	35.089	33.223	22.920
EEMD + sum	27.552	30.033	31.024	27.598	25.395
EEMD + linear	18.072	26.038	21.379	22.792	18.165
EEMD + MLP	23.655	28.645	22.166	25.464	18.232
CEEMDAN + sum	46.705	48.293	45.486	47.839	26.736
CEEMDAN + linear	28.026	38.748	40.342	37.731	20.284
CEEMDAN + MLP	43.151	39.521	45.883	42.264	29.699

Table S2. Results of the ensemble learning methods using optimised aggregation against baselines methods in Melbourne data in 20 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site14005	site14049	site14059	site14061	site14063
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	168.088	220.471	157.780	185.657	126.495
Bagging + mean	171.022	196.109	166.367	175.077	131.451
Bagging + linear	151.968	146.785	130.233	132.041	107.955
Bagging + MLP	171.727	194.182	166.648	175.574	131.652
Multi-reso + mean	157.531	187.951	165.750	172.591	129.091
Multi-reso + linear	133.143	132.405	118.111	119.863	97.361
Multi-reso + MLP	155.654	181.271	161.850	168.124	126.484
EMD + sum	94.398	134.153	114.826	75.965	64.813
EMD + linear	92.409	133.055	114.661	74.660	64.449
EMD + MLP	90.155	134.548	115.101	73.298	64.164
EEMD + sum	69.780	106.008	85.209	78.267	63.857
EEMD + linear	66.627	97.370	78.276	76.613	59.646
EEMD + MLP	67.008	100.784	83.639	79.671	60.903
CEEMDAN + sum	68.625	99.215	114.977	120.708	78.895
CEEMDAN + linear	68.147	96.676	115.781	120.438	76.568
CEEMDAN + MLP	92.812	97.215	106.806	124.112	64.261
I = 240 minutes					
LSTM	181.545	183.589	169.875	160.861	148.645
Bagging + mean	170.790	197.453	164.540	172.695	130.666
Bagging + linear	141.775	153.691	125.302	133.091	107.187
Bagging + MLP	172.397	196.333	165.668	173.398	131.635
Multi-reso + mean	158.073	170.478	142.550	144.793	113.019
Multi-reso + linear	129.195	130.757	107.494	117.146	89.574
Multi-reso + MLP	156.143	165.349	136.996	139.077	109.473
EMD + sum	107.169	184.028	85.590	128.544	92.563
EMD + linear	103.339	150.136	83.122	115.489	87.110
EMD + MLP	106.087	156.120	85.012	126.978	91.461
EEMD + sum	69.692	147.998	69.372	70.467	59.527
EEMD + linear	66.329	107.002	65.186	66.873	60.781
EEMD + MLP	68.234	133.414	66.697	66.993	59.884
CEEMDAN + sum	101.131	139.536	110.442	117.769	102.258
CEEMDAN + linear	102.154	134.143	103.457	111.979	93.629
CEEMDAN + MLP	105.902	141.672	124.281	116.937	98.208
I = 360 minutes					
LSTM	181.859	171.747	159.916	157.990	121.795
Bagging + mean	170.753	197.440	171.016	175.365	131.831
Bagging + linear	145.660	152.760	122.589	133.231	111.334
Bagging + MLP	172.268	195.618	170.662	175.939	132.947
Multi-reso + mean	152.236	172.159	138.852	137.994	118.081
Multi-reso + linear	134.852	127.983	106.525	111.063	87.064
Multi-reso + MLP	150.013	167.509	133.905	132.017	114.718
EMD + sum	90.251	160.173	73.654	106.500	80.100
EMD + linear	91.061	152.928	73.959	109.649	71.280
EMD + MLP	90.629	155.914	74.255	104.050	73.587
EEMD + sum	62.182	81.385	73.244	77.354	46.707
EEMD + linear	59.541	74.574	70.516	69.891	42.520
EEMD + MLP	60.732	77.221	70.544	73.242	41.942
CEEMDAN + sum	86.679	121.532	132.379	125.620	62.708
CEEMDAN + linear	89.389	120.010	124.748	121.857	62.178
CEEMDAN + MLP	90.764	120.496	127.628	121.756	62.553

Table S3. Results of the ensemble learning methods using optimised aggregation against baselines methods in Melbourne data in 30 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site14005	site14049	site14059	site14061	site14063
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	168.088	220.471	157.780	185.657	126.495
Bagging + mean	171.022	196.109	166.367	175.077	131.451
Bagging + linear	151.968	146.785	130.233	132.041	107.955
Bagging + MLP	171.727	194.182	166.648	175.574	131.652
Multi-reso + mean	157.531	187.951	165.750	172.591	129.091
Multi-reso + linear	133.143	132.405	118.111	119.863	97.361
Multi-reso + MLP	155.654	181.271	161.850	168.124	126.484
EMD + sum	94.398	134.153	114.826	75.965	64.813
EMD + linear	92.409	133.055	114.661	74.660	64.449
EMD + MLP	90.155	134.548	115.101	73.298	64.164
EEMD + sum	69.780	106.008	85.209	78.267	63.857
EEMD + linear	66.627	97.370	78.276	76.613	59.646
EEMD + MLP	67.008	100.784	83.639	79.671	60.903
CEEMDAN + sum	68.625	99.215	114.977	120.708	78.895
CEEMDAN + linear	68.147	96.676	115.781	120.438	76.568
CEEMDAN + MLP	92.812	97.215	106.806	124.112	64.261
I = 240 minutes					
LSTM	181.545	183.589	169.875	160.861	148.645
Bagging + mean	170.790	197.453	164.540	172.695	130.666
Bagging + linear	141.775	153.691	125.302	133.091	107.187
Bagging + MLP	172.397	196.333	165.668	173.398	131.635
Multi-reso + mean	158.073	170.478	142.550	144.793	113.019
Multi-reso + linear	129.195	130.757	107.494	117.146	89.574
Multi-reso + MLP	156.143	165.349	136.996	139.077	109.473
EMD + sum	107.169	184.028	85.590	128.544	92.563
EMD + linear	103.339	150.136	83.122	115.489	87.110
EMD + MLP	106.087	156.120	85.012	126.978	91.461
EEMD + sum	69.692	147.998	69.372	70.467	59.527
EEMD + linear	66.329	107.002	65.186	66.873	60.781
EEMD + MLP	68.234	133.414	66.697	66.993	59.884
CEEMDAN + sum	101.131	139.536	110.442	117.769	102.258
CEEMDAN + linear	102.154	134.143	103.457	111.979	93.629
CEEMDAN + MLP	105.902	141.672	124.281	116.937	98.208
I = 360 minutes					
LSTM	181.859	171.747	159.916	157.990	121.795
Bagging + mean	170.753	197.440	171.016	175.365	131.831
Bagging + linear	145.660	152.760	122.589	133.231	111.334
Bagging + MLP	172.268	195.618	170.662	175.939	132.947
Multi-reso + mean	152.236	172.159	138.852	137.994	118.081
Multi-reso + linear	134.852	127.983	106.525	111.063	87.064
Multi-reso + MLP	150.013	167.509	133.905	132.017	114.718
EMD + sum	90.251	160.173	73.654	106.500	80.100
EMD + linear	91.061	152.928	73.959	109.649	71.280
EMD + MLP	90.629	155.914	74.255	104.050	73.587
EEMD + sum	62.182	81.385	73.244	77.354	46.707
EEMD + linear	59.541	74.574	70.516	69.891	42.520
EEMD + MLP	60.732	77.221	70.544	73.242	41.942
CEEMDAN + sum	86.679	121.532	132.379	125.620	62.708
CEEMDAN + linear	89.389	120.010	124.748	121.857	62.178
CEEMDAN + MLP	90.764	120.496	127.628	121.756	62.553

Table S4. Results of the ensemble learning methods using optimised aggregation against baselines methods in PEMS data in 10 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site400146	site400486	site400740	site400835	site400949
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	74.210	95.186	69.197	43.661	67.437
Bagging + mean	63.393	69.447	59.565	40.055	50.346
Bagging + linear	57.508	63.582	57.286	35.420	46.634
Bagging + MLP	63.210	68.575	59.188	39.257	49.421
Multi-reso + mean	65.866	75.381	65.440	45.827	62.504
Multi-reso + linear	55.835	60.063	56.178	34.664	46.525
Multi-reso + MLP	64.717	74.046	66.055	46.739	61.520
EMD + sum	36.803	41.677	37.412	25.633	30.375
EMD + linear	32.911	37.301	34.304	23.732	28.881
EMD + MLP	32.518	38.912	39.180	24.304	29.482
EEMD + sum	38.626	31.079	25.684	18.561	25.145
EEMD + linear	26.658	30.187	20.265	18.589	22.857
EEMD + MLP	27.630	31.056	24.384	20.067	25.644
CEEMDAN + sum	31.488	40.311	35.193	21.387	34.909
CEEMDAN + linear	31.677	38.096	33.051	21.808	30.922
CEEMDAN + MLP	33.426	38.922	33.987	22.749	38.762
I = 240 minutes					
LSTM	82.859	87.283	80.890	59.845	89.982
Bagging + mean	63.297	69.144	60.009	38.638	51.755
Bagging + linear	58.771	66.109	57.337	36.721	47.271
Bagging + MLP	61.773	69.199	59.772	38.545	50.604
Multi-reso + mean	71.558	77.886	72.268	48.236	76.166
Multi-reso + linear	56.717	60.066	57.284	35.351	47.023
Multi-reso + MLP	68.663	76.177	71.119	49.303	76.447
EMD + sum	43.433	40.105	46.666	29.277	40.951
EMD + linear	37.175	39.025	44.193	25.547	34.012
EMD + MLP	42.160	40.696	49.538	28.260	40.863
EEMD + sum	23.797	29.070	27.703	22.388	26.793
EEMD + linear	22.606	24.265	23.139	18.984	22.651
EEMD + MLP	22.390	26.655	24.180	19.401	23.063
CEEMDAN + sum	38.233	41.410	31.816	23.424	29.296
CEEMDAN + linear	32.416	36.772	29.579	23.280	27.285
CEEMDAN + MLP	36.058	36.579	30.353	24.792	29.141
I = 360 minutes					
LSTM	70.397	83.007	79.897	65.375	99.269
Bagging + mean	64.009	71.828	60.651	40.186	53.293
Bagging + linear	58.748	65.843	57.411	37.392	46.608
Bagging + MLP	62.325	71.246	60.443	39.778	51.403
Multi-reso + mean	76.734	81.010	76.929	50.364	86.898
Multi-reso + linear	55.787	61.419	57.582	35.423	48.690
Multi-reso + MLP	74.782	81.450	76.489	50.475	88.545
EMD + sum	42.922	55.650	42.379	24.287	47.895
EMD + linear	37.178	47.242	39.528	23.018	34.960
EMD + MLP	42.679	50.803	40.105	24.510	41.591
EEMD + sum	30.297	35.644	23.986	20.205	34.822
EEMD + linear	25.029	25.786	22.673	20.369	23.690
EEMD + MLP	25.784	27.664	21.605	22.191	30.488
CEEMDAN + sum	41.680	40.842	35.493	26.560	31.937
CEEMDAN + linear	33.016	35.098	33.669	26.311	27.708
CEEMDAN + MLP	37.297	39.805	40.940	26.449	30.149

Table S5. Results of the ensemble learning methods using optimised aggregation against baselines methods in PEMS data in 20 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site400146	site400486	site400740	site400835	site400949
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	133.075	146.974	148.089	144.826	132.715
Bagging + mean	118.992	131.929	112.738	76.785	104.224
Bagging + linear	117.692	127.985	116.555	78.680	97.994
Bagging + MLP	119.203	132.144	112.607	76.464	103.964
Multi-reso + mean	126.986	136.431	143.158	83.218	125.725
Multi-reso + linear	115.980	124.559	115.052	66.207	98.794
Multi-reso + MLP	126.362	135.675	143.974	78.646	128.025
EMD + sum	91.145	81.133	76.528	43.986	72.339
EMD + linear	85.065	82.919	71.604	45.005	74.764
EMD + MLP	88.838	81.813	72.613	46.336	74.005
EEMD + sum	71.062	117.795	61.700	47.431	67.035
EEMD + linear	65.068	107.893	55.591	43.465	60.729
EEMD + MLP	71.645	109.237	59.585	43.611	60.841
CEEMDAN + sum	85.950	81.217	76.581	41.579	78.385
CEEMDAN + linear	88.326	73.592	69.779	41.795	73.550
CEEMDAN + MLP	79.148	78.088	67.784	40.038	79.937
I = 240 minutes					
LSTM	147.625	137.407	155.411	98.472	164.325
Bagging + mean	119.807	132.694	113.871	75.899	105.094
Bagging + linear	117.305	128.898	117.162	76.791	98.596
Bagging + MLP	118.648	133.009	114.082	76.557	101.990
Multi-reso + mean	140.900	136.965	136.651	87.100	161.905
Multi-reso + linear	119.998	121.601	116.722	71.500	103.035
Multi-reso + MLP	143.155	130.371	139.374	86.332	164.529
EMD + sum	80.275	96.013	78.777	79.871	88.366
EMD + linear	78.001	80.289	70.235	84.445	76.271
EMD + MLP	79.731	82.628	73.811	75.783	84.757
EEMD + sum	72.854	83.214	72.659	47.720	72.244
EEMD + linear	60.919	77.726	60.212	45.496	65.726
EEMD + MLP	66.976	79.710	75.930	45.741	66.999
CEEMDAN + sum	66.826	68.014	76.538	42.209	81.034
CEEMDAN + linear	61.579	69.235	69.501	39.853	67.865
CEEMDAN + MLP	67.919	84.858	71.655	40.252	79.975
I = 360 minutes					
LSTM	166.108	139.929	162.786	104.095	167.490
Bagging + mean	122.267	135.085	115.927	76.113	107.157
Bagging + linear	118.564	131.861	118.236	74.265	101.272
Bagging + MLP	122.004	134.239	114.728	75.735	105.097
Multi-reso + mean	154.815	145.259	146.757	90.288	169.292
Multi-reso + linear	117.772	123.531	129.824	73.425	114.509
Multi-reso + MLP	160.246	143.774	148.819	89.455	169.243
EMD + sum	86.800	98.300	89.211	50.431	93.474
EMD + linear	77.269	82.428	85.310	46.635	78.355
EMD + MLP	81.869	84.544	85.183	45.626	76.559
EEMD + sum	91.277	84.305	69.767	46.200	91.169
EEMD + linear	64.976	70.494	58.096	42.970	58.913
EEMD + MLP	78.378	73.687	60.149	43.044	83.273
CEEMDAN + sum	119.476	73.657	62.490	41.517	81.735
CEEMDAN + linear	87.661	69.200	54.985	41.810	68.414
CEEMDAN + MLP	106.243	79.491	65.912	41.727	71.553

Table S6. Results of the ensemble learning methods using optimised aggregation against baselines methods in PEMS data in 30 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site400146	site400486	site400740	site400835	site400949
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	347.114	275.020	306.900	233.097	255.978
Bagging + mean	179.064	190.054	194.409	120.209	185.453
Bagging + linear	185.026	193.805	194.434	120.021	201.180
Bagging + MLP	178.639	190.011	195.336	118.688	185.519
Multi-reso + mean	252.966	217.519	267.434	164.680	229.419
Multi-reso + linear	212.477	196.551	194.445	120.491	161.811
Multi-reso + MLP	252.237	216.580	246.188	156.311	221.669
EMD + sum	154.950	154.136	163.072	83.220	137.496
EMD + linear	137.374	149.726	155.020	73.891	127.535
EMD + MLP	148.919	159.985	157.794	79.282	145.001
EEMD + sum	126.484	161.490	119.999	71.968	120.528
EEMD + linear	101.514	133.644	107.651	69.463	120.312
EEMD + MLP	109.384	160.305	114.941	70.540	125.820
CEEMDAN + sum	138.653	114.664	133.088	69.362	105.504
CEEMDAN + linear	133.875	109.814	118.088	69.146	106.611
CEEMDAN + MLP	131.853	111.220	117.435	70.492	109.445
I = 240 minutes					
LSTM	244.361	212.736	222.166	159.520	267.827
Bagging + mean	178.141	190.202	193.742	118.201	186.385
Bagging + linear	196.713	196.995	188.366	120.878	178.264
Bagging + MLP	179.014	189.731	193.113	118.096	186.214
Multi-reso + mean	210.473	192.185	200.962	153.575	238.733
Multi-reso + linear	232.736	195.622	179.322	116.632	193.241
Multi-reso + MLP	214.166	191.754	202.756	154.965	247.321
EMD + sum	185.522	162.560	159.811	89.945	148.276
EMD + linear	154.303	154.725	143.998	84.546	150.965
EMD + MLP	178.007	160.064	153.173	87.940	156.057
EEMD + sum	147.032	140.125	131.821	73.853	134.803
EEMD + linear	135.253	146.182	120.642	72.668	130.091
EEMD + MLP	136.513	143.850	141.334	73.813	133.861
CEEMDAN + sum	112.835	125.459	130.040	73.129	116.233
CEEMDAN + linear	111.322	125.433	122.084	71.875	106.259
CEEMDAN + MLP	111.566	128.340	128.334	71.901	113.805
I = 360 minutes					
LSTM	252.933	201.710	221.925	154.749	254.216
Bagging + mean	179.783	192.059	196.137	119.196	188.712
Bagging + linear	195.987	213.144	181.766	128.139	185.329
Bagging + MLP	180.170	191.961	194.103	118.880	189.456
Multi-reso + mean	212.791	190.395	212.053	145.035	230.754
Multi-reso + linear	213.717	197.707	202.701	131.517	192.496
Multi-reso + MLP	211.335	188.897	213.145	134.528	226.679
EMD + sum	154.717	196.361	166.713	76.241	187.304
EMD + linear	148.737	160.097	148.733	79.279	150.803
EMD + MLP	149.770	161.785	155.154	78.601	168.541
EEMD + sum	155.914	151.313	146.185	79.237	140.613
EEMD + linear	128.305	150.337	135.671	80.959	118.754
EEMD + MLP	137.096	149.727	153.593	90.200	119.457
CEEMDAN + sum	137.648	143.562	120.376	74.357	128.844
CEEMDAN + linear	124.722	130.630	109.918	71.150	127.995
CEEMDAN + MLP	134.841	136.709	114.965	74.585	125.268

Table S7. Results of the ensemble learning methods using optimised aggregation against baselines methods in Portland data in 10 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site1345	site1353	site1361	site1387	site1395
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	21.020	25.042	29.678	20.465	23.908
Bagging + mean	19.795	23.435	26.006	17.530	19.541
Bagging + linear	19.814	23.371	26.175	17.675	19.544
Bagging + MLP	19.759	22.371	25.767	17.047	17.607
Multi-reso + mean	20.005	23.832	26.778	18.944	23.183
Multi-reso + linear	19.484	22.173	25.002	16.083	17.480
Multi-reso + MLP	19.954	23.672	26.614	18.422	22.273
EMD + sum	12.064	13.641	16.369	13.250	17.793
EMD + linear	11.006	13.258	15.576	11.022	11.387
EMD + MLP	12.021	14.145	15.085	12.567	17.792
EEMD + sum	8.524	12.673	12.569	9.811	8.976
EEMD + linear	8.318	9.942	11.758	7.681	7.493
EEMD + MLP	8.248	9.806	13.087	9.518	8.231
CEEMDAN + sum	13.550	14.535	14.784	12.708	13.855
CEEMDAN + linear	10.568	13.287	14.419	10.000	12.719
CEEMDAN + MLP	12.186	14.095	13.139	14.453	14.845
I = 240 minutes					
LSTM	20.451	25.329	25.914	18.271	21.966
Bagging + mean	19.364	24.741	24.996	17.350	19.691
Bagging + linear	19.449	23.410	24.512	16.306	17.844
Bagging + MLP	19.363	24.640	25.105	17.444	19.678
Multi-reso + mean	19.888	23.944	25.842	16.916	20.084
Multi-reso + linear	18.912	22.780	23.527	15.451	17.113
Multi-reso + MLP	19.913	23.996	25.836	17.062	19.945
EMD + sum	13.015	16.005	17.170	11.748	23.317
EMD + linear	18.723	14.205	18.220	10.790	18.597
EMD + MLP	15.562	14.865	18.930	14.348	18.876
EEMD + sum	9.517	12.401	11.391	8.887	9.301
EEMD + linear	8.160	10.899	10.512	9.098	7.837
EEMD + MLP	9.737	14.189	11.948	9.562	8.094
CEEMDAN + sum	11.487	15.663	14.222	10.544	12.692
CEEMDAN + linear	11.171	13.096	13.412	9.596	11.560
CEEMDAN + MLP	11.521	17.718	14.162	10.630	12.141
I = 360 minutes					
LSTM	20.143	24.555	27.379	19.516	21.367
Bagging + mean	18.844	23.998	24.885	17.151	19.715
Bagging + linear	18.843	22.451	23.876	16.287	17.057
Bagging + MLP	18.804	23.943	24.797	16.966	19.075
Multi-reso + mean	19.043	23.685	25.942	17.903	20.536
Multi-reso + linear	18.294	22.164	23.400	15.792	16.399
Multi-reso + MLP	18.946	23.700	25.847	17.718	19.413
EMD + sum	11.856	15.293	17.135	16.659	24.645
EMD + linear	22.578	13.633	17.363	13.991	13.914
EMD + MLP	24.361	14.870	17.187	14.858	19.964
EEMD + sum	8.237	11.083	12.530	11.393	10.825
EEMD + linear	7.631	9.541	10.252	9.035	8.980
EEMD + MLP	9.473	11.616	11.081	11.077	9.058
CEEMDAN + sum	11.407	17.029	17.189	10.364	16.084
CEEMDAN + linear	10.073	12.479	13.960	9.032	10.508
CEEMDAN + MLP	11.228	13.083	15.912	10.982	15.242

Table S8. Results of the ensemble learning methods using optimised aggregation against baselines methods in Portland data in 20 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site1345	site1353	site1361	site1387	site1395
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	39.381	44.821	50.602	37.168	44.716
Bagging + mean	39.316	41.808	49.585	33.762	41.381
Bagging + linear	42.218	42.280	46.893	28.209	31.618
Bagging + MLP	39.258	41.718	49.428	33.211	39.633
Multi-reso + mean	40.224	40.374	50.527	33.501	35.999
Multi-reso + linear	41.637	42.472	46.673	30.155	33.273
Multi-reso + MLP	40.201	40.369	50.460	33.189	35.463
EMD + sum	22.132	20.170	30.466	21.985	21.147
EMD + linear	20.672	18.030	29.024	20.380	20.493
EMD + MLP	19.866	20.549	27.255	21.673	21.263
EEMD + sum	13.288	15.711	17.038	13.733	18.827
EEMD + linear	12.955	14.926	15.739	12.504	16.683
EEMD + MLP	20.178	15.171	16.781	14.260	21.990
CEEMDAN + sum	21.068	24.319	28.776	23.455	22.078
CEEMDAN + linear	19.909	22.721	28.616	22.473	19.486
CEEMDAN + MLP	20.135	22.947	31.063	23.268	20.961
I = 240 minutes					
LSTM	38.545	46.051	48.752	36.320	56.026
Bagging + mean	39.788	44.989	48.745	32.989	36.855
Bagging + linear	40.922	44.454	45.572	30.164	33.605
Bagging + MLP	39.683	44.951	48.688	32.642	36.020
Multi-reso + mean	37.609	44.828	47.305	32.470	42.557
Multi-reso + linear	40.715	42.253	43.137	26.834	30.283
Multi-reso + MLP	37.584	44.601	46.616	32.250	40.838
EMD + sum	32.424	21.841	32.076	24.368	32.340
EMD + linear	24.251	21.384	29.696	22.633	27.487
EMD + MLP	29.270	24.243	29.967	23.760	31.962
EEMD + sum	14.928	17.335	18.666	15.649	16.019
EEMD + linear	14.047	16.905	16.532	14.960	12.924
EEMD + MLP	16.302	24.720	17.920	15.627	13.064
CEEMDAN + sum	20.906	23.124	26.846	17.692	21.260
CEEMDAN + linear	19.770	22.847	24.211	16.887	19.660
CEEMDAN + MLP	20.372	24.527	26.050	17.520	21.914
I = 360 minutes					
LSTM	40.172	45.644	49.589	37.886	47.773
Bagging + mean	38.360	43.397	47.730	33.153	35.451
Bagging + linear	40.002	42.855	44.057	30.693	32.604
Bagging + MLP	38.229	43.394	47.541	32.435	34.359
Multi-reso + mean	37.353	43.578	46.905	32.600	40.750
Multi-reso + linear	39.170	40.603	41.934	26.943	29.600
Multi-reso + MLP	37.604	43.307	46.369	31.647	39.517
EMD + sum	31.402	25.692	58.832	25.164	31.067
EMD + linear	35.637	26.100	36.549	25.362	50.061
EMD + MLP	33.804	29.097	39.576	25.491	44.121
EEMD + sum	14.751	16.835	20.582	18.319	15.386
EEMD + linear	13.694	15.024	18.321	17.089	13.479
EEMD + MLP	15.762	16.381	27.427	18.051	13.593
CEEMDAN + sum	18.815	21.707	39.981	19.234	19.094
CEEMDAN + linear	18.212	22.537	37.183	19.079	17.569
CEEMDAN + MLP	18.294	23.977	37.993	20.821	18.761

Table S9. Results of the ensemble learning methods using optimised aggregation against baselines methods in Portland data in 30 minutes forecasting horizons. The method(s) highlighted in bold if its performance is statistically the best one(s).

	site1345	site1353	site1361	site1387	site1395
Model	RMSE	RMSE	RMSE	RMSE	RMSE
I = 120 minutes					
LSTM	60.765	70.238	75.965	57.004	76.349
Bagging + mean	56.294	61.852	68.894	51.997	52.768
Bagging + linear	61.598	63.751	64.984	49.586	50.871
Bagging + MLP	56.012	61.477	69.178	51.734	52.100
Multi-reso + mean	57.882	67.904	71.891	54.734	62.443
Multi-reso + linear	59.973	59.972	66.384	50.051	51.888
Multi-reso + MLP	58.559	67.904	72.548	54.053	61.330
EMD + sum	27.711	45.268	44.769	47.770	30.416
EMD + linear	26.808	45.479	46.488	47.337	29.819
EMD + MLP	27.266	60.998	45.834	49.246	31.495
EEMD + sum	21.039	24.166	25.304	22.800	33.818
EEMD + linear	20.429	21.556	26.330	20.460	28.073
EEMD + MLP	21.810	23.545	27.552	20.749	31.163
CEEMDAN + sum	24.625	34.182	39.048	33.644	28.063
CEEMDAN + linear	22.562	32.419	38.196	32.995	26.426
CEEMDAN + MLP	24.557	33.448	39.559	40.729	26.762
I = 240 minutes					
LSTM	58.752	69.169	72.222	51.240	79.002
Bagging + mean	55.598	65.837	66.738	51.625	53.753
Bagging + linear	60.896	61.428	64.536	48.248	51.352
Bagging + MLP	55.741	66.032	66.598	51.534	53.216
Multi-reso + mean	57.147	63.440	67.926	51.585	66.472
Multi-reso + linear	57.213	56.085	55.943	41.921	45.228
Multi-reso + MLP	57.329	62.650	60.188	50.266	66.655
EMD + sum	29.863	33.403	51.907	29.797	57.410
EMD + linear	37.100	32.233	46.791	30.602	68.117
EMD + MLP	30.692	34.963	47.628	37.908	48.969
EEMD + sum	19.920	21.551	25.640	24.545	26.932
EEMD + linear	18.991	21.166	24.012	22.546	23.120
EEMD + MLP	19.632	33.679	25.062	24.127	25.840
CEEMDAN + sum	25.114	41.015	38.729	38.924	32.413
CEEMDAN + linear	25.008	40.442	37.090	36.295	29.697
CEEMDAN + MLP	24.865	48.673	35.858	38.908	46.531
I = 360 minutes					
LSTM	59.294	69.644	70.305	57.596	78.789
Bagging + mean	53.857	63.174	66.169	51.611	54.542
Bagging + linear	58.915	61.673	63.307	49.102	51.735
Bagging + MLP	53.931	63.032	66.060	51.767	53.712
Multi-reso + mean	55.312	61.866	66.749	50.798	67.004
Multi-reso + linear	57.549	61.059	53.578	40.682	46.467
Multi-reso + MLP	53.847	63.122	66.105	51.541	54.209
EMD + sum	28.417	29.472	45.681	33.738	65.530
EMD + linear	38.038	27.775	45.868	31.796	71.370
EMD + MLP	28.603	27.437	63.385	32.252	63.447
EEMD + sum	24.247	24.587	20.250	26.875	29.347
EEMD + linear	22.961	22.111	19.255	22.750	26.803
EEMD + MLP	23.153	24.216	20.652	24.780	290.944
CEEMDAN + sum	25.654	36.363	35.430	32.666	42.373
CEEMDAN + linear	23.523	34.827	34.698	31.361	37.310
CEEMDAN + MLP	27.589	35.405	37.025	31.258	46.978