Intercomparison of operational wave forecasting systems against buoys: data from ECMWF, MetOffice, FNMOC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA and KMA
May 2008 to July 2008

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August 11, 2008

0.1 Forewords

Outputs from different operational forecasting centres are compared to buoy and platform data as broadcasted to the meteorological community via the Global Telecommunication System (GTS). On a monthly basis, data are gathered informally from operational weather services with an interest in wave forecasting (Bidlot and Holt, 2006). The different data sets are subsequently merged and made available to all participating partners for further evaluation. In this documents, examples, in graphical and tabular forms, are shown. These results have been processed at ECMWF and should served as an example to the kind of information that could be obtained from such comparison. No statement of quality, nor reasons why the different systems are performing differently will be given.

0.2 Data

Before using observations for verification, care has to be taken to process the data to remove any erroneous observations and also in order to match the scale of both model and observations. This scale matching is achieved by averaging the hourly data in ± 2 hour time windows centered on the four major synoptic times corresponding to the normal model output times. The original quality control and averaging procedure was discussed in Bidlot *et al.* (2002). It was extended to include platform data as described in Sætra and Bidlot (2004). Note that in this paper we refer to these data as buoy data since most of them are from moored buoys, except if stated otherwise.

The intercomparison relies on the exchange of model output at buoy locations. An agreed upon list of locations is used where observations are known to be available. Because buoy networks are changing with time, as witnessed by a rapid increase in the number of buoys available via the GTS since the mid-nineties, updates to the list have been necessary. Not all participating centres have been able to update their list however. Other participants are only running limited area model(s) or do produce the parameter(s) that can be compared to the buoy data. Because of the limited number of buoys, a fair comparison between the different systems can only be achieved if the same number of buoys and the same number of buoy-model collocations are used.

In this document, data that are common to ECMWF, MetOffice, FNMOC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA and KMA are used. The other participants are left blank in the plots below.

References

Bidlot J.-R., D. J. Holmes, P. A. Wittmann, R. Lalbeharry, H. S. Chen, 2002: Intercomparison of the performance of operational ocean wave forecasting systems with buoy data. *Wea. Forecasting*, **17**, 287-310.

Bidlot J.-R. and M.W. Holt, 2006: Verification of operational global and regional wave forecasting systems against measurements from moored buoys. *JCOMM Technical Report*, **30**. WMO/TD-No. 1333.

Sætra, Ø. and J.-R. Bidlot, 2004: On the potential benefit of using probabilistic forecast for waves and marine winds based on the ECMWF ensemble prediction system. *Wea. Forecasting*, **19**, 673-689.

0.3 Results

In the remaining pages, some of the results of the comparison with buoys are presented for all common buoys and for common buoys within a sub-area as displayed by the corresponding maps. Summary forecast scores are shown first, followed by density scatter diagrams with associated statistics for each subarea. Only common data to ECMWF, MetOffice, FNMOC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA and KMA are used.

0.3.1 Comparison for all buoys

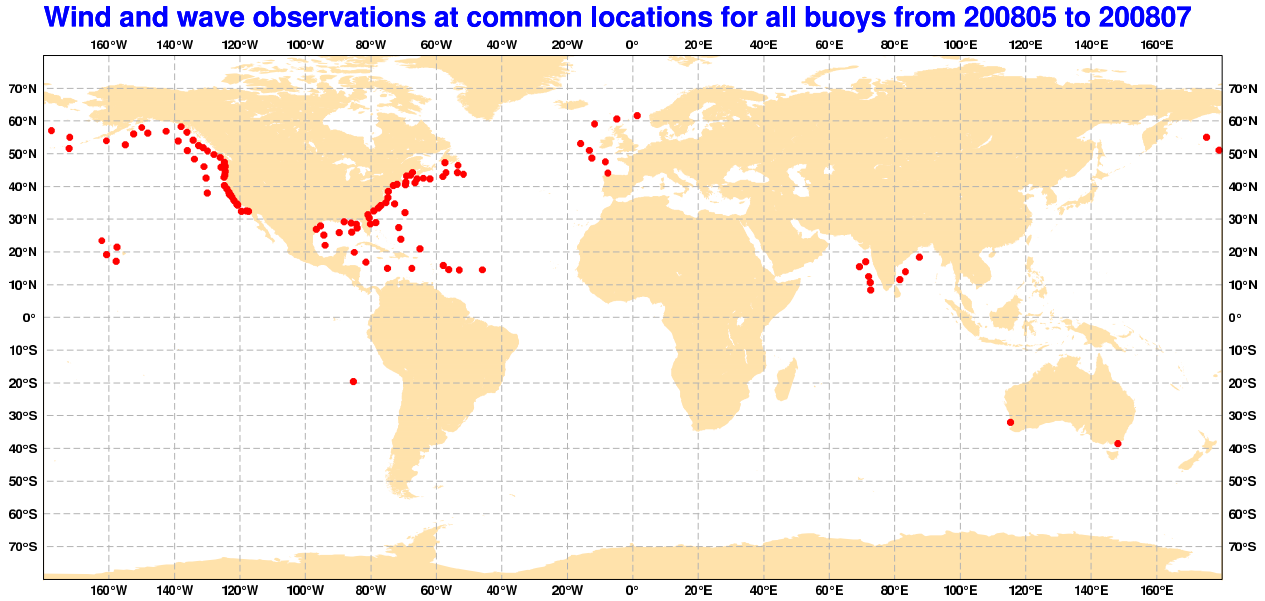
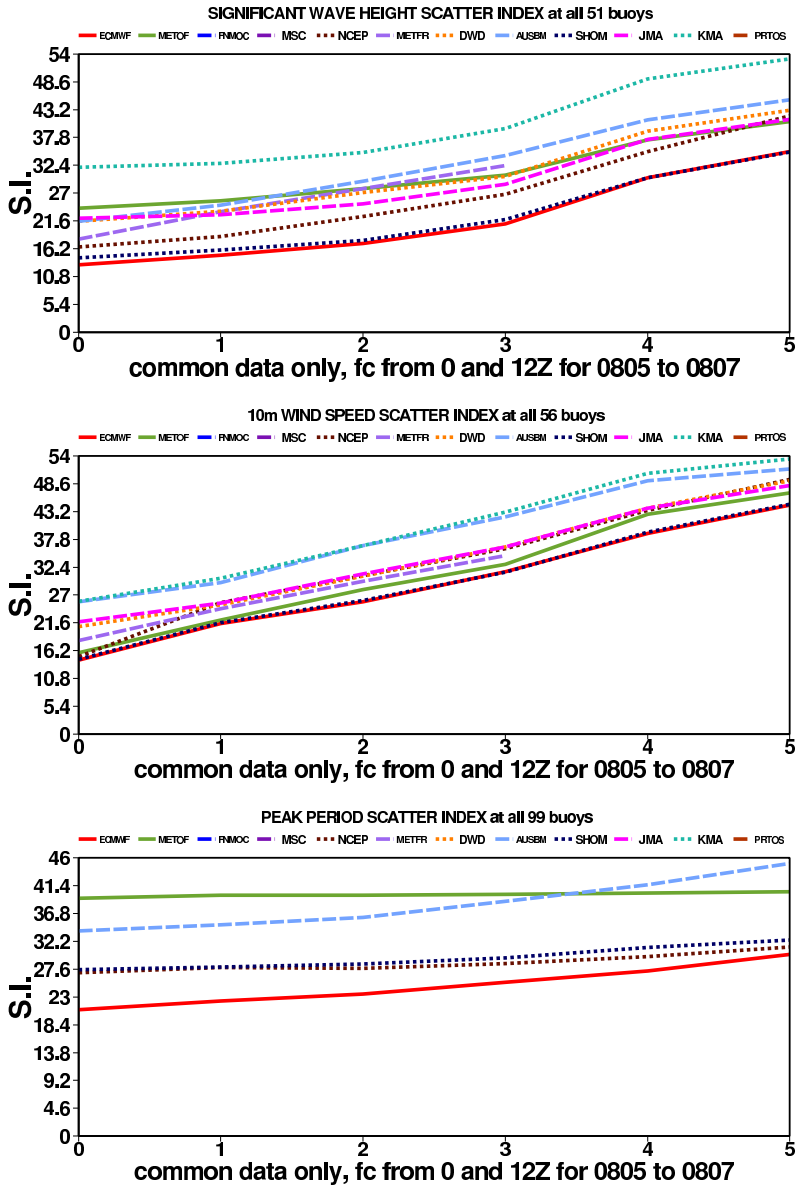
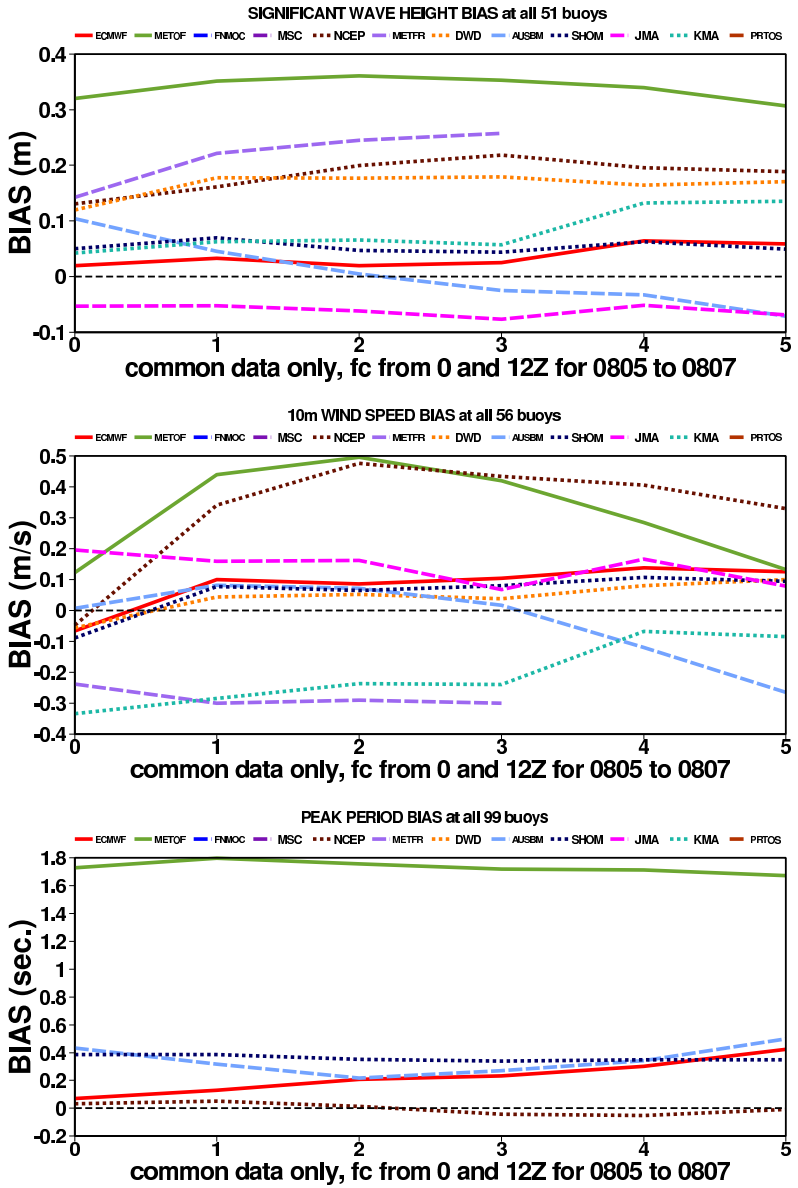


Figure 1: Buoy locations

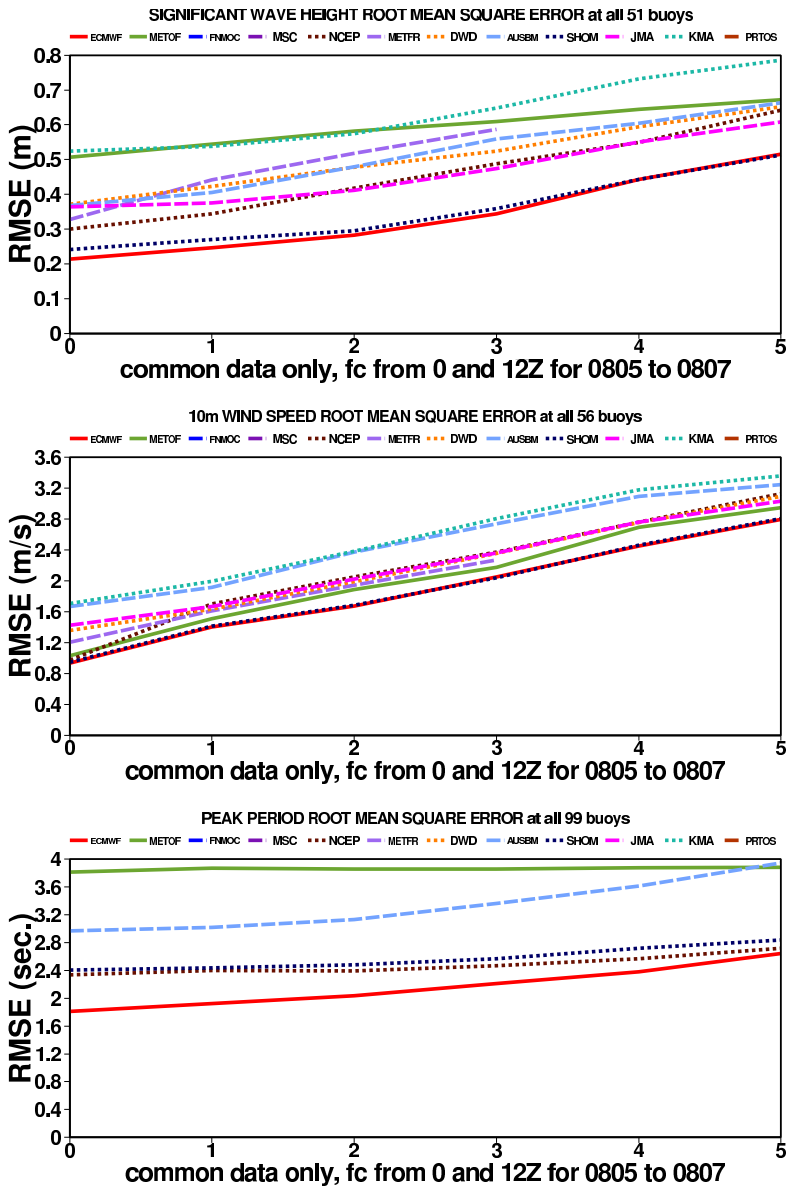


(a) Scatter Index (%)

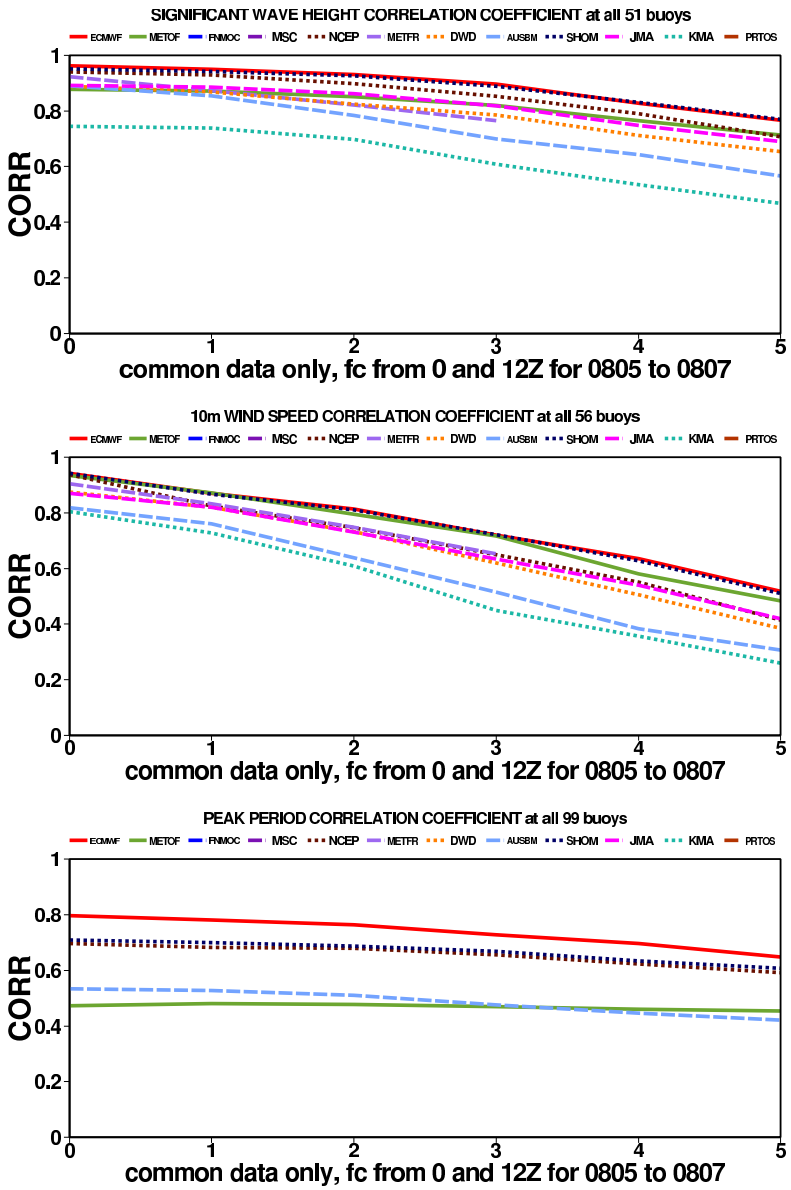


(b) Bias (model-buoy)

Figure 2: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common all buoys.

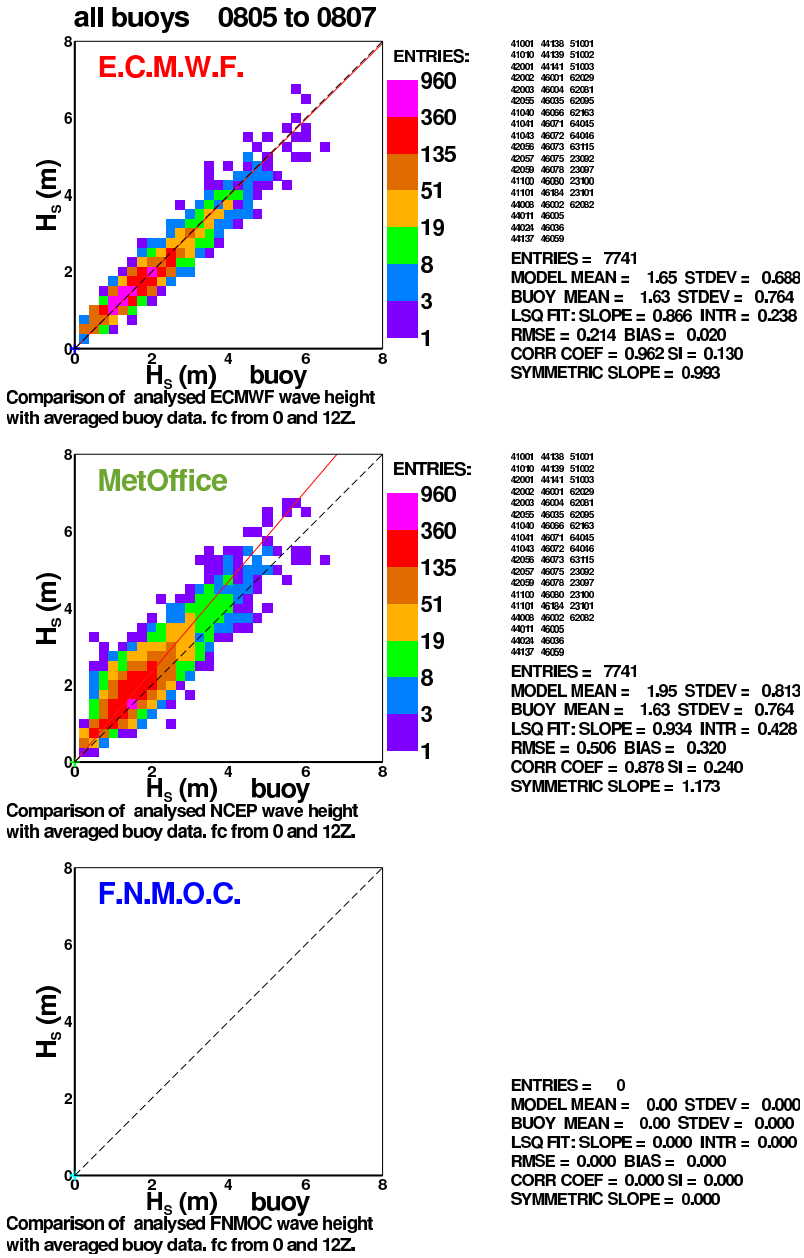


(a) R.M.S.E.



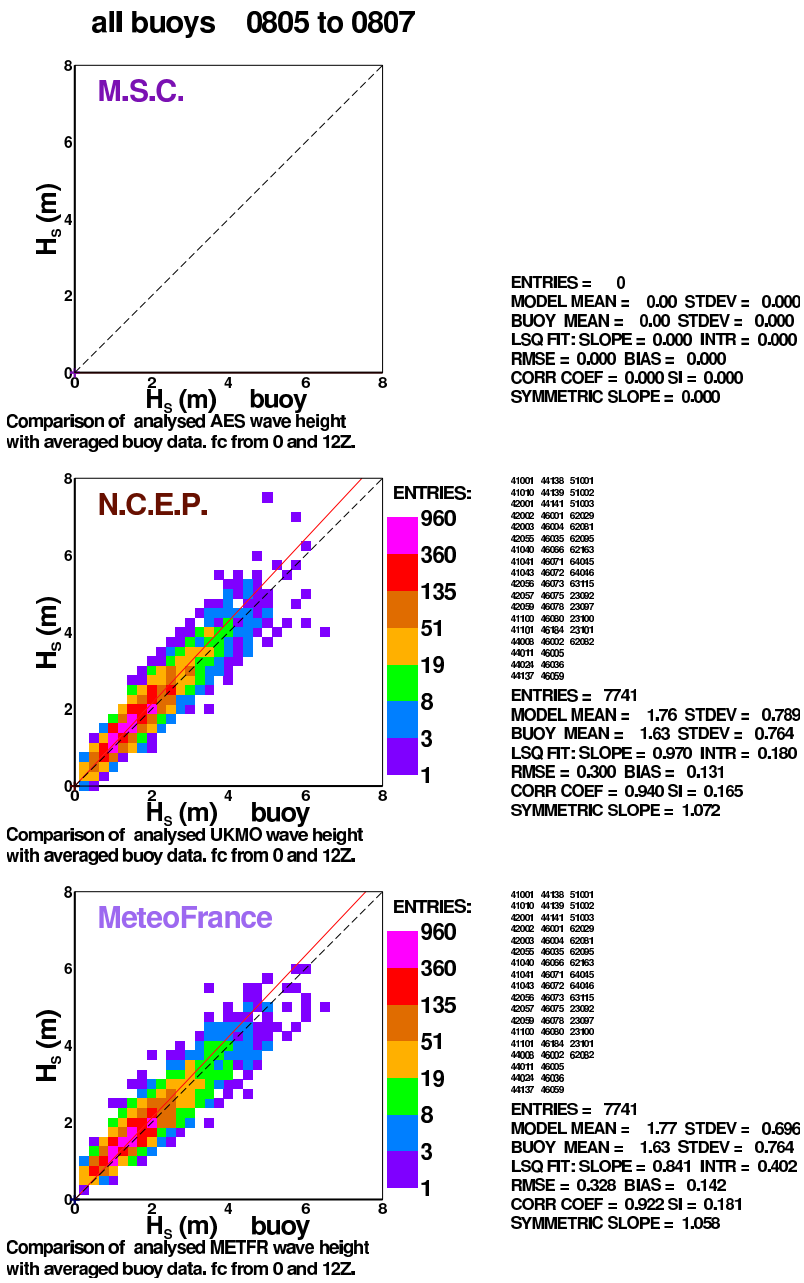
(b) Correlation Coefficient

Figure 3: Forecast root mean square error (RMSE) and linear correlation coefficient at common all buoys.

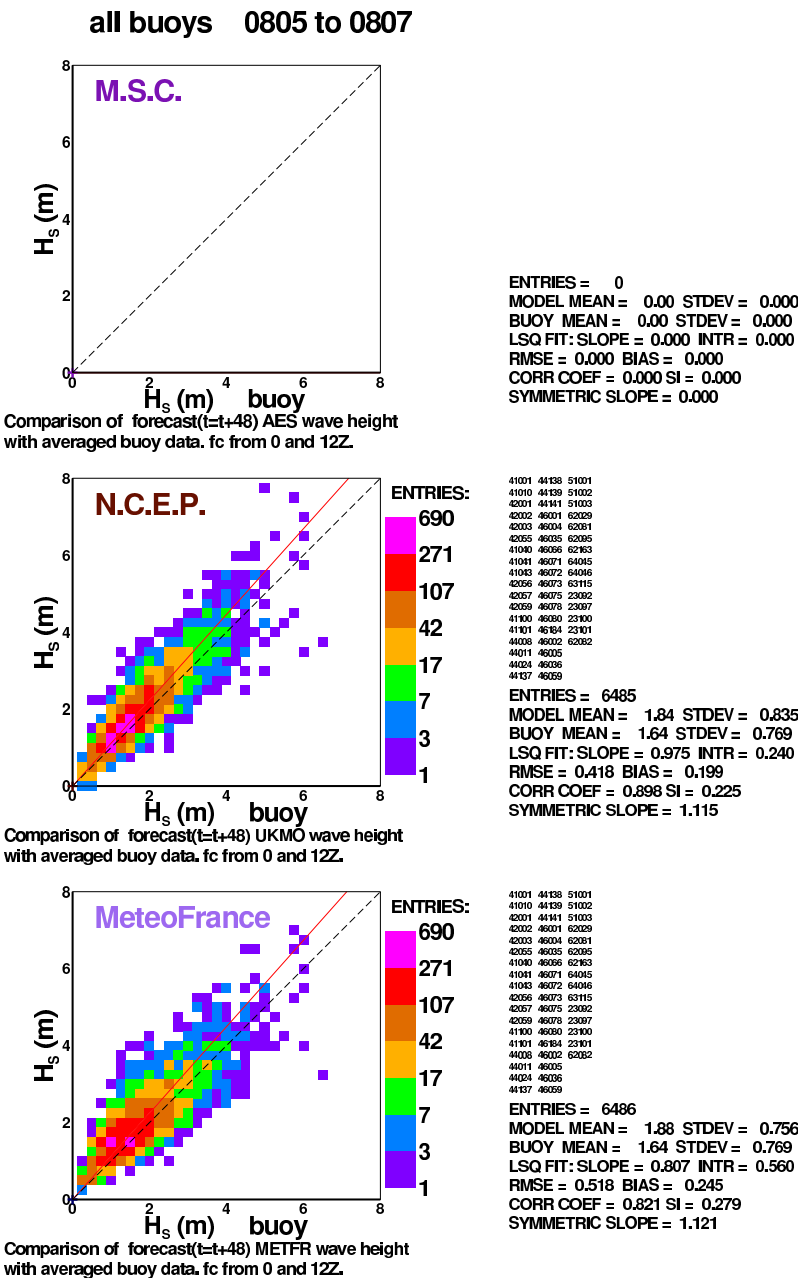


(a) t+0 (b) t+48

Figure 4: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.



(a) t+0



(b) t+48

Figure 5: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.

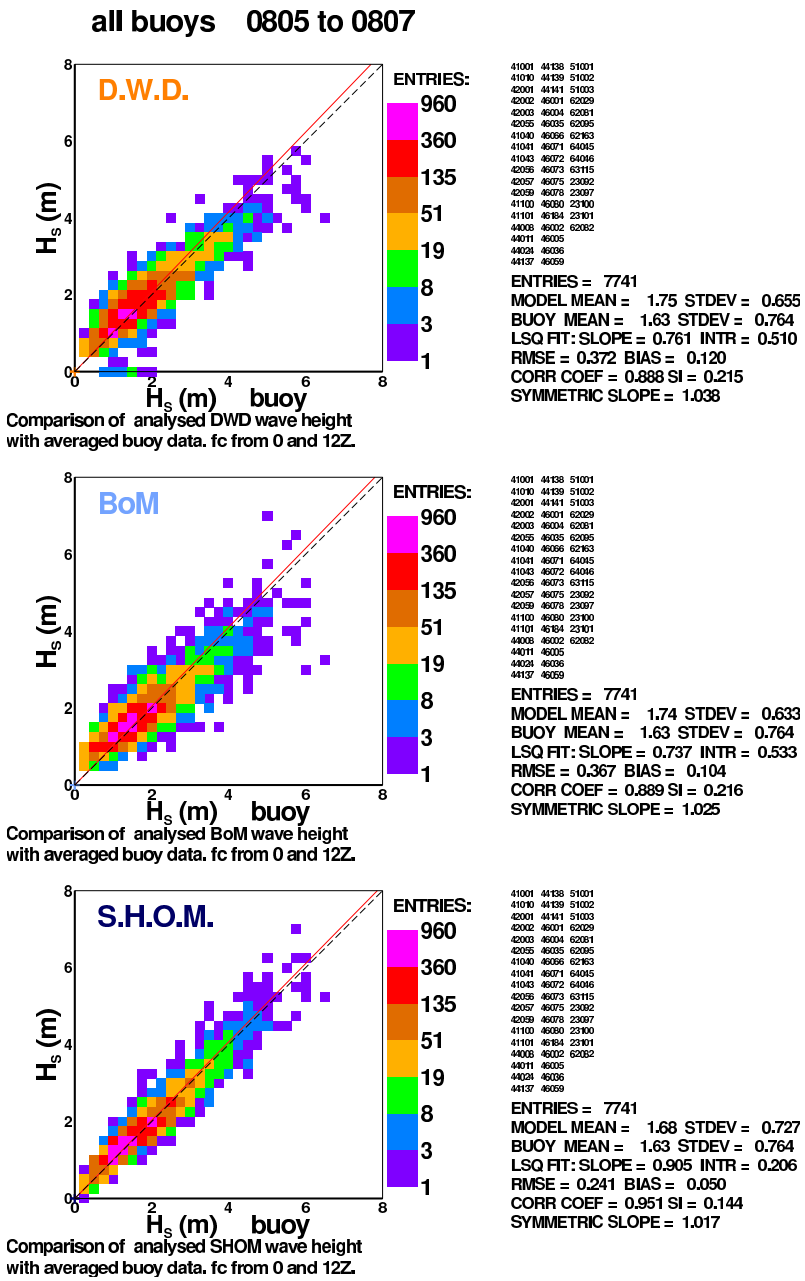
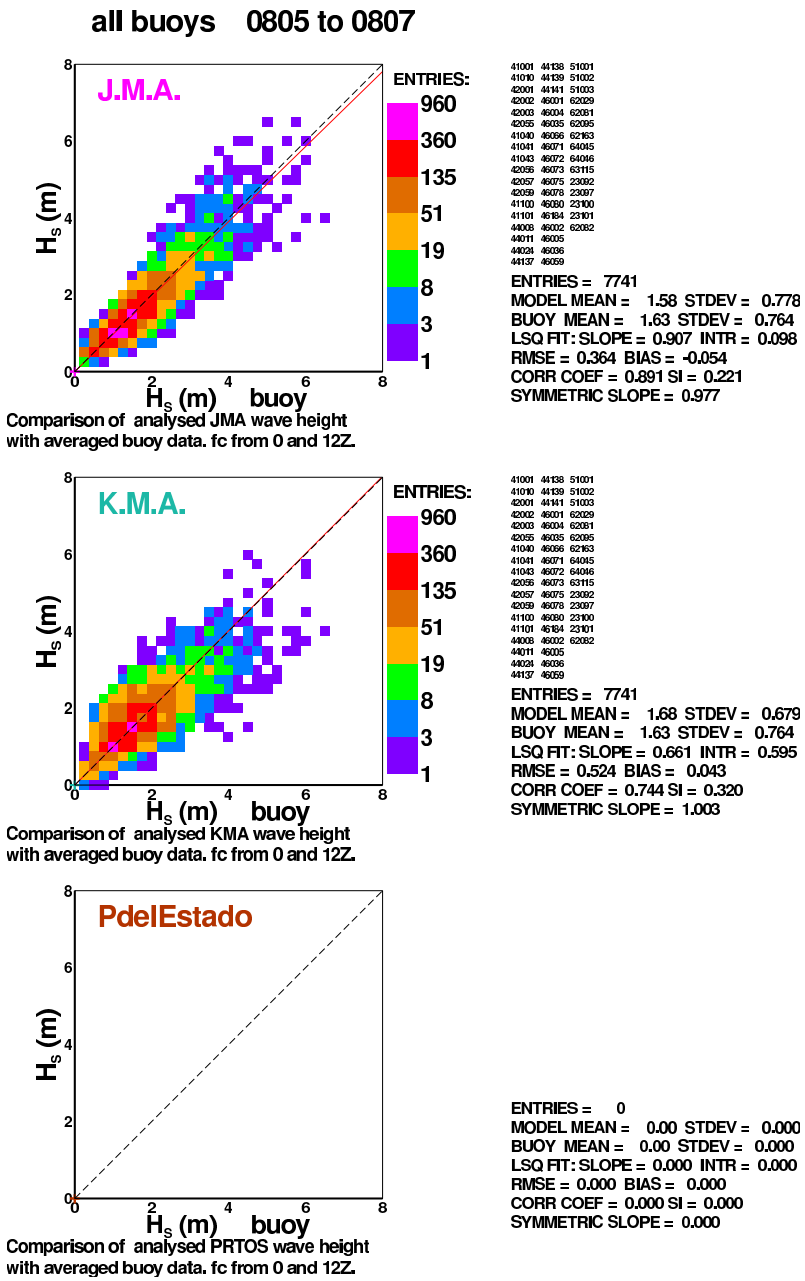
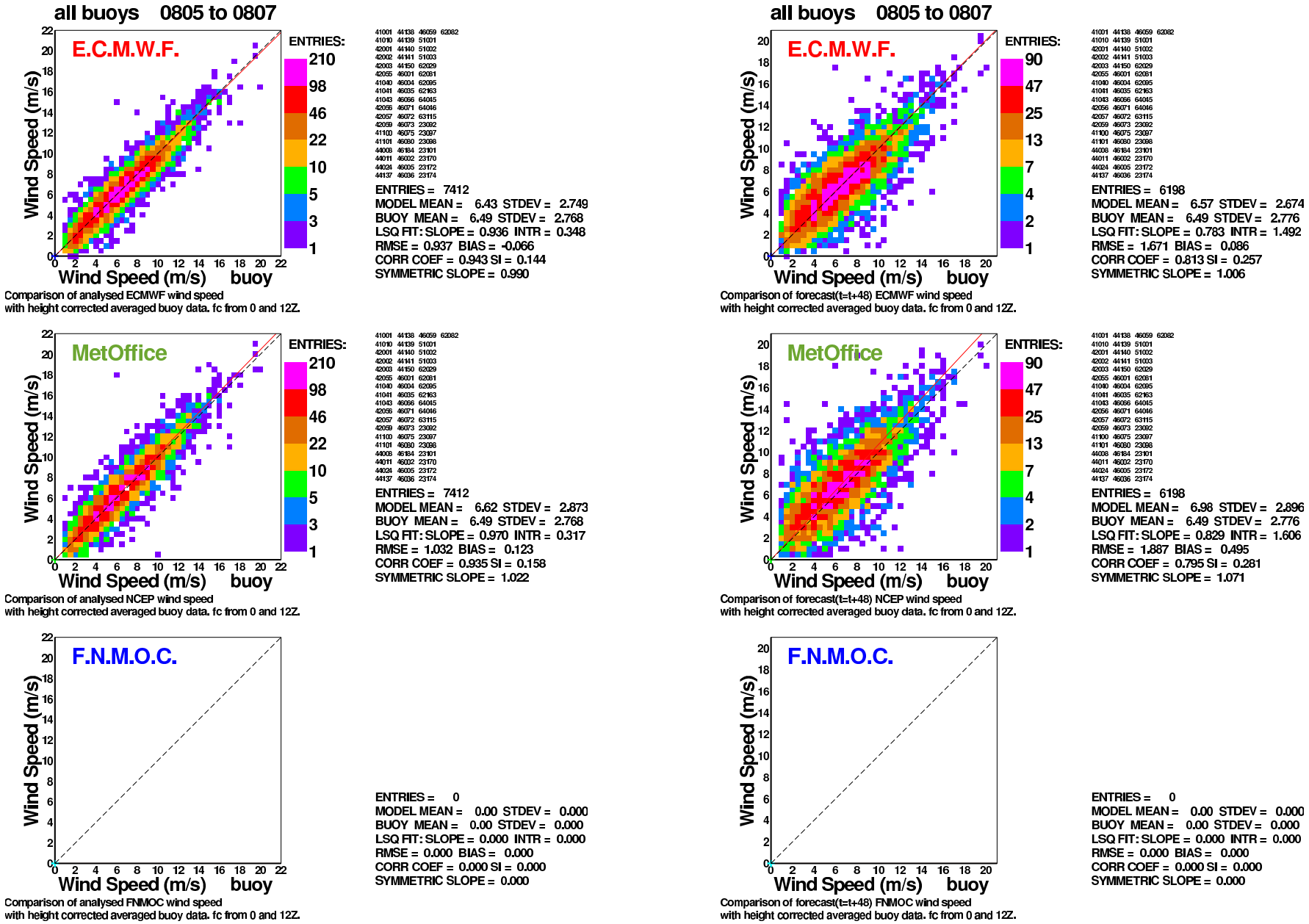


Figure 6: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.



(a) t+0 (b) t+48

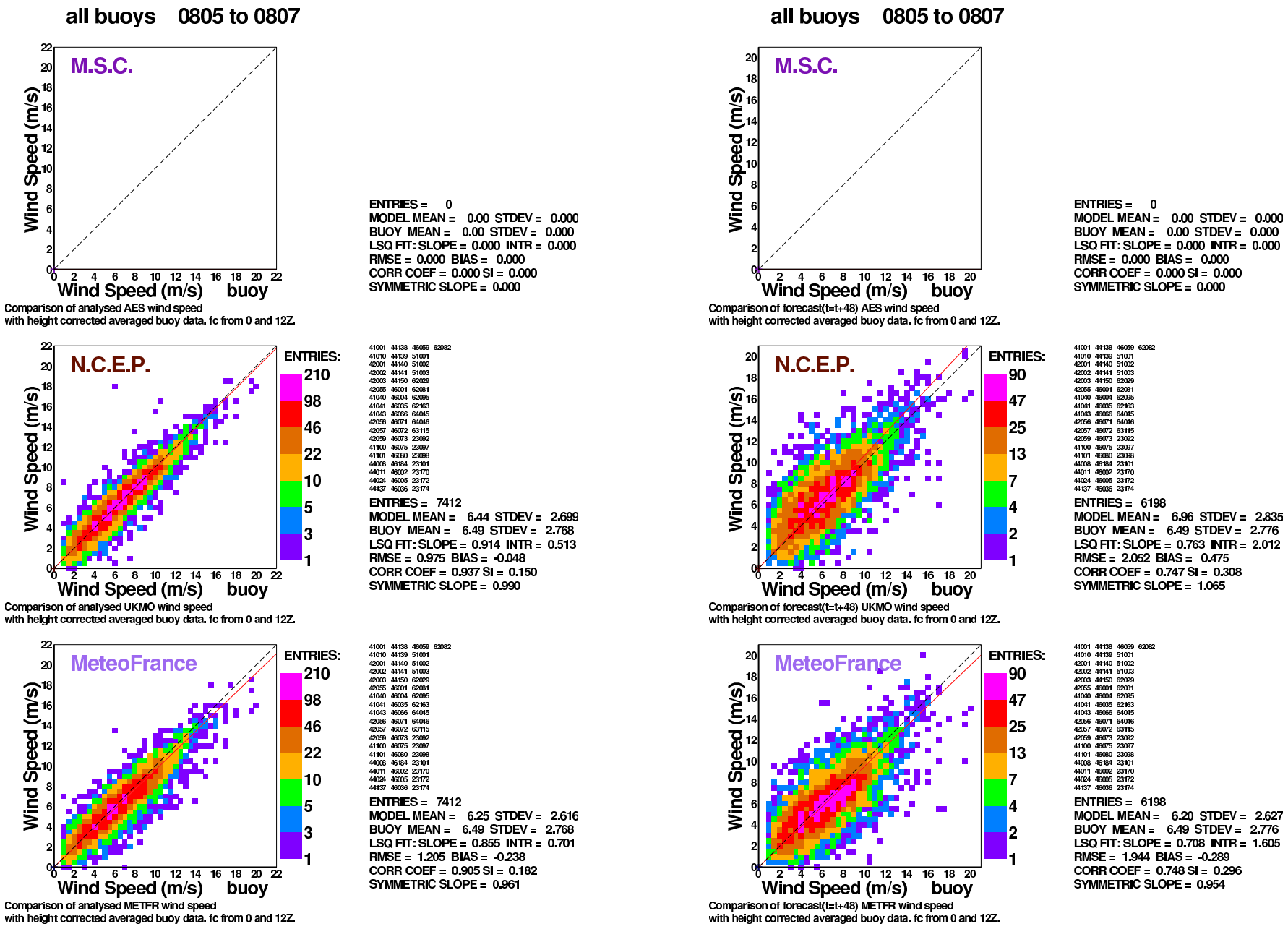
Figure 7: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.



(a) t+0

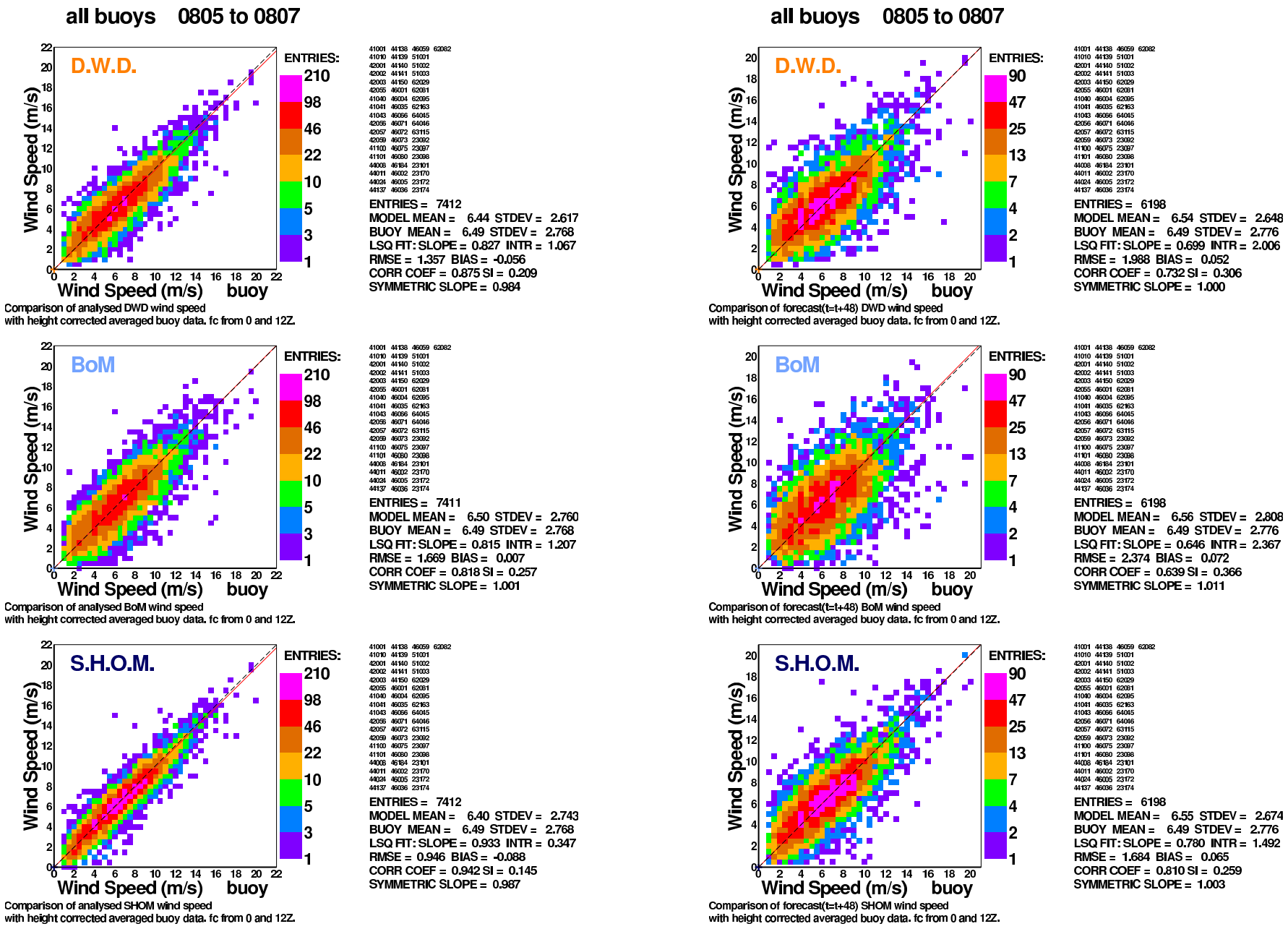
(b) t+48

Figure 8: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.



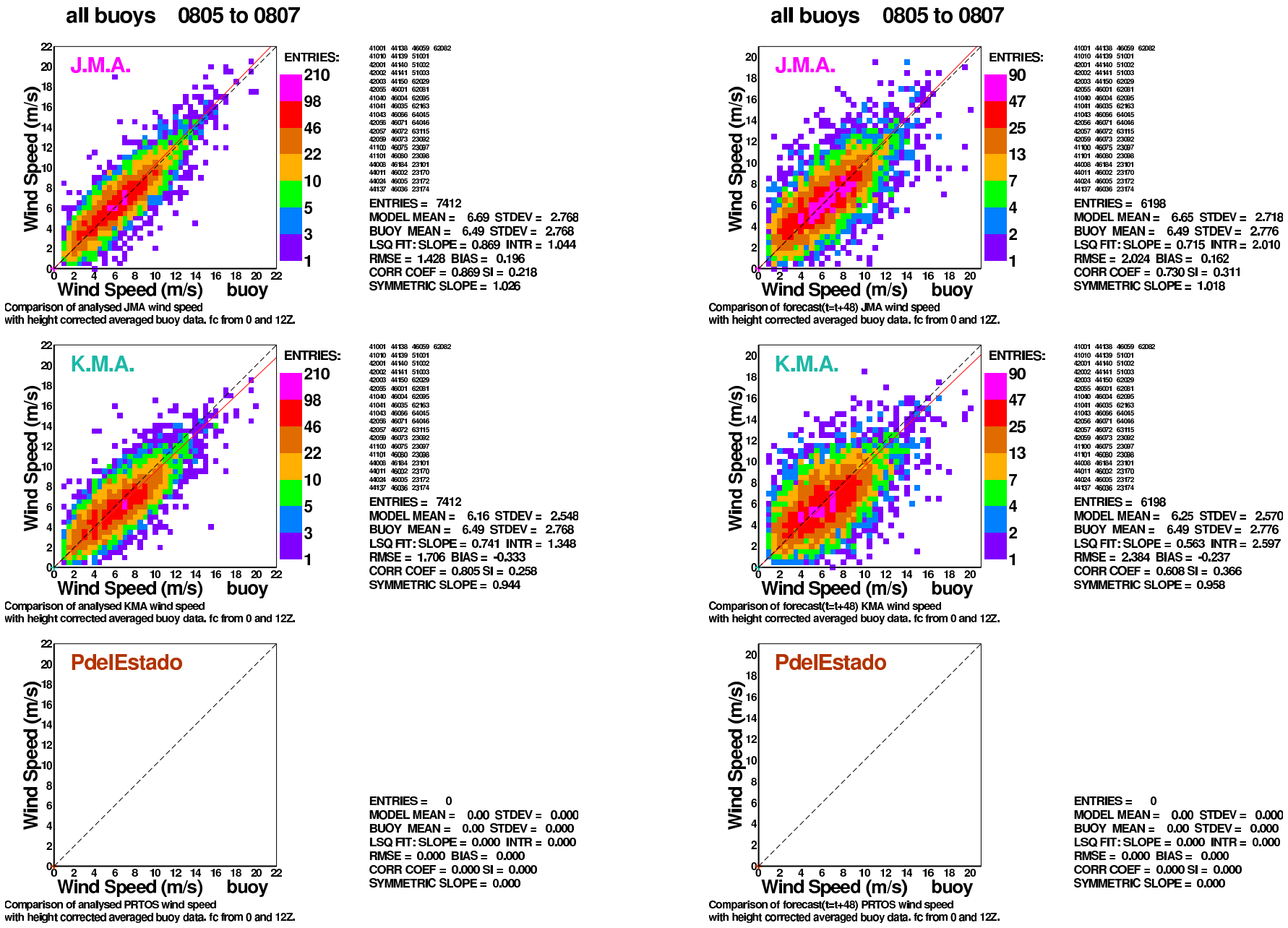
(a) t+0 (b) t+48

Figure 9: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.



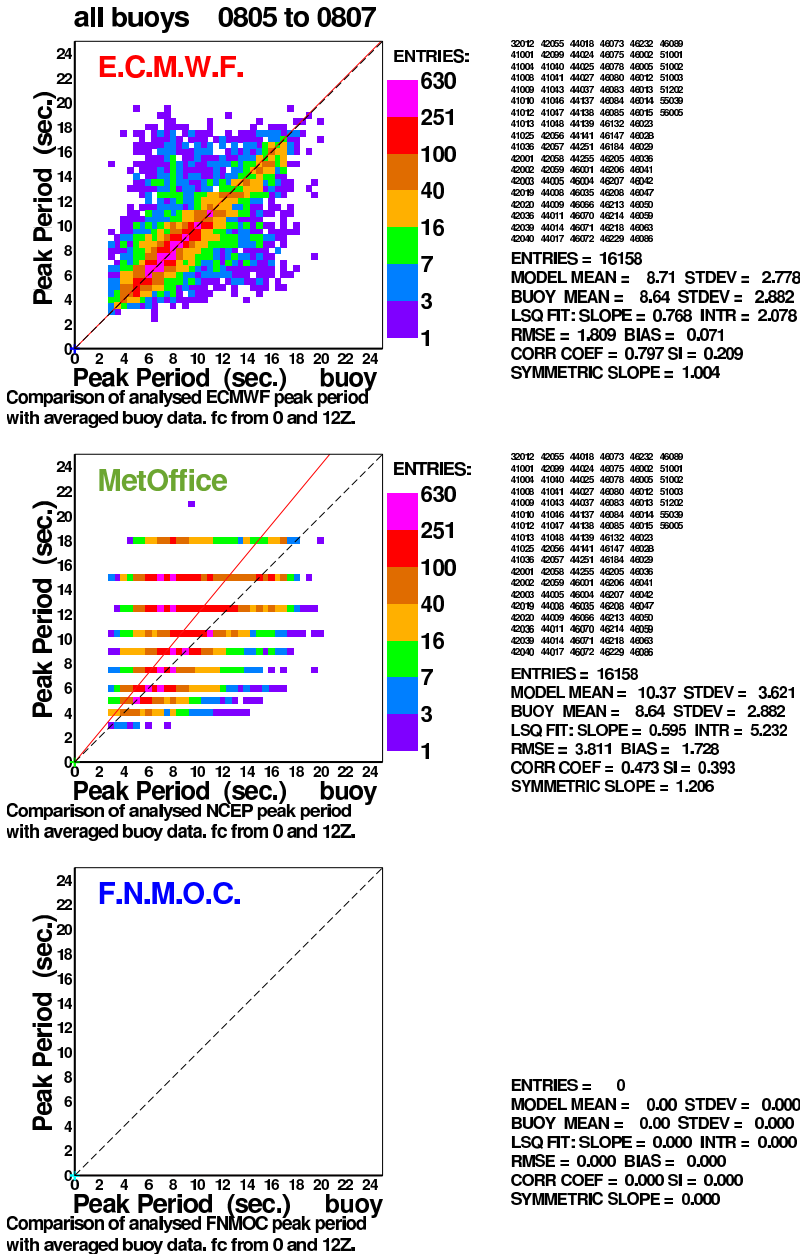
(a) t+0 (b) t+48

Figure 10: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.

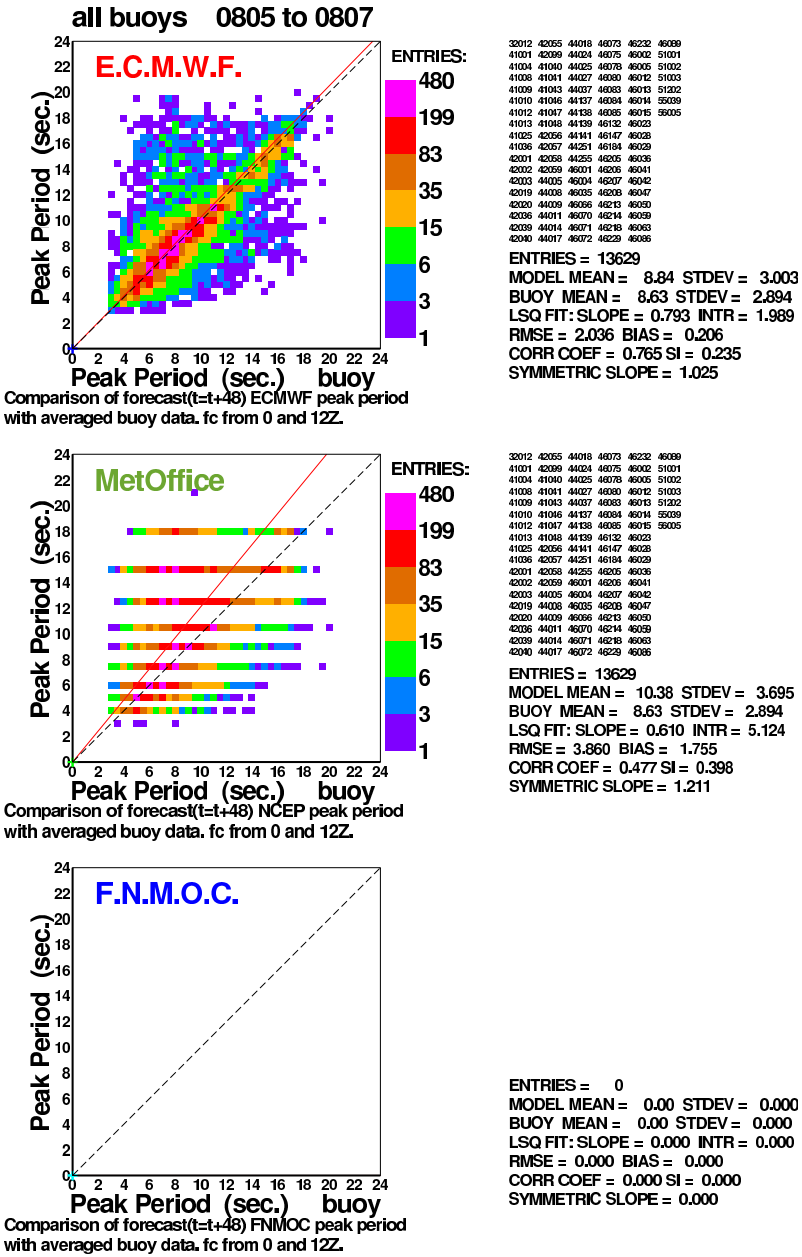


(a) t+0 (b) t+48

Figure 11: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.

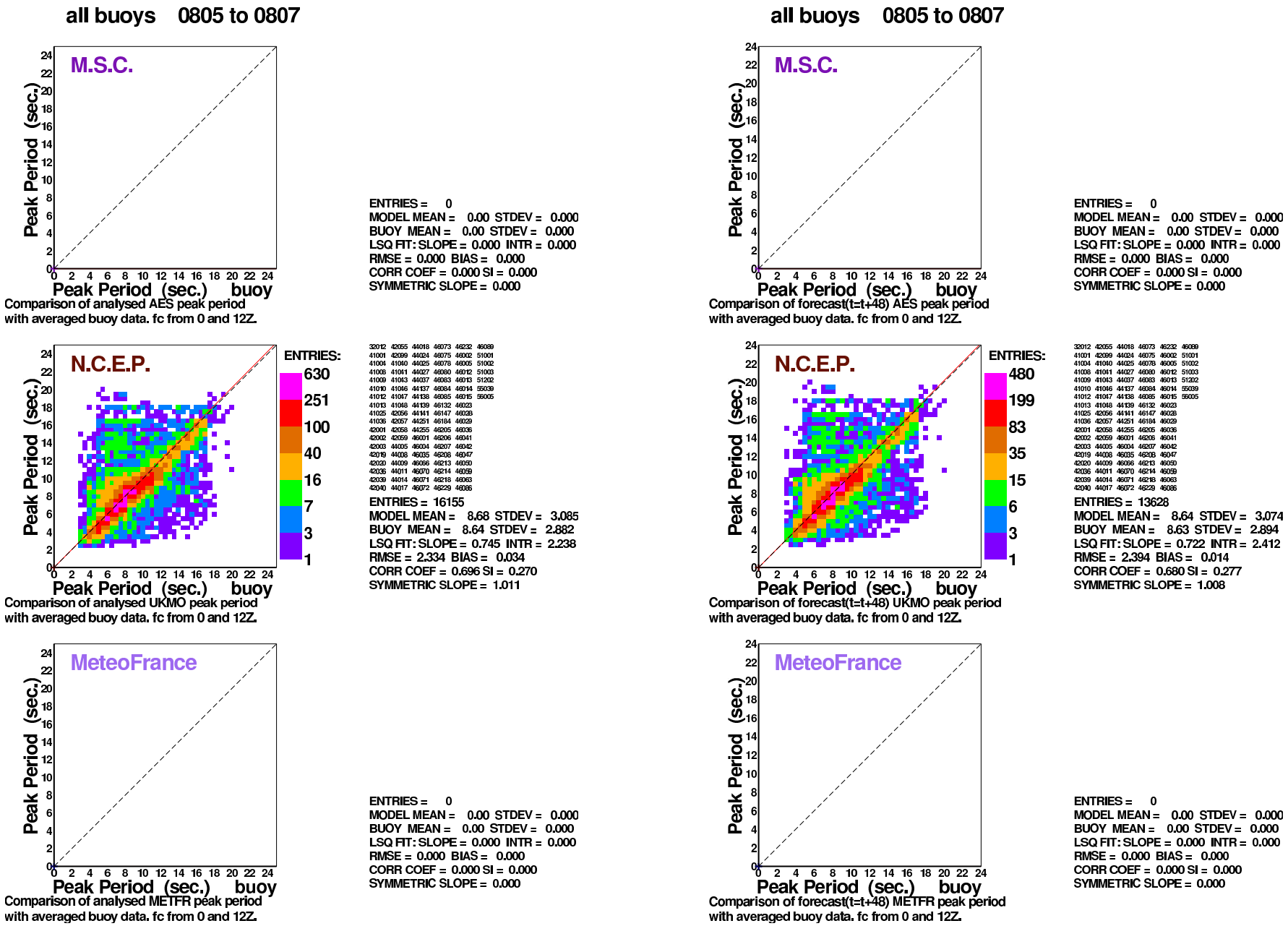


(a) t+0



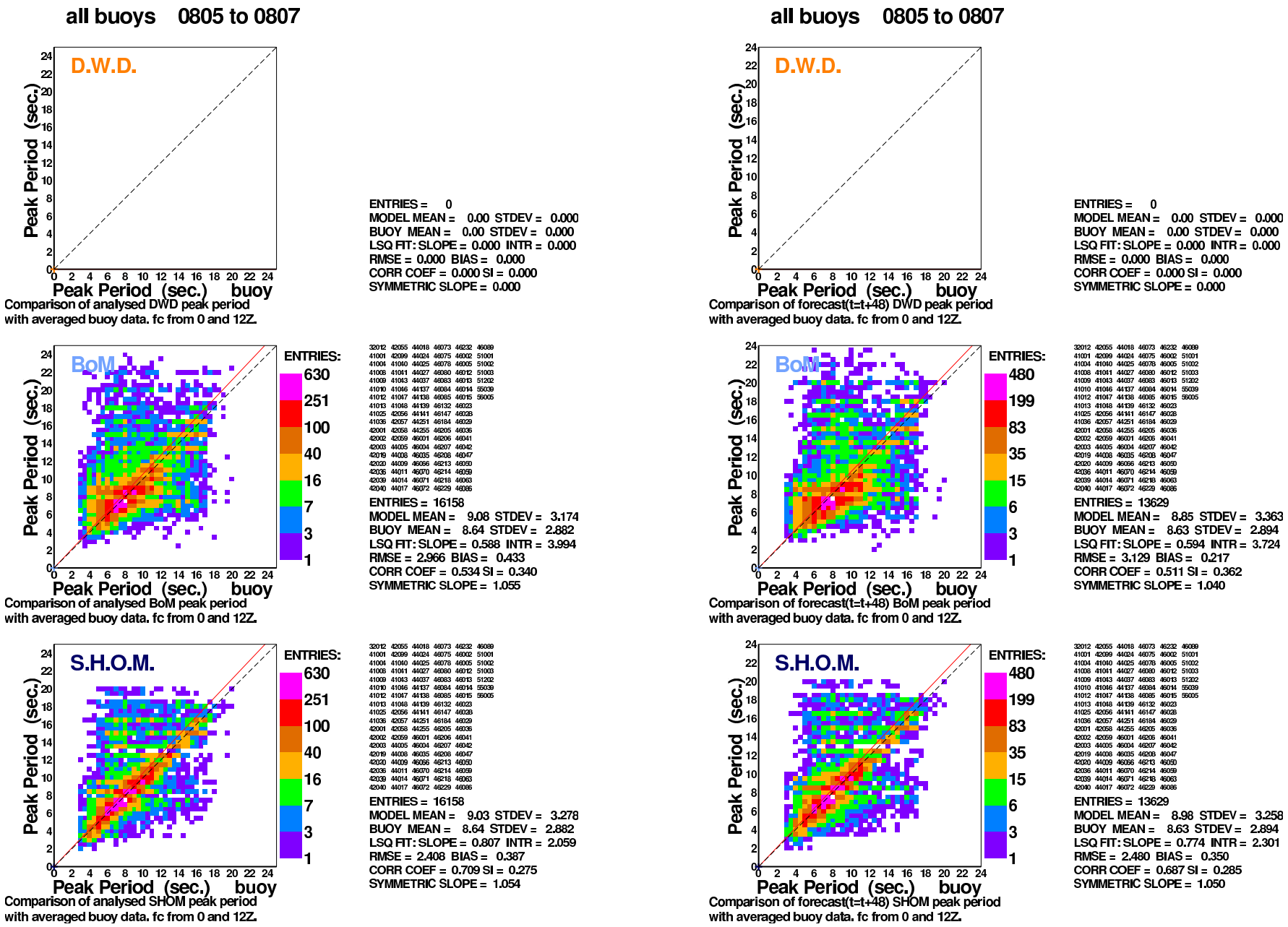
(b) t+48

Figure 12: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.



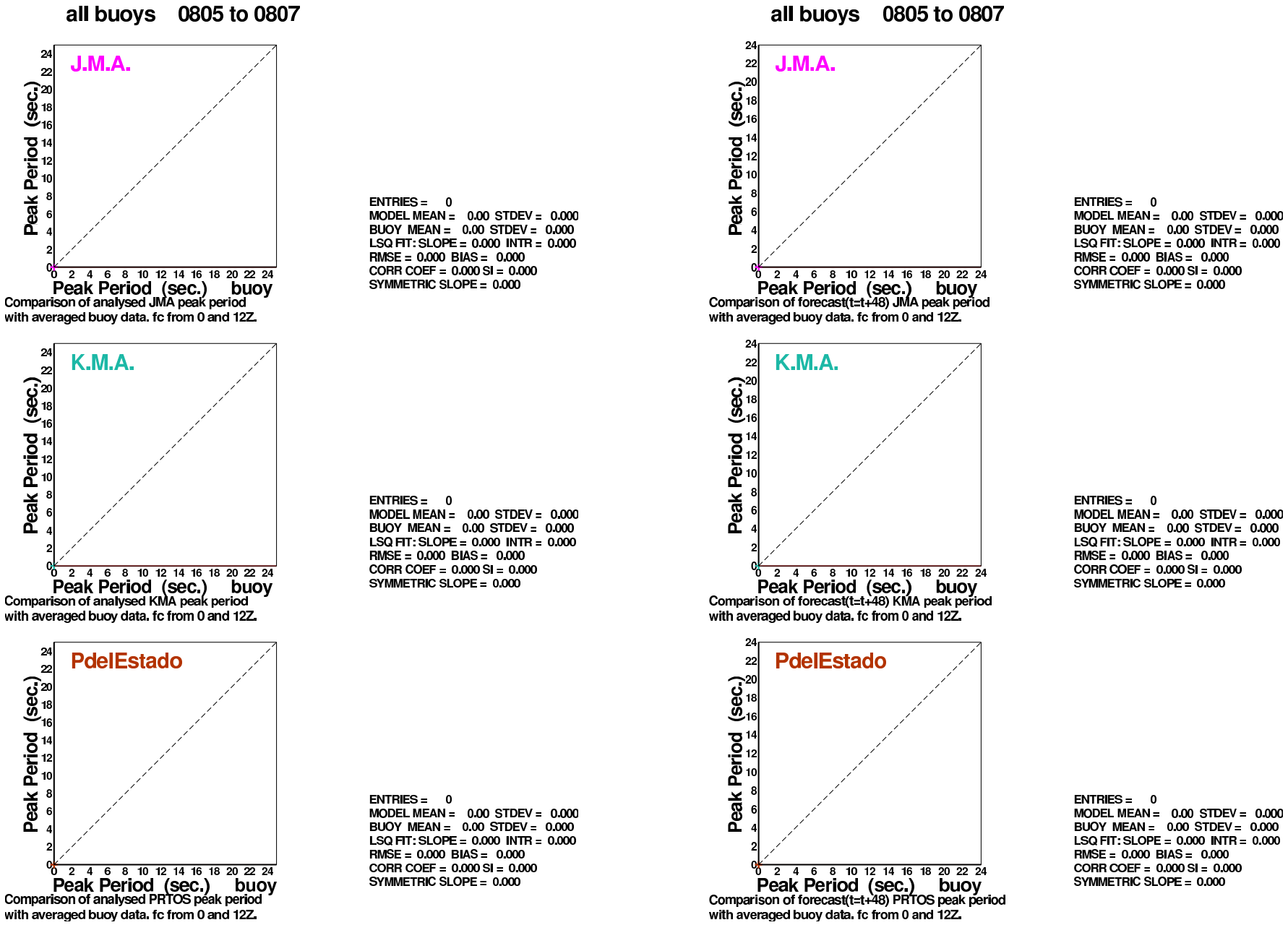
(a) t+0 (b) t+48

Figure 13: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.



(a) t+0 (b) t+48

Figure 14: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.



(a) t+0 (b) t+48

Figure 15: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.

0.3.2 Comparison for Hawaiian buoys

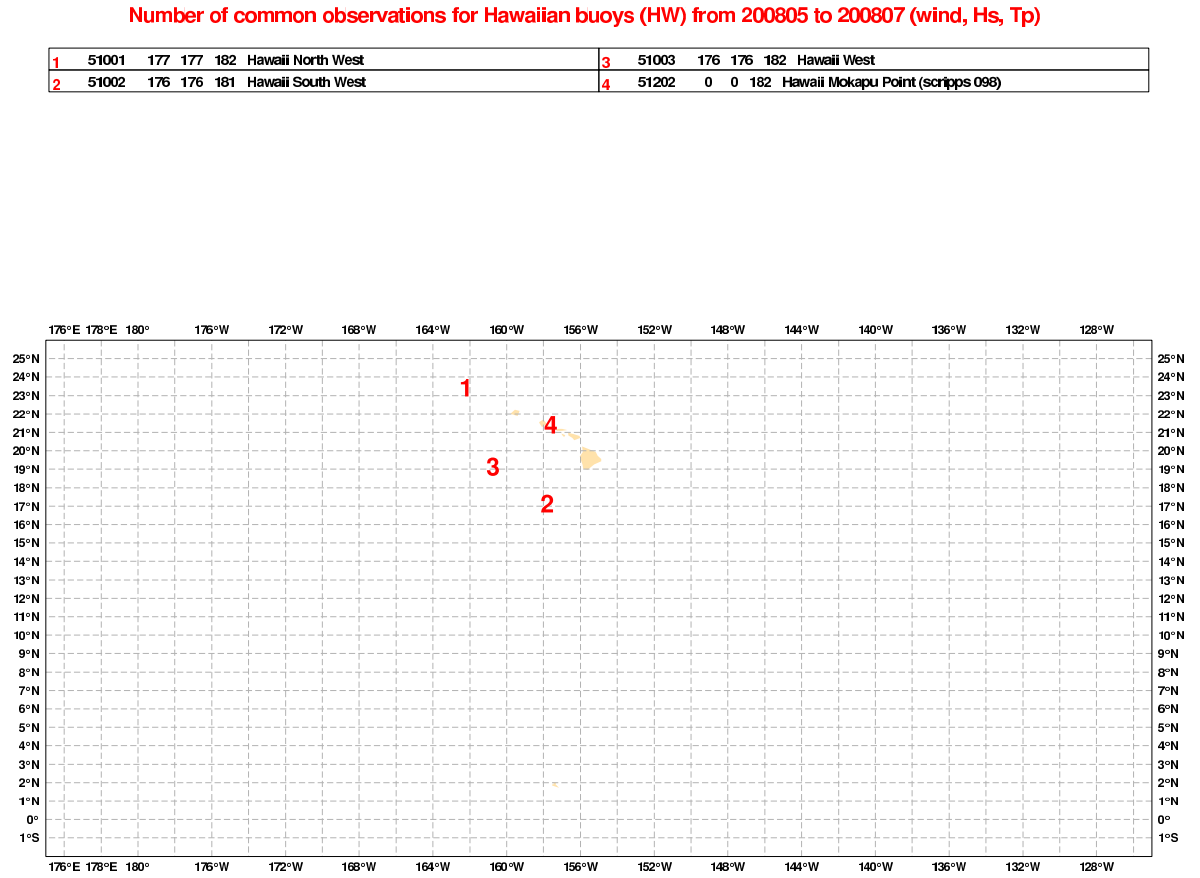
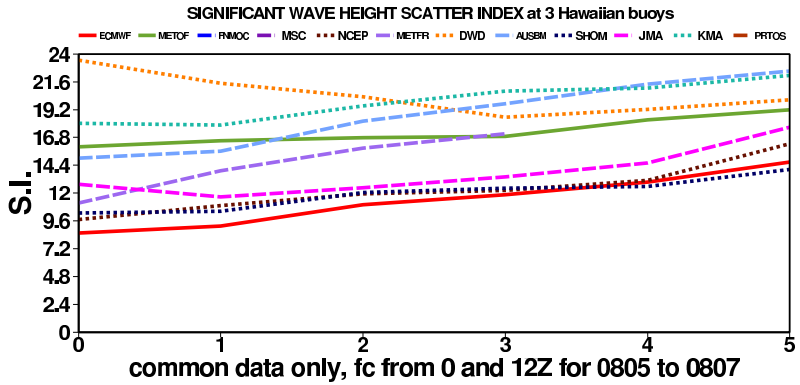
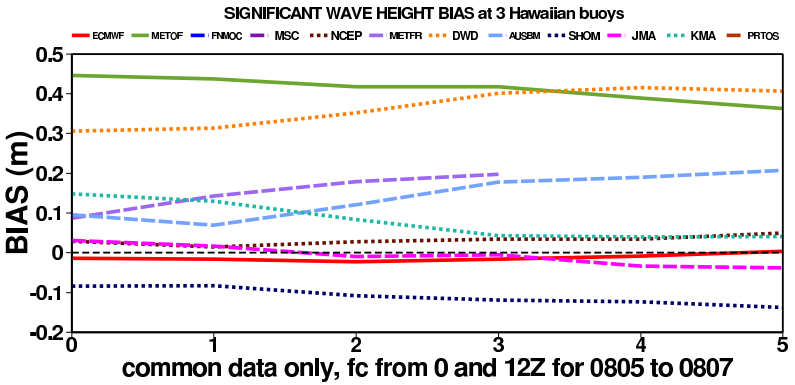
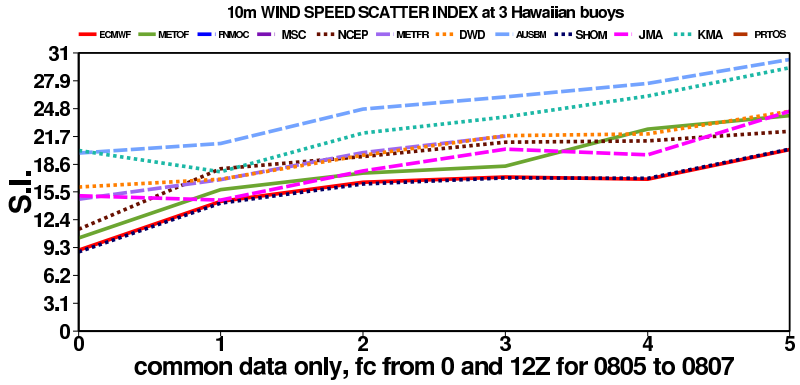
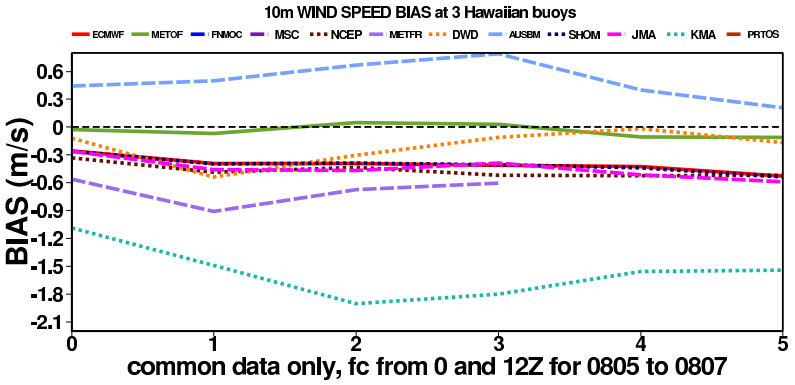


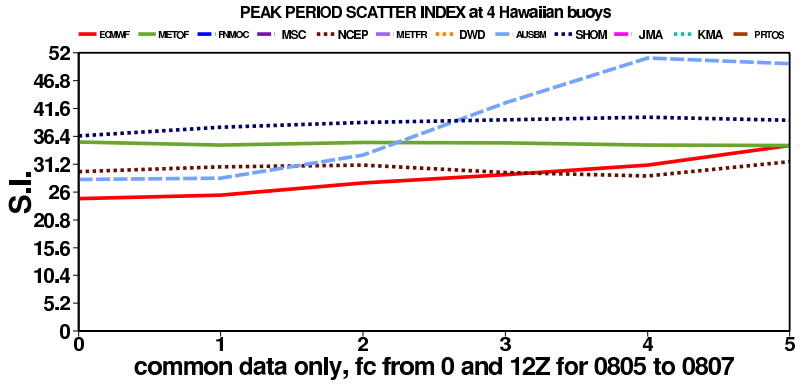
Figure 16: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

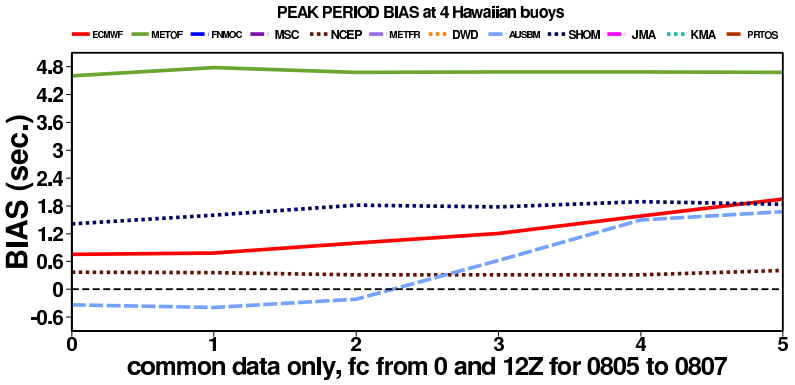








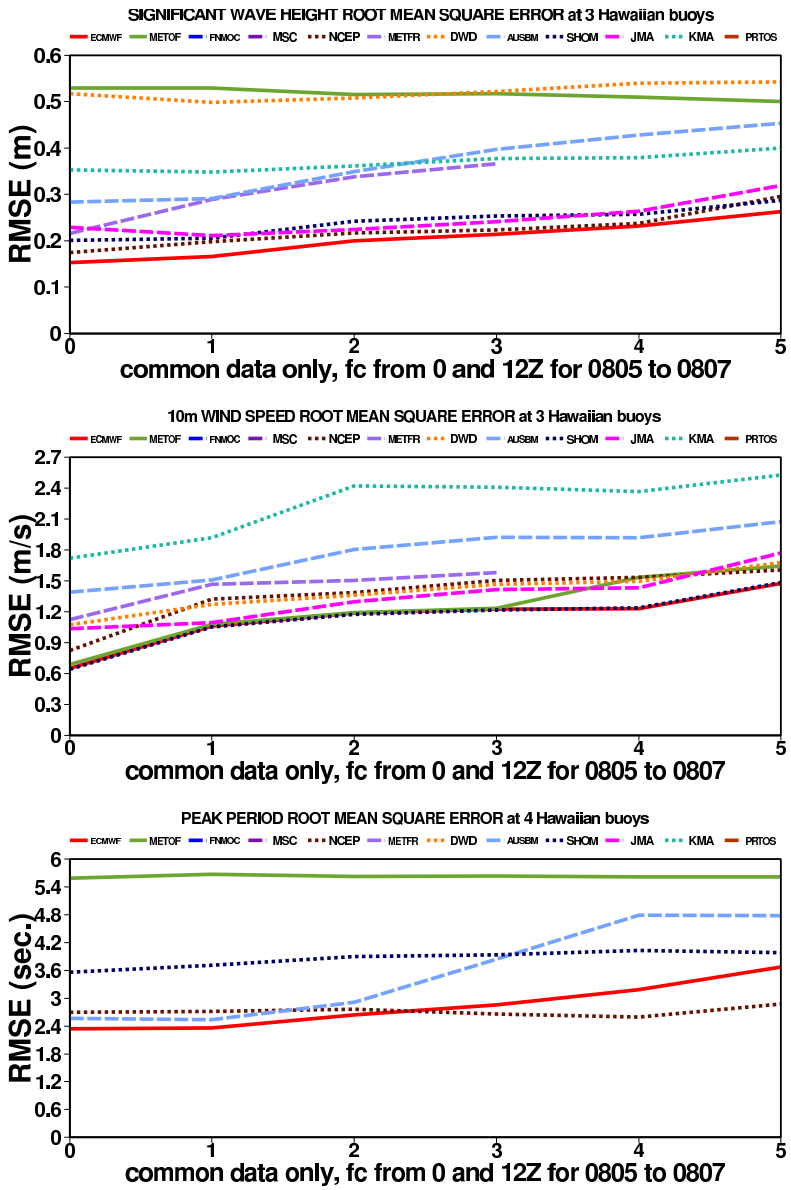




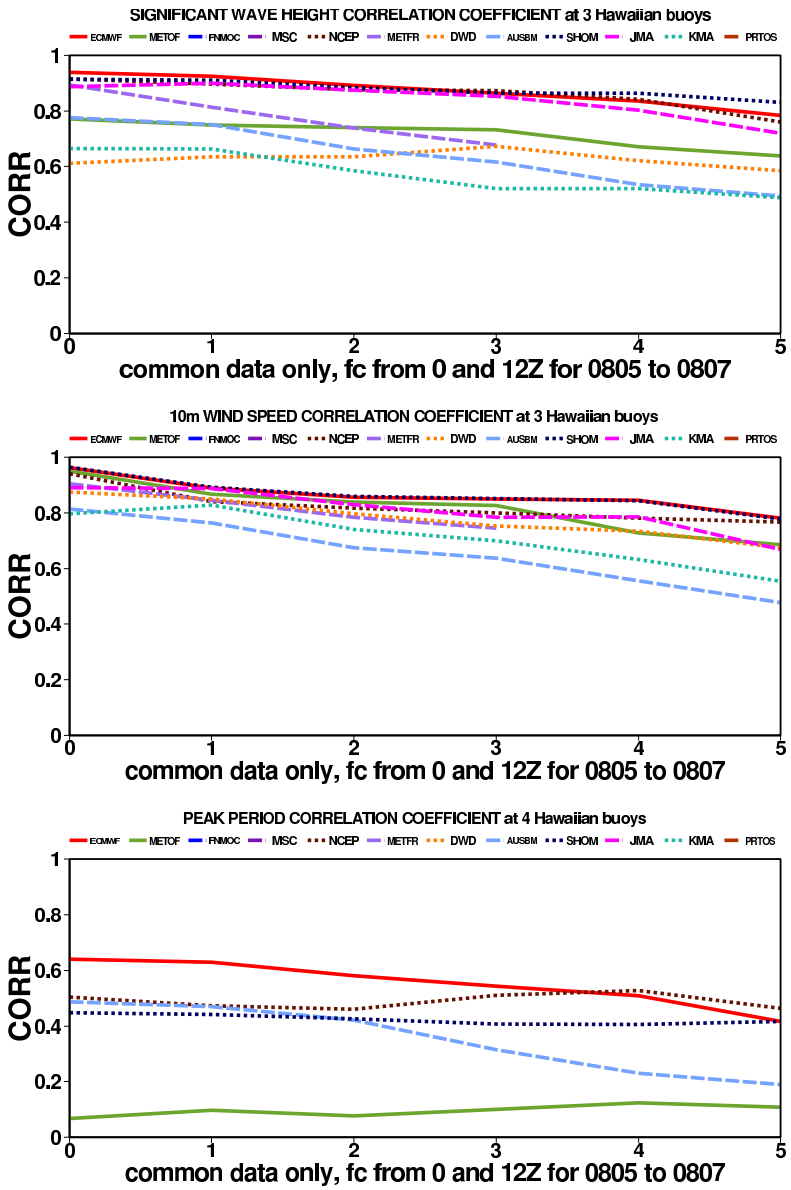
(a) Scatter Index (%)

(b) Bias (model-buoy)

Figure 17: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Hawaiian buoys.



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 18: Forecast root mean square error (RMSE) and linear correlation coefficient at common Hawaiian buoys.

0.3.3 Comparison for North Pacific buoys

Number of common observations for North Pacific buoys (NPC) from 200805 to 200807 (wind, Hs, Tp)

1	46001	180	180	182	Gulf of Alaska
2	46004	175	177	181	Canada West Coast, Middle Nomad
3	46035	180	179	181	Bering Sea
4	46066	180	180	182	Gulf of Alaska, S Aleutians
5	46070	0	0	177	Southwest Bering Sea
6	46071	103	103	105	North Pacific, Western Aleutians
7	46072	71	180	182	North Pacific, Central Aleutians
8	46073	180	178	180	Southeast Bering Sea
9	46075	2	178	180	North Pacific, Shumagin Islands
10	46078	0	180	182	Gulf of Alaska, Albatross Banks
11	46080	7	7	7	Gulf of Alaska, Kennedy Entrance
12	46083	0	0	182	Gulf of Alaska, Fairweather Grounds
13	46084	0	0	180	Gulf of Alaska, Cape Edgecumbe
14	46085	0	0	179	Central Gulf of Alaska
15	46132	0	0	182	Canada West Coast, South Brooks
16	46147	0	0	171	Canada West Coast, South Moresby
17	46184	177	177	180	Canada West Coast, North Nomad
18	46205	0	0	179	Canada West Coast, W. Dixon Entrance
19	46206	0	0	95	Canada West Coast, La Perouse Bank
20	46207	0	0	182	Canada West Coast, East Dellwood
21	46208	0	0	180	Canada West Coast, West Moresby

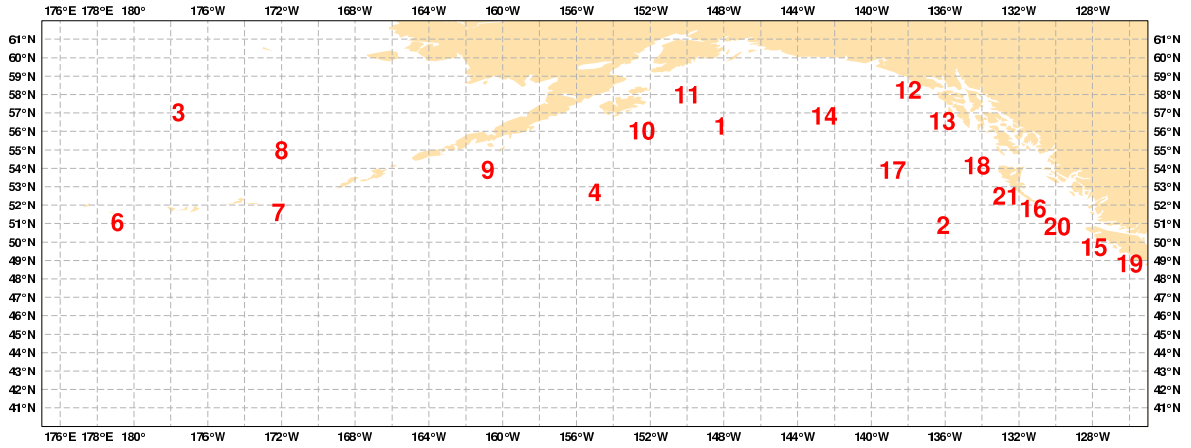
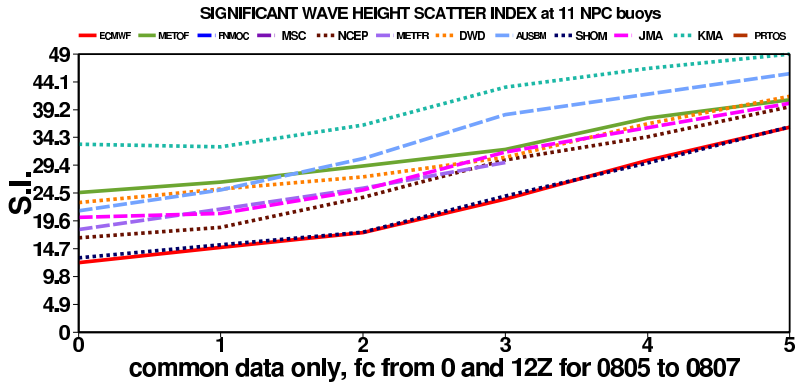
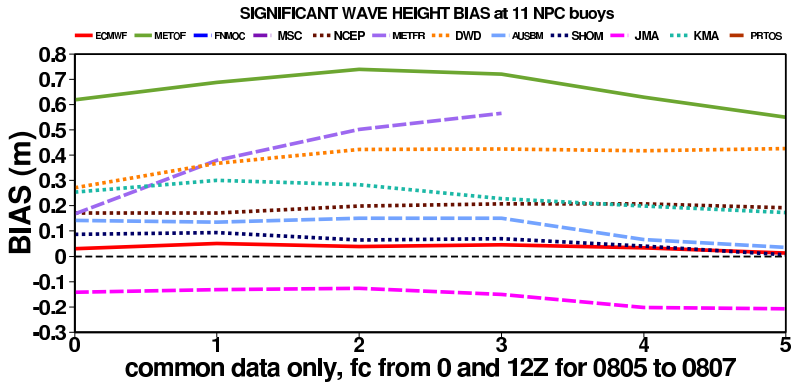
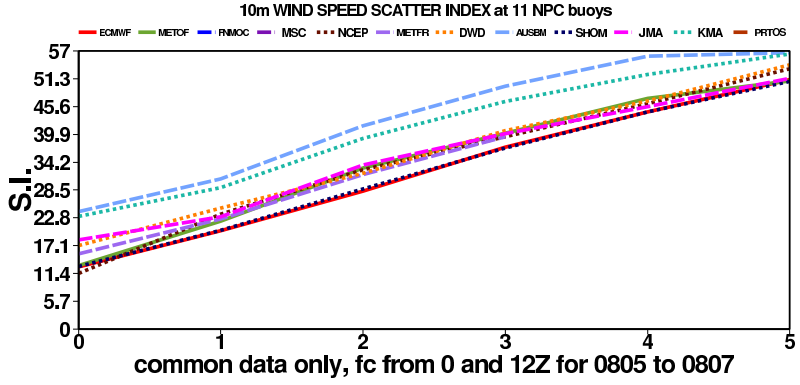
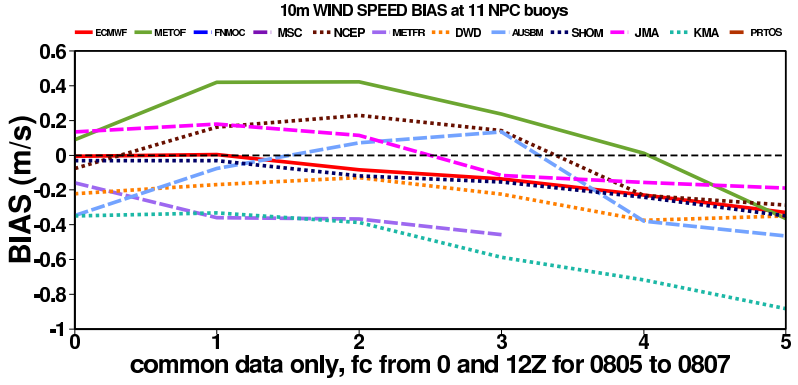


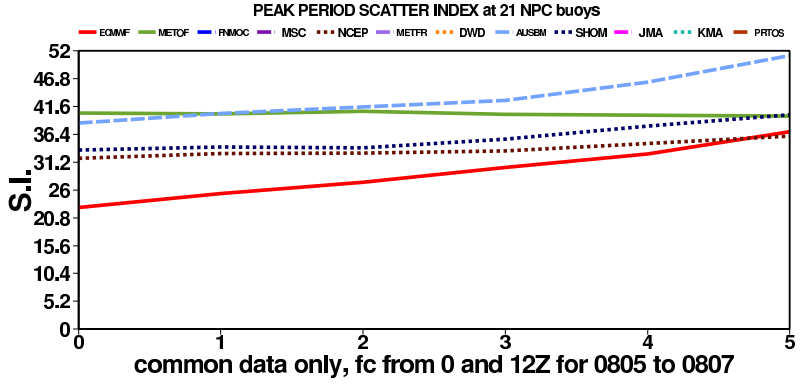
Figure 19: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

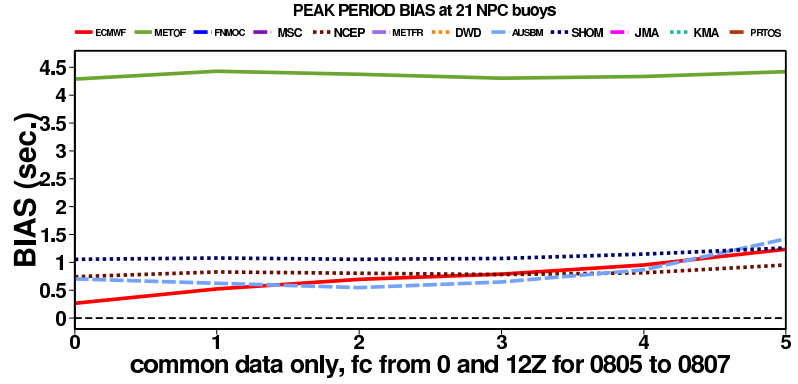








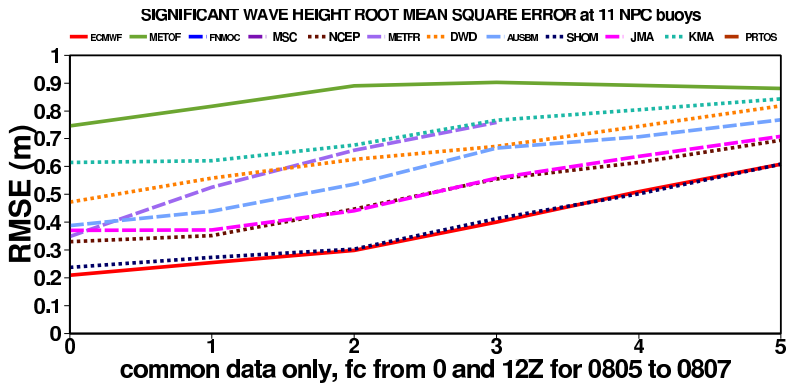


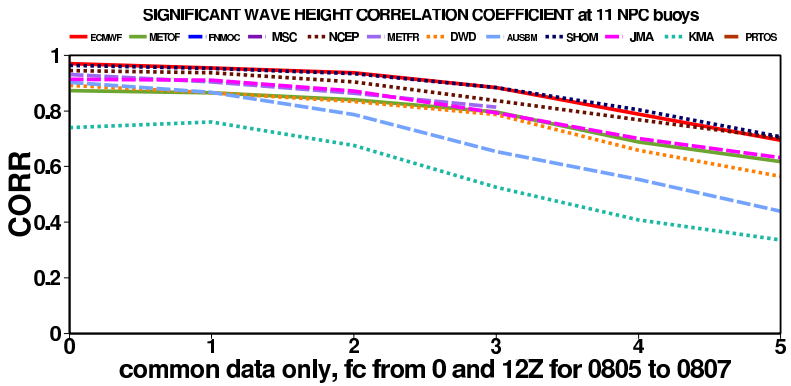


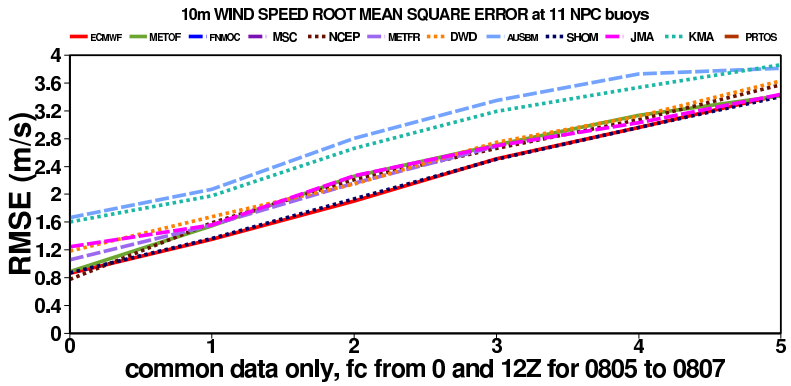
(a) Scatter Index (%)

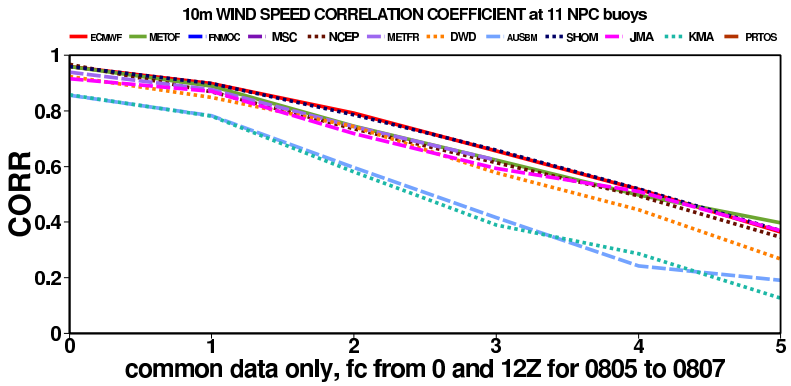
(b) Bias (model-buoy)

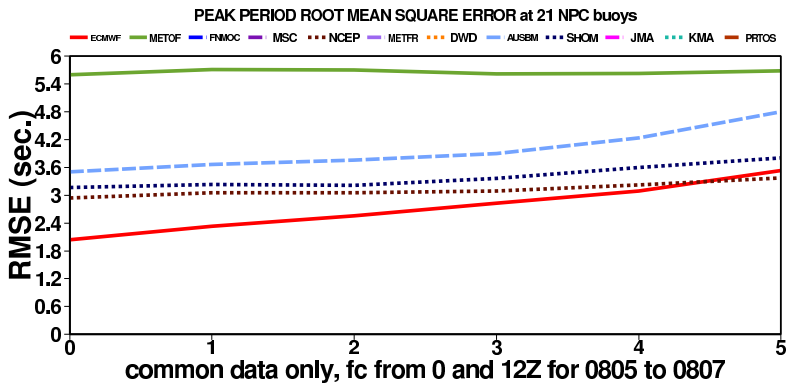
Figure 20: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North Pacific buoys .

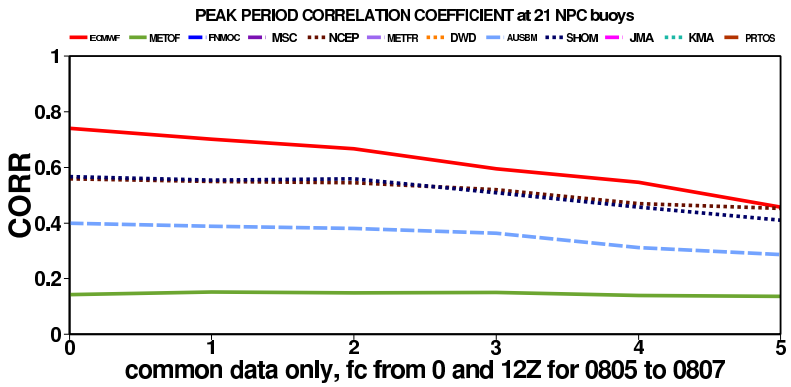












(a) R.M.S.E.

(b) Correlation Coefficient

Figure 21: Forecast root mean square error (RMSE) and linear correlation coefficient at common North Pacific buoys .

0.3.4 Comparison for US West Coast buoys

Number of common observations for US West Coast buoys (USWC) from 200805 to 200807 (wind, Hs, Tp)

1	46002	134	135	135	US West Coast,Oregon
2	46005	75	74	74	US North-West Coast, W Astoria
3	46012	0	0	182	US South-West Coast, Half Moon Bay
4	46013	0	0	182	US South-West Coast, Bodega
5	46014	0	0	181	US South-West Coast, Point Arena
6	46015	0	0	175	US West Coast, Port Orford
7	46023	0	0	182	US South-West Coast, Point Arguello
8	46028	0	0	181	US South-West Coast, Cape St Martin
9	46029	0	0	182	US West Coast, Columbia River Bar
10	46036	179	180	181	Canada West Coast, South Nomad
11	46041	0	0	182	US North-West Coast, Cape Elisabeth
12	46042	0	0	158	US South-West Coast, Monterey
13	46047	0	0	182	US South-West Coast, Tanner Banks
14	46050	0	0	182	US West Coast, Yaquina Bay
15	46059	176	176	182	US West Coast, California
16	46063	0	0	182	US West Coast, Pt Conception
17	46086	0	0	41	US South-West Coast, San Clemente Basin
18	46089	0	0	68	US West Coast, Tillamook, OR
19	46213	0	0	180	US South-West Coast, Cape Mendocino (scripps 094)
20	46214	0	0	182	US South-West Coast, Point Reyes (scripps 029)
21	46218	0	0	182	US South-West Coast, Harvest (scripps 071)
22	46229	0	0	182	US West Coast, Coos Bay (scripps 126)
23	46232	0	0	181	US South West Coast, Coranado Islands MX (scripps 133)

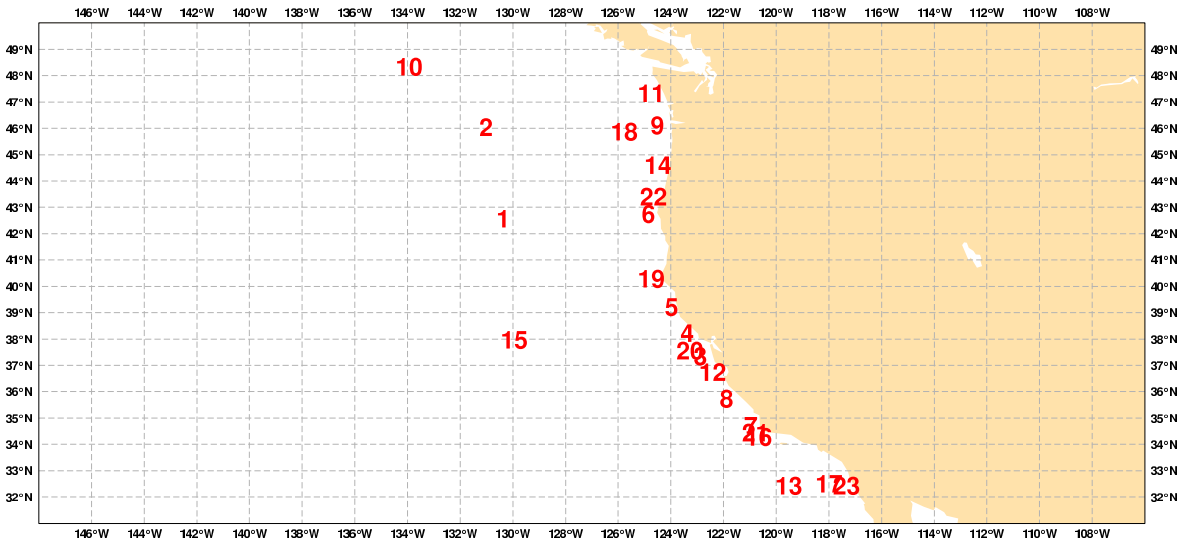
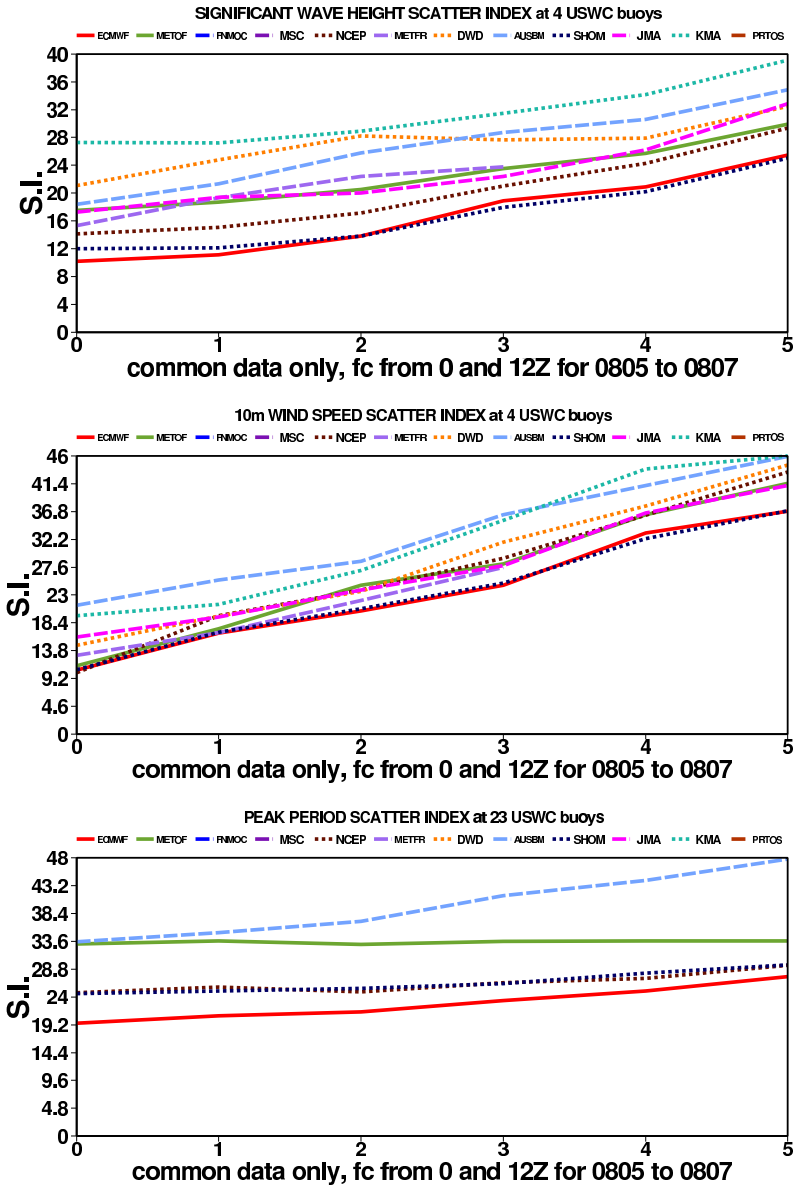
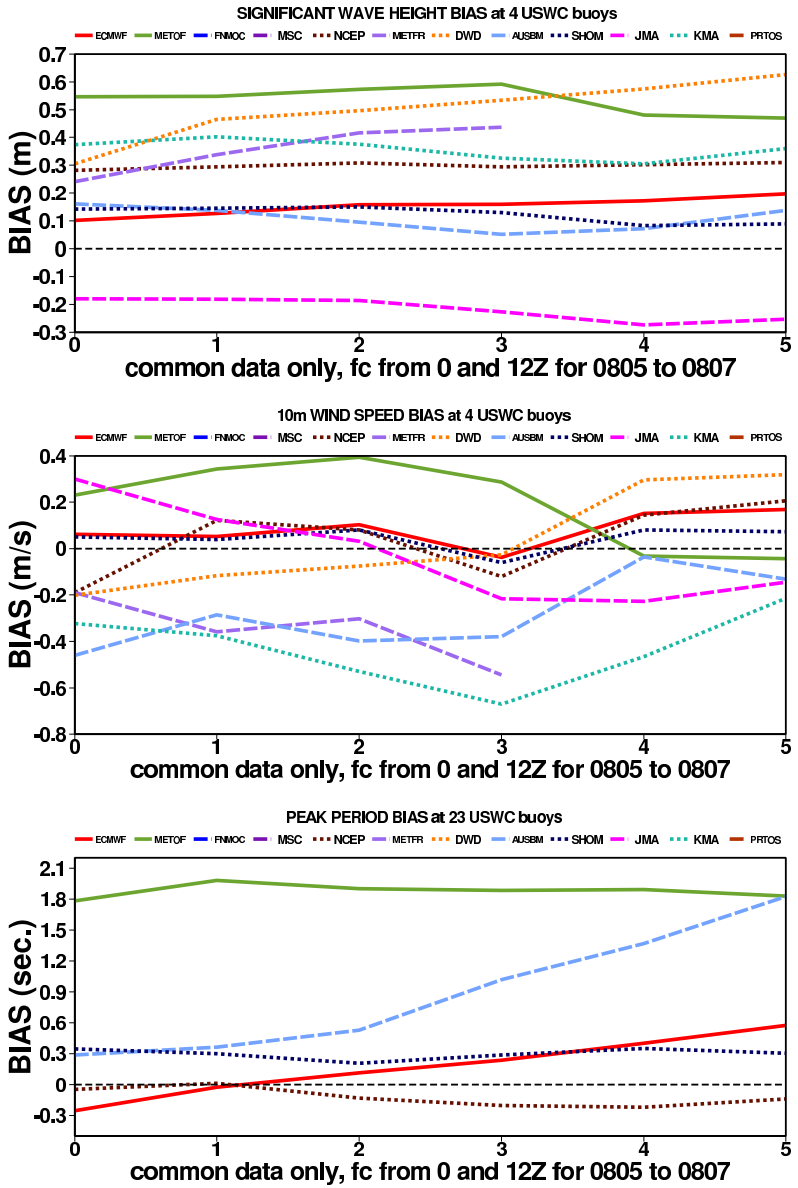


Figure 22: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

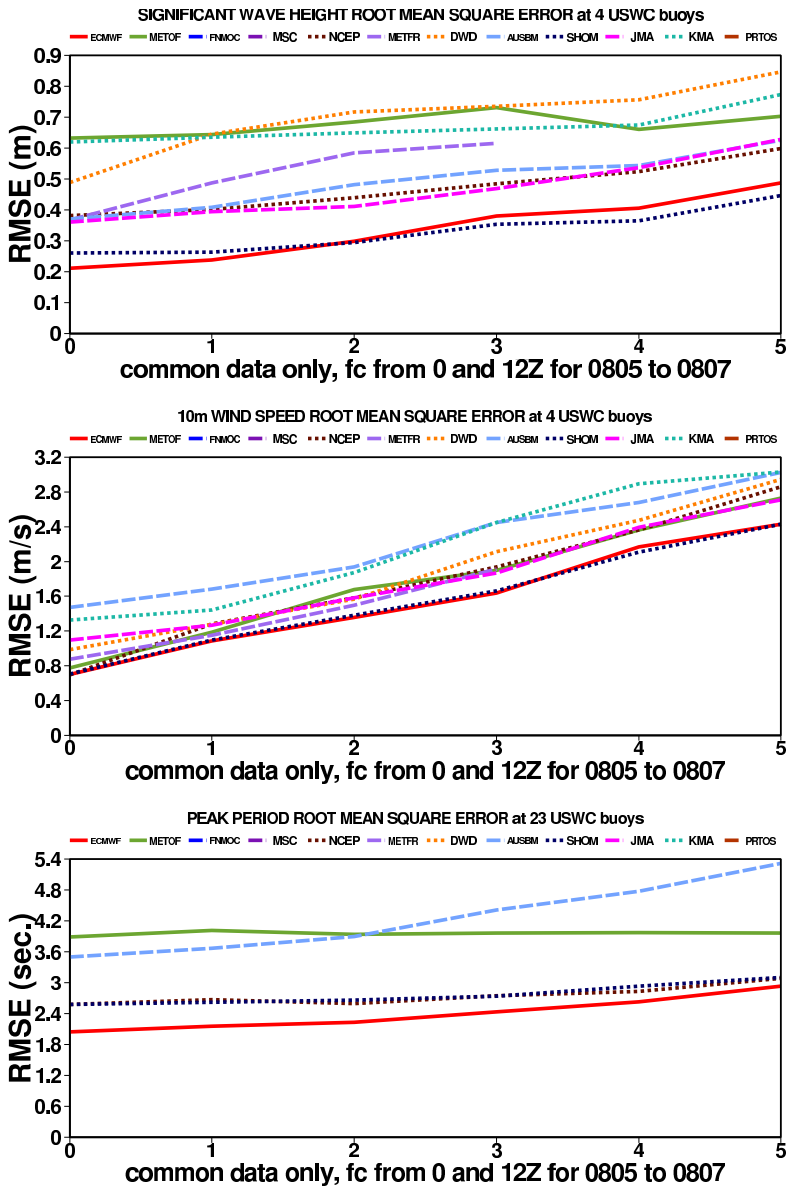


(a) Scatter Index (%)

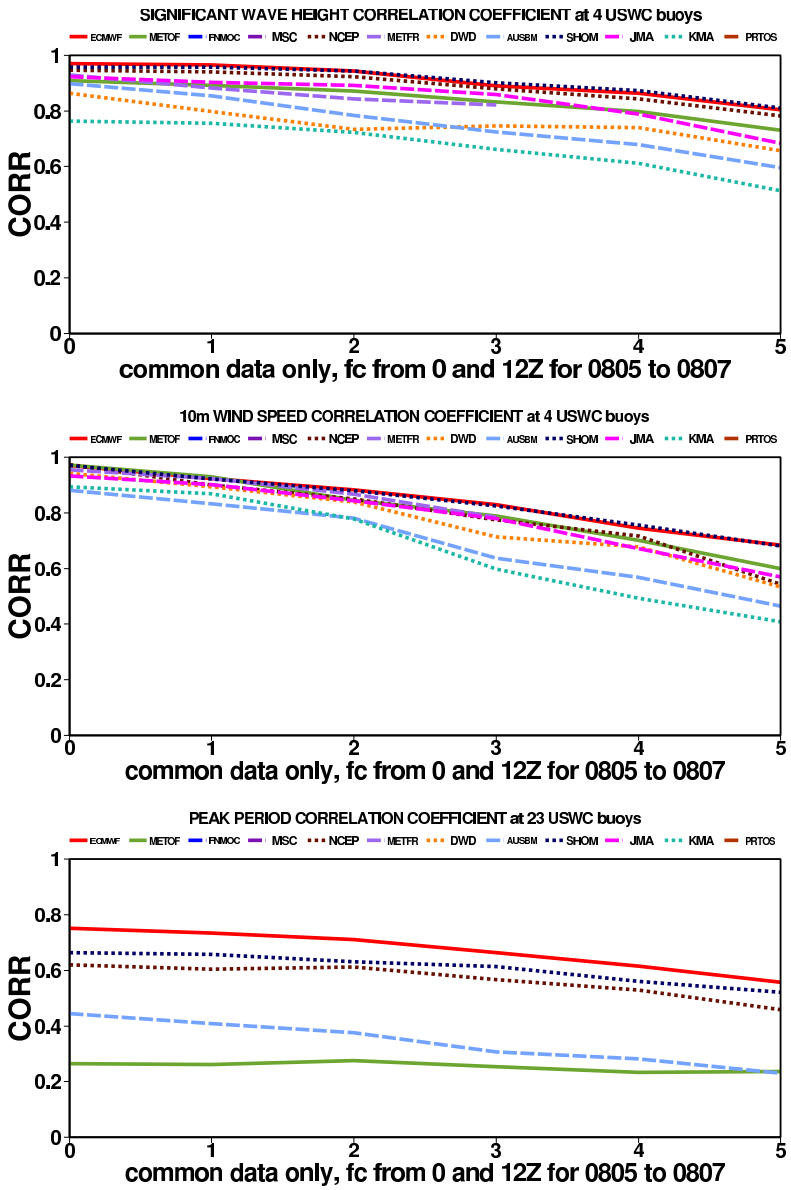


(b) Bias (model-buoy)

Figure 23: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common US West Coast buoys .



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 24: Forecast root mean square error (RMSE) and linear correlation coefficient at common US West Coast buoys .

0.3.5 Comparison for US East Coast buoys

Number of common observations for US East Coast buoys (USEC) from 200805 to 200807 (wind, Hs, Tp)

1	41001	71	71	75	US East Coast, E Hatteras	12	44008	168	180	182	US North-East Coast, Nantucket
2	41004	0	0	178	US South-East Coast, Edisto	13	44009	0	0	182	US North-East Coast, Delaware bay
3	41008	0	0	181	US South-East Coast, Grays reef	14	44011	177	178	181	US North-East Coast, Georges Bank
4	41009	0	0	148	US East Florida , Cape Canaveral	15	44014	0	0	120	US East Coast, Virginia Beach
5	41010	173	171	174	US East Florida , Cape Canaveral East	16	44017	0	0	181	US North-East Coast, Montauk Point
6	41012	0	0	125	US East Florida , St Augustine	17	44018	0	0	182	US North-East Coast, SE Cape Cod
7	41013	0	0	182	US South-East Coast , Frying Pan Shoals	18	44024	178	178	182	US North East Coast, Northeast Channel
8	41025	0	0	182	US East Coast, Diamond Shoals (Red Buoy)	19	44025	0	0	182	US North East Coast, Long Island
9	41036	0	0	182	US East Coast, Onslow Bay offshore	20	44027	0	0	177	US North East Coast, Jonesport
10	41048	0	0	178	W Bermuda	21	44037	0	0	181	US North East Coast, Jordan Basin
11	44005	0	0	16	US North East Coast, Gulf of Maine						

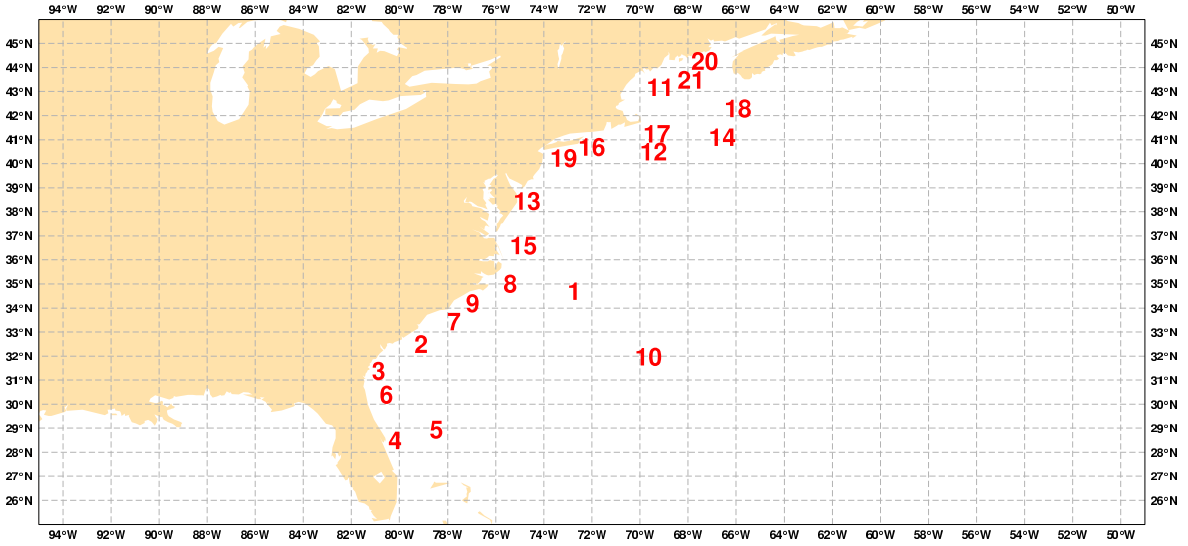
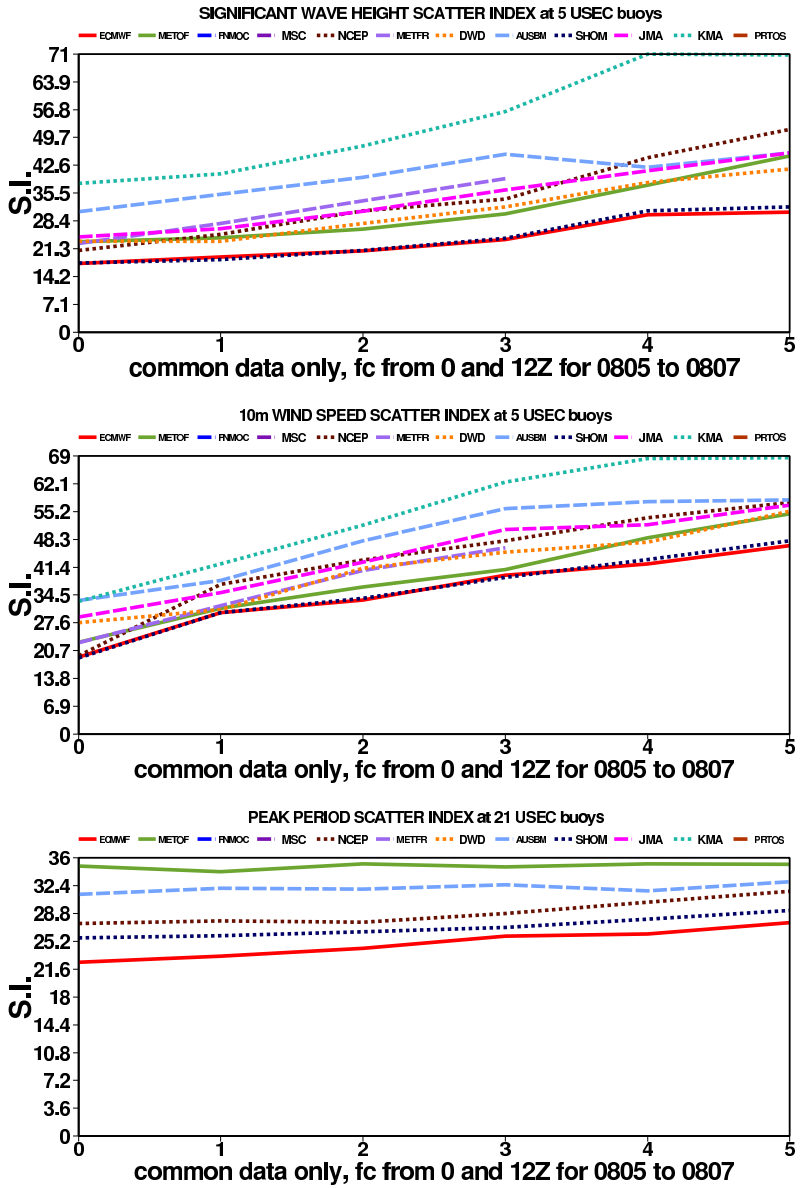
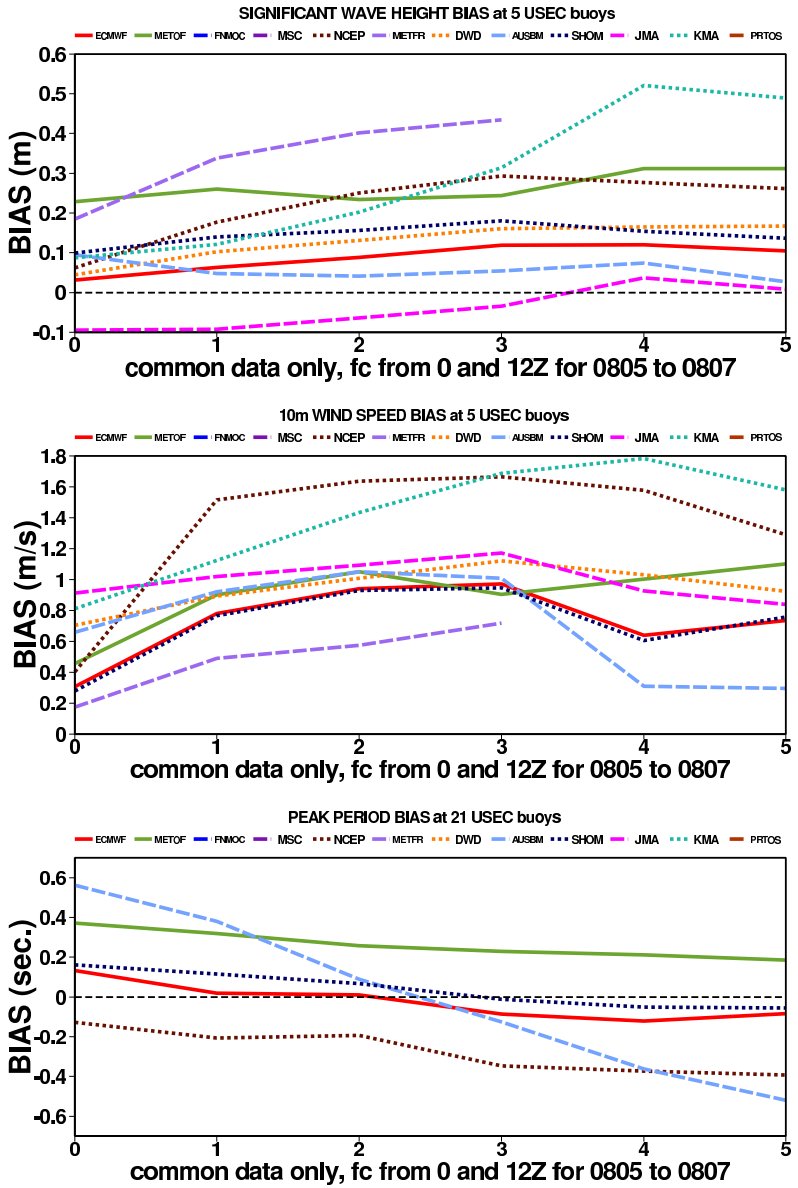


Figure 25: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

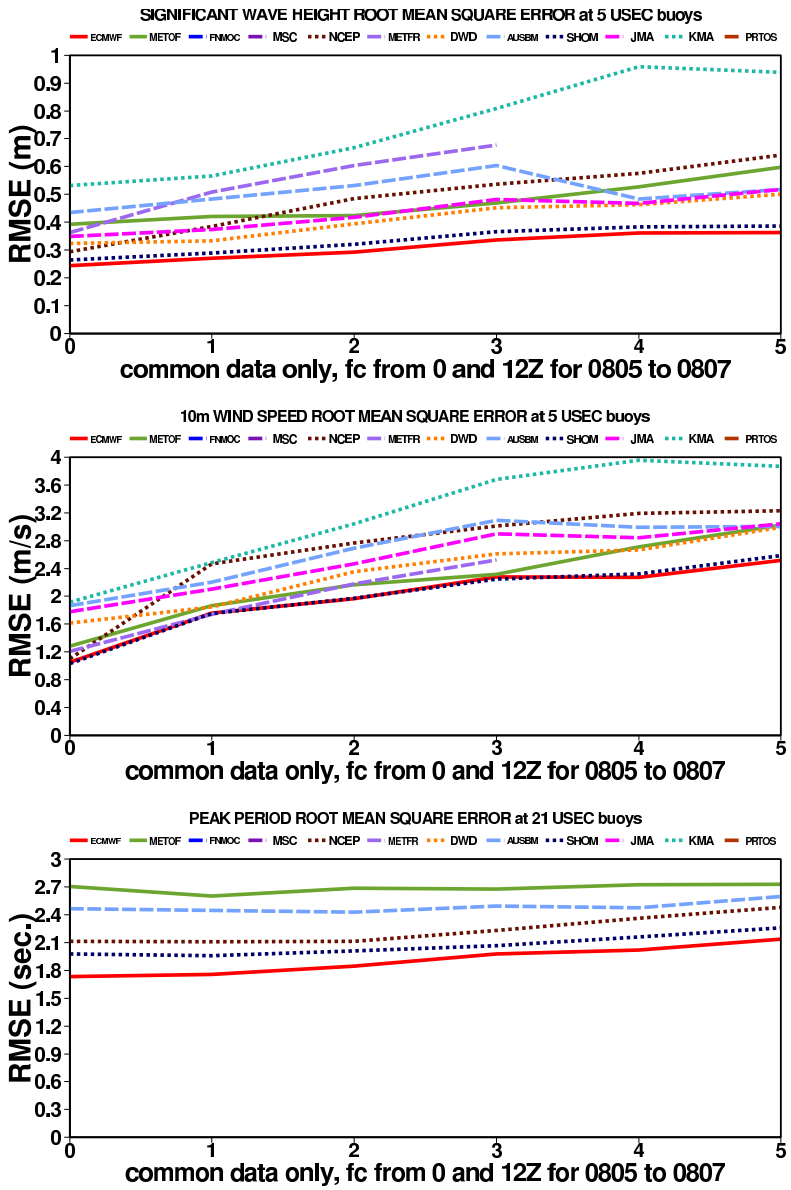


(a) Scatter Index (%)

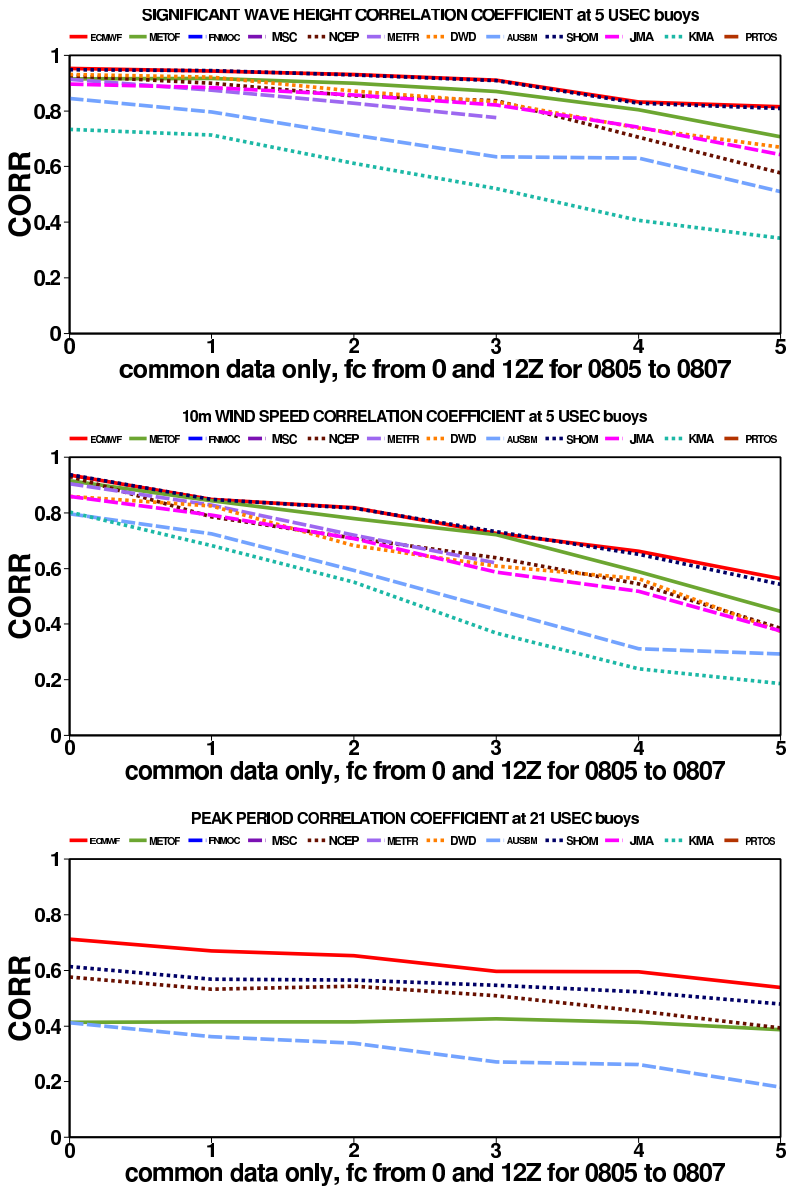


(b) Bias (model-buoy)

Figure 26: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common US East Coast buoys .



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 27: Forecast root mean square error (RMSE) and linear correlation coefficient at common US East Coast buoys .

0.3.6 Comparison for Gulf of Mexico buoys

Number of common observations for Gulf of Mexico buoys (GM) from 200805 to 200807 (wind, Hs, Tp)

1	42001	178	177	174	Mid Gulf of Mexico	6	42036	0	0	163	Gulf of Mexico W Tampa
2	42002	180	178	174	Western Gulf of Mexico	7	42039	0	0	173	Gulf of Mexico Pensacola S
3	42003	176	176	177	East Gulf of Mexico	8	42040	0	0	162	Gulf of Mexico Mobile S
4	42019	0	0	182	Gulf of Mexico Lanelle	9	42055	177	177	178	Bay of Campeche
5	42020	0	0	181	Gulf of Mexico Corpus Christi	10	42099	0	0	174	Gulf Mexico, St Peterburg (scripps 144)

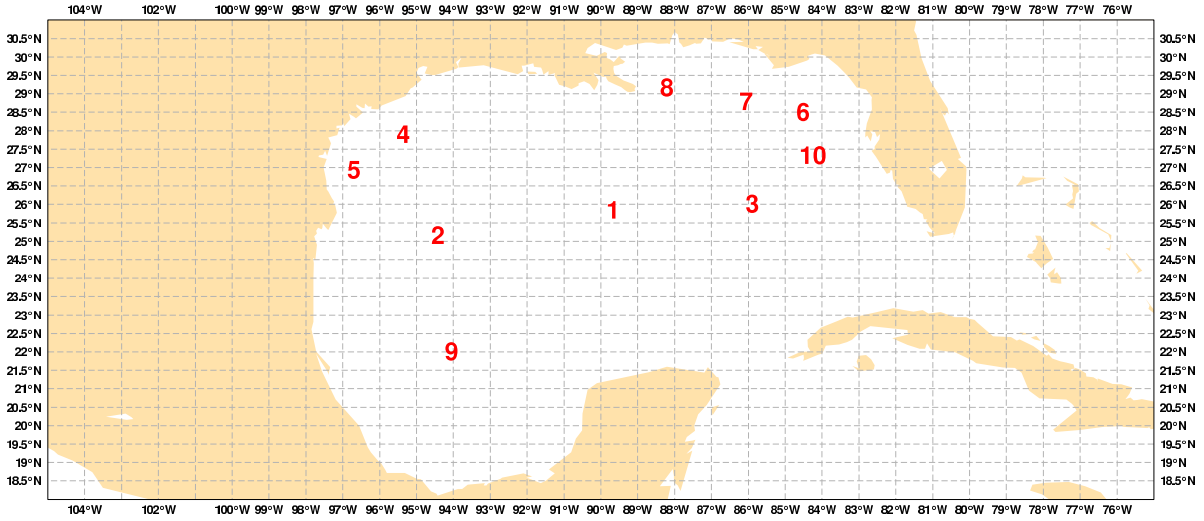
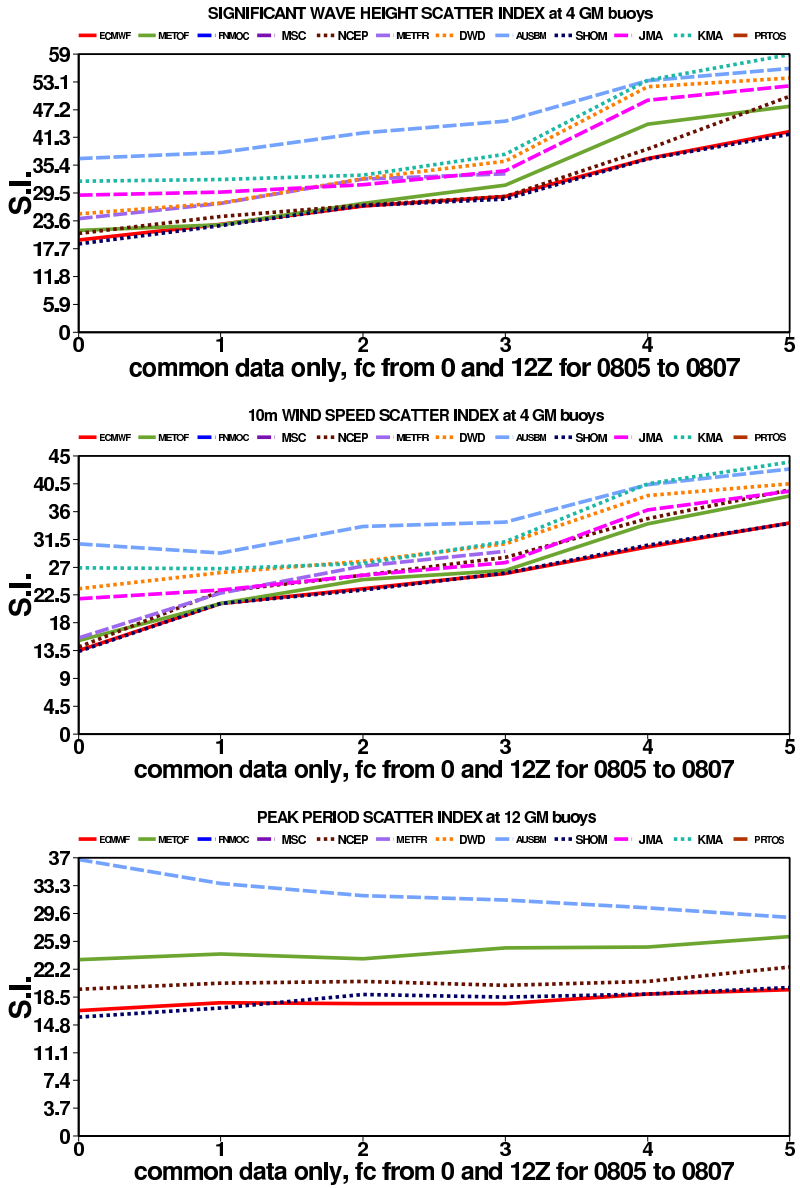
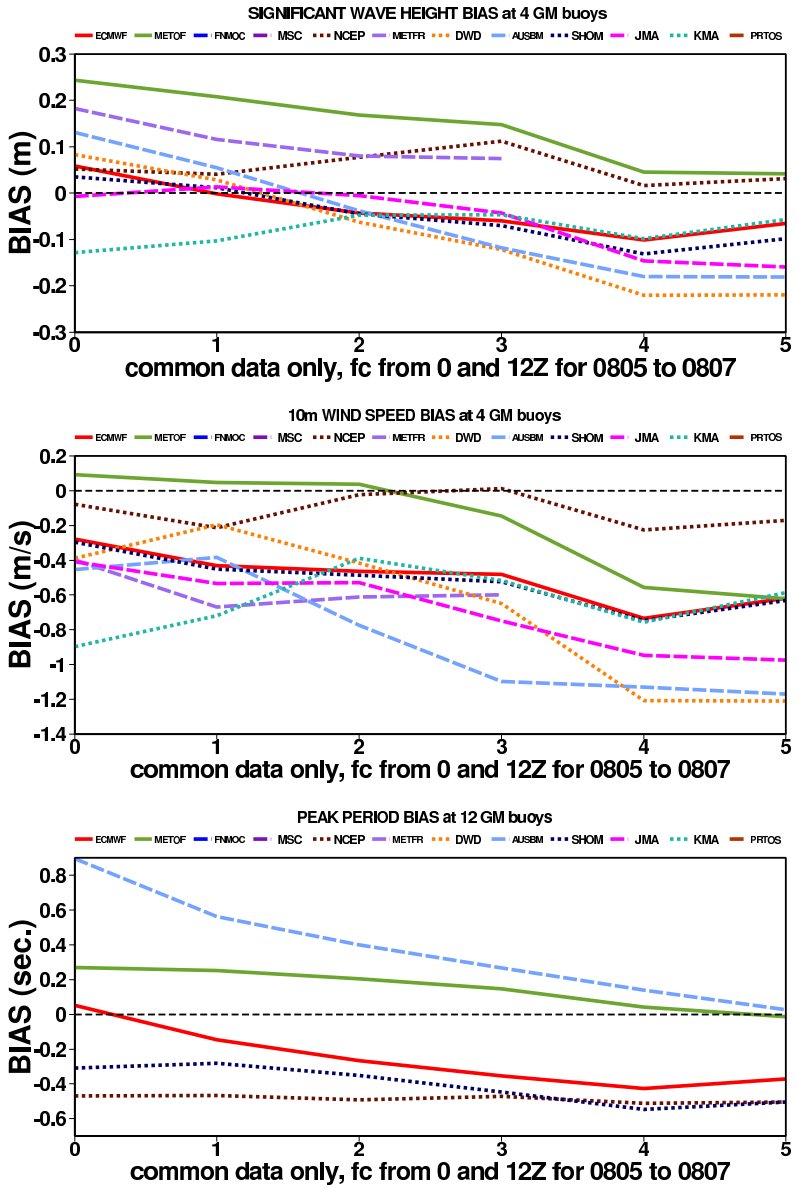


Figure 28: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

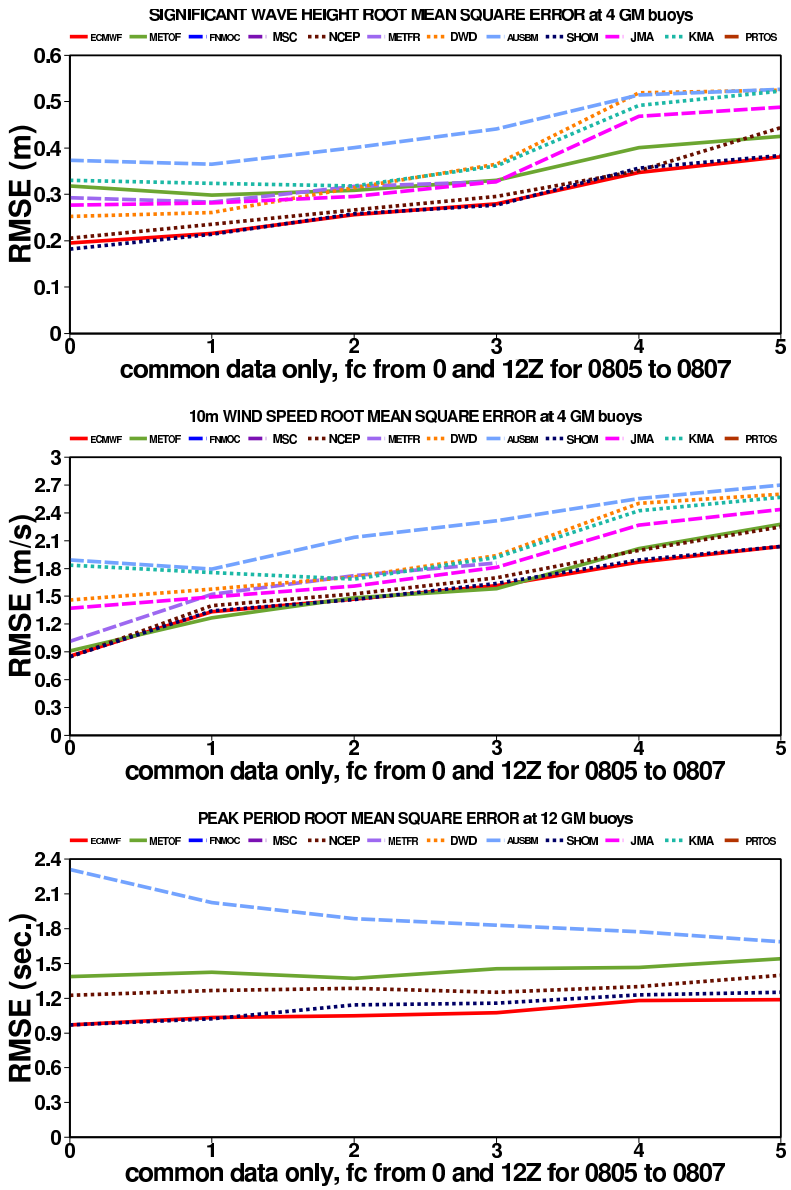


(a) Scatter Index (%)

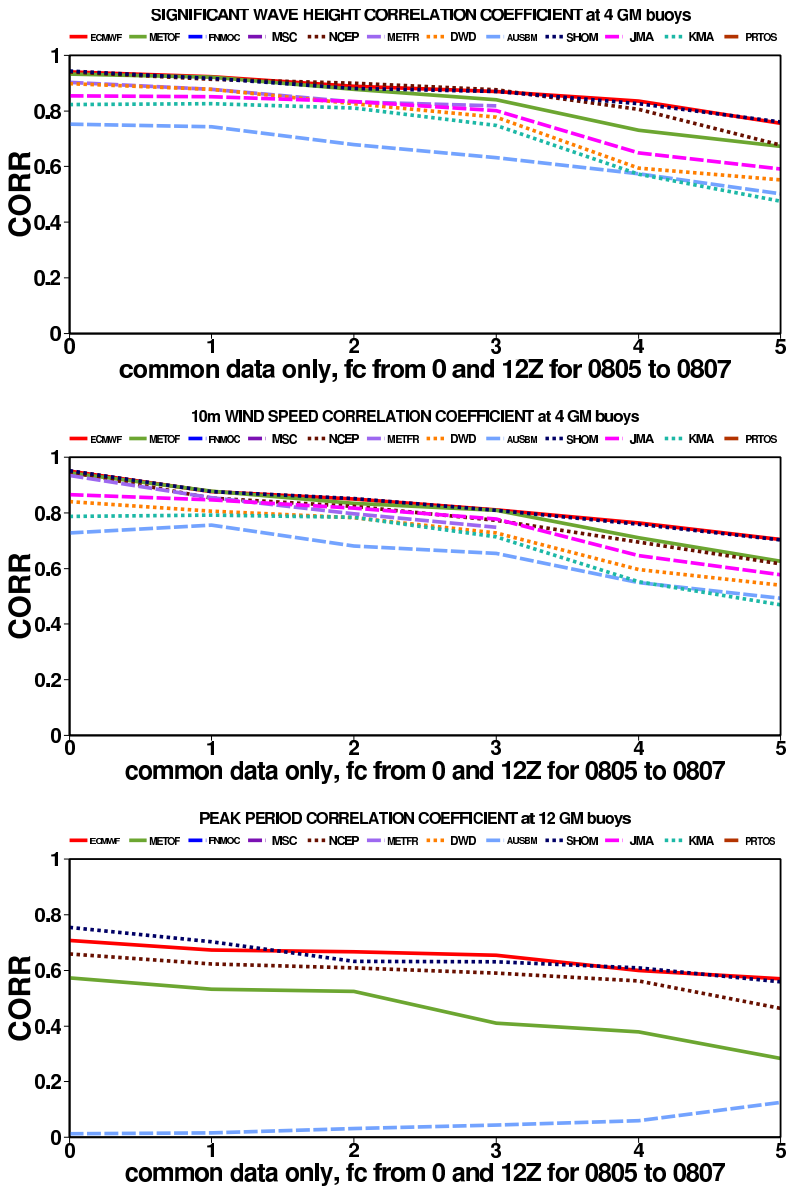


(b) Bias (model-buoy)

Figure 29: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Gulf of Mexico buoys .



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 30: Forecast root mean square error (RMSE) and linear correlation coefficient at common Gulf of Mexico buoys .

0.3.7 Comparison for Canadian East Coast buoys

Number of common observations for Canadian East Coast buoys (CANEC) from 200805 to 200807 (wind, Hs, Tp)

1	44137	162	178	180	Nova Scotia, East Scotia slope	5	44141	32	177	179	Nova Scotia, Laurentian Fan
2	44138	178	178	182	Newfoundland, SW Grand Bank	6	44150	180	0	0	Nova Scotia, La Have Bank
3	44139	179	179	181	Newfoundland, Banquerau	7	44251	0	0	127	Newfoundland, Nickerson Bank
4	44140	172	0	0	Newfoundland, Tail Of The Bank	8	44255	0	0	182	Newfoundland, NE Bugeo Bank

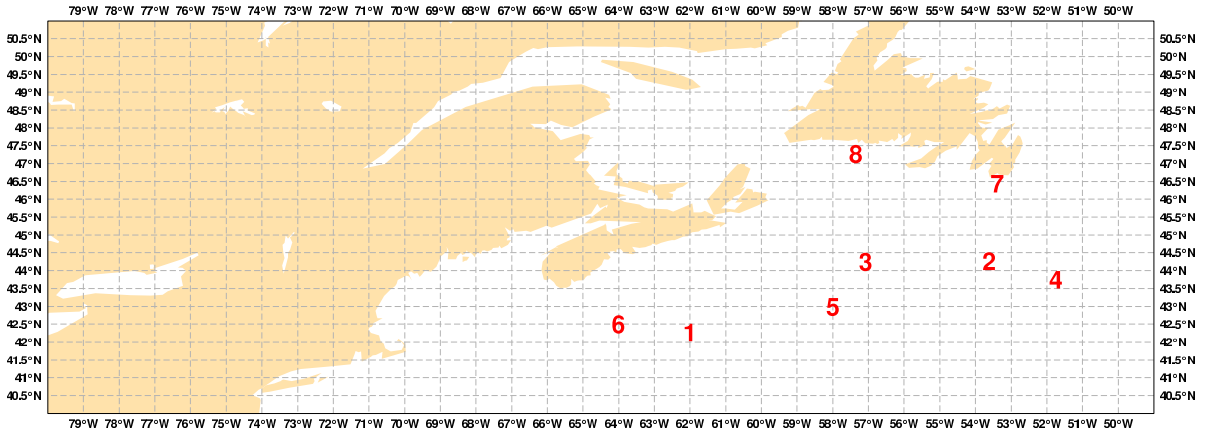
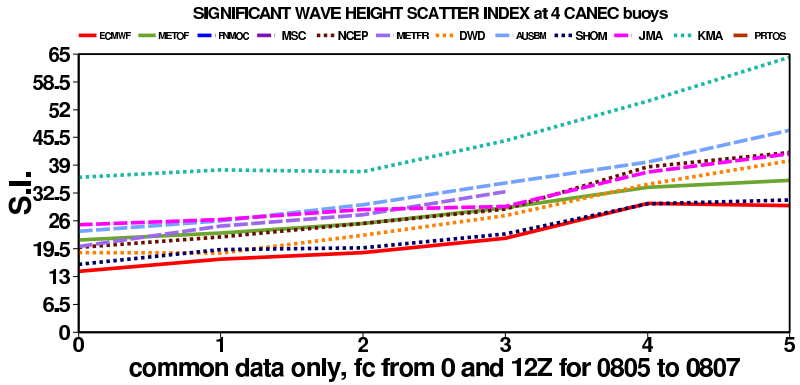
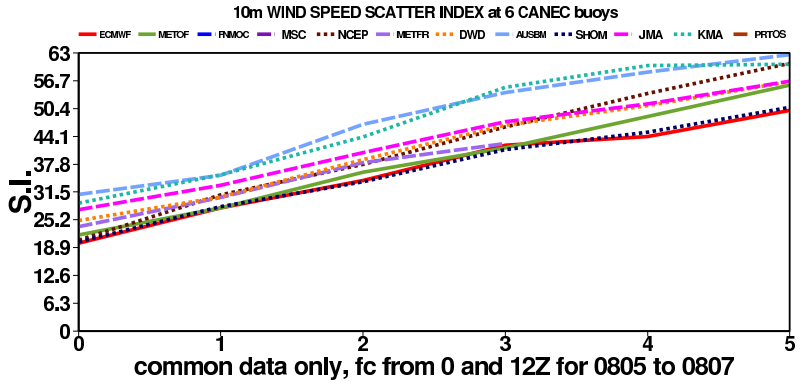
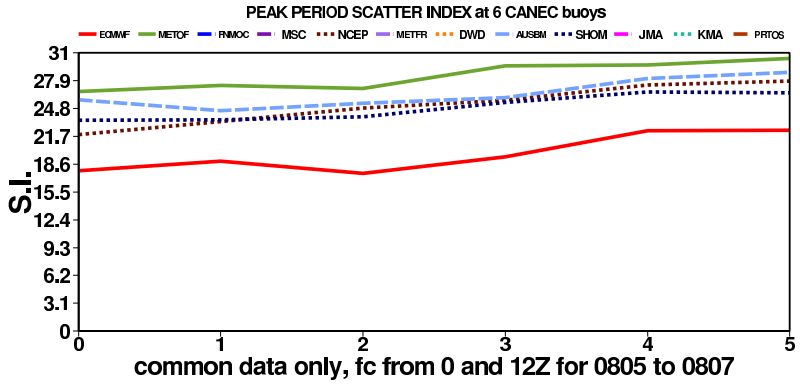


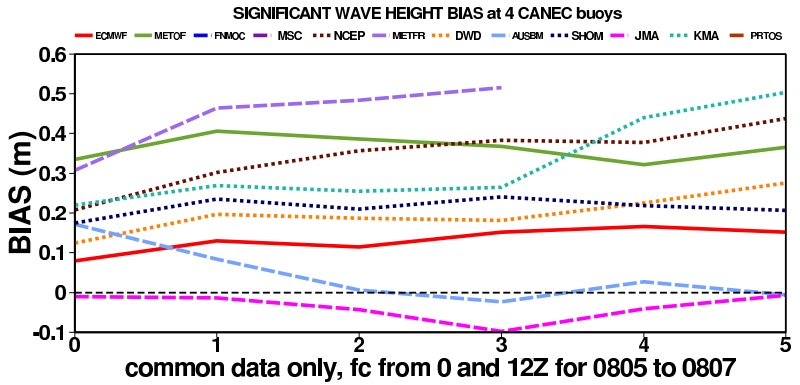
Figure 31: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

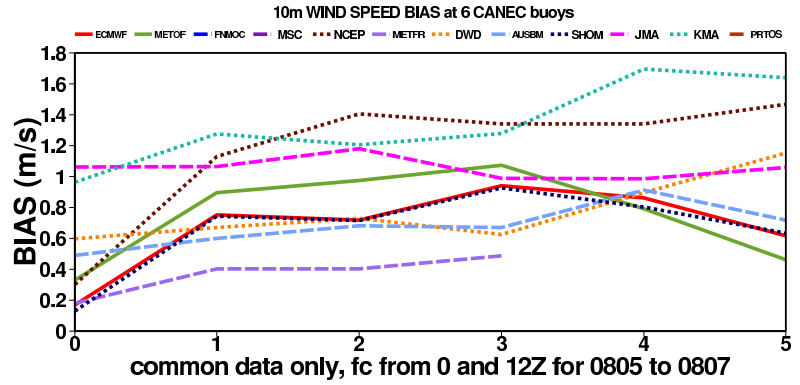


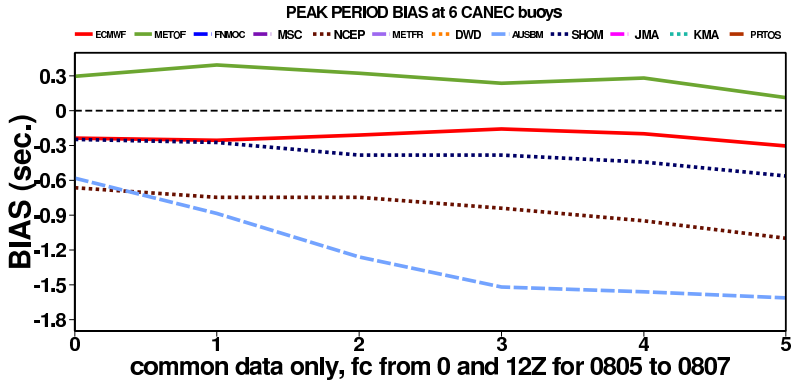




(a) Scatter Index (%)

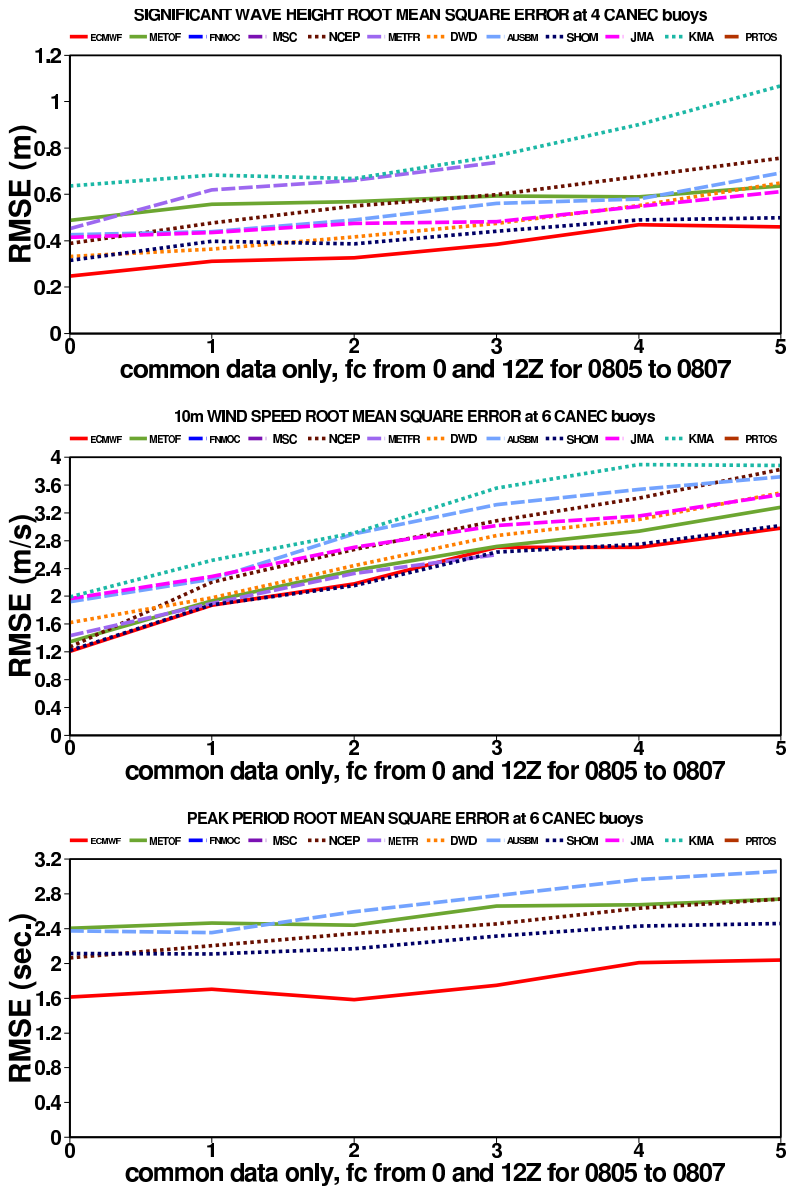




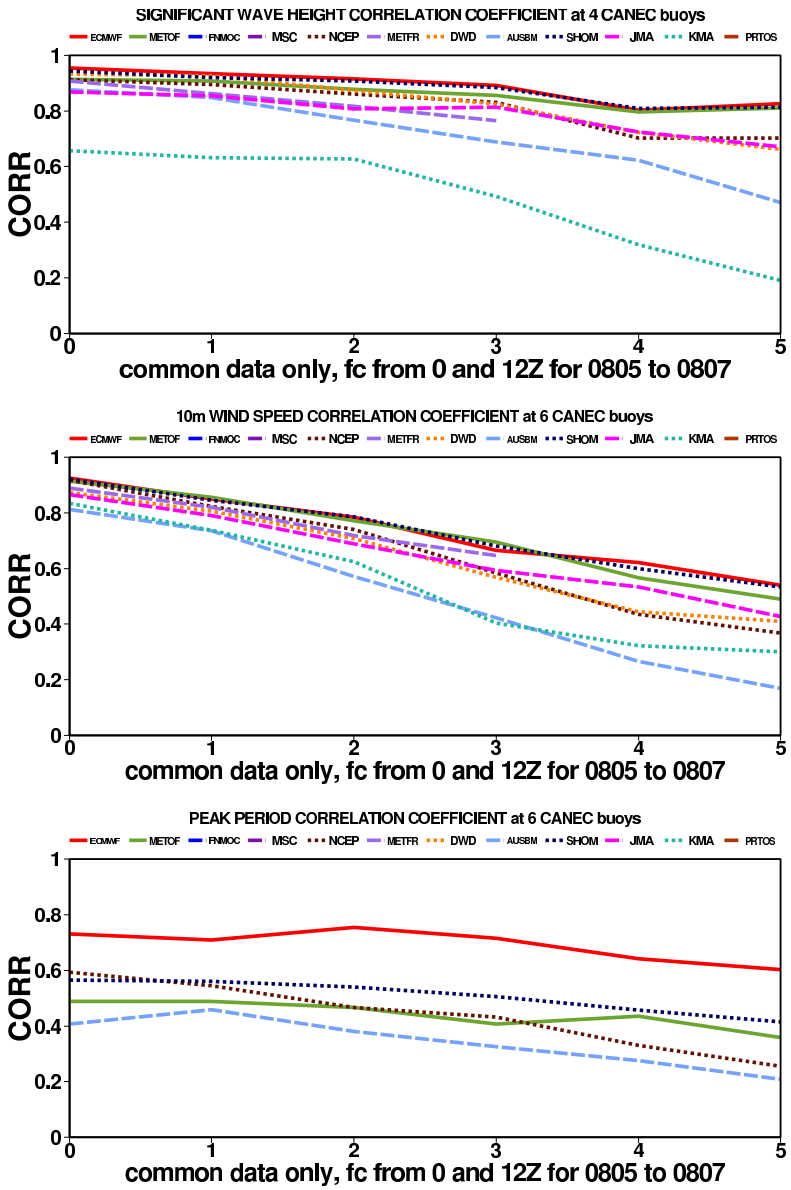


(b) Bias (model-buoy)

Figure 32: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Canadian East Coast buoys .



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 33: Forecast root mean square error (RMSE) and linear correlation coefficient at common Canadian East Coast buoys .

0.3.8 Comparison for North East Atlantic buoys

Number of common observations for North East Atlantic buoys (NEATL) from 200805 to 200807 (wind, Hs, Tp)

1	62029	115 177 0	UK Celtic Sea shelf break (K1)		
2	62081	180 180 0	UK East Atlantic (K2)		
3	62082	92 92 0	Estaca de Bares (Spain)		
4	62095	93 26 0	West Ireland (M6), West Coast		
5	62163	178 178 0	UK Celtic Sea shelf break (Brittany)		
6	64045	21 175 0	UK North-East Atlantic (K5)		
7	64046	171 163 0	UK North-East Atlantic (K7)		

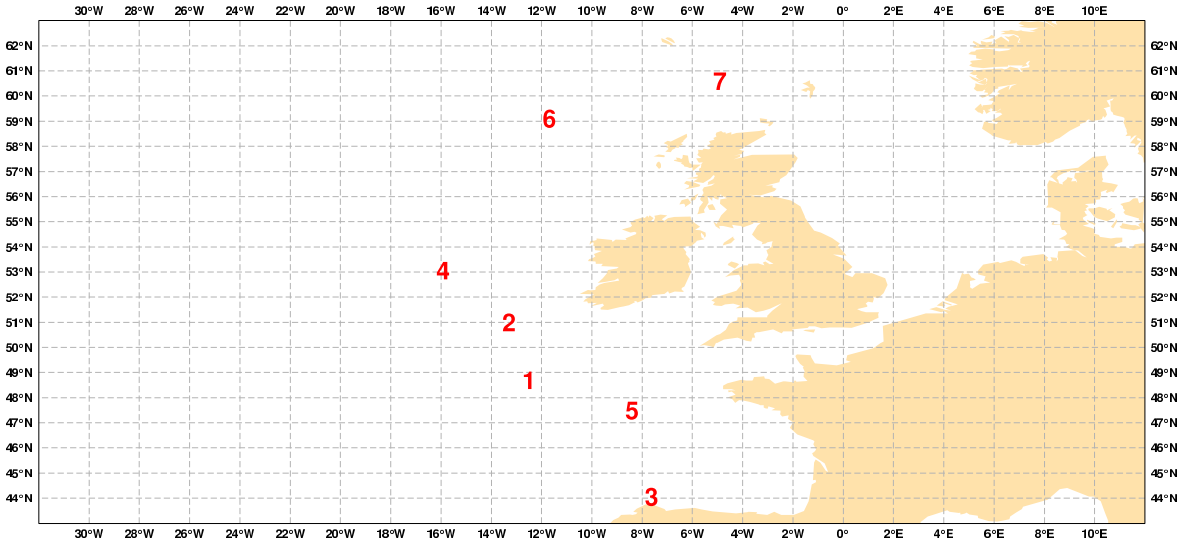
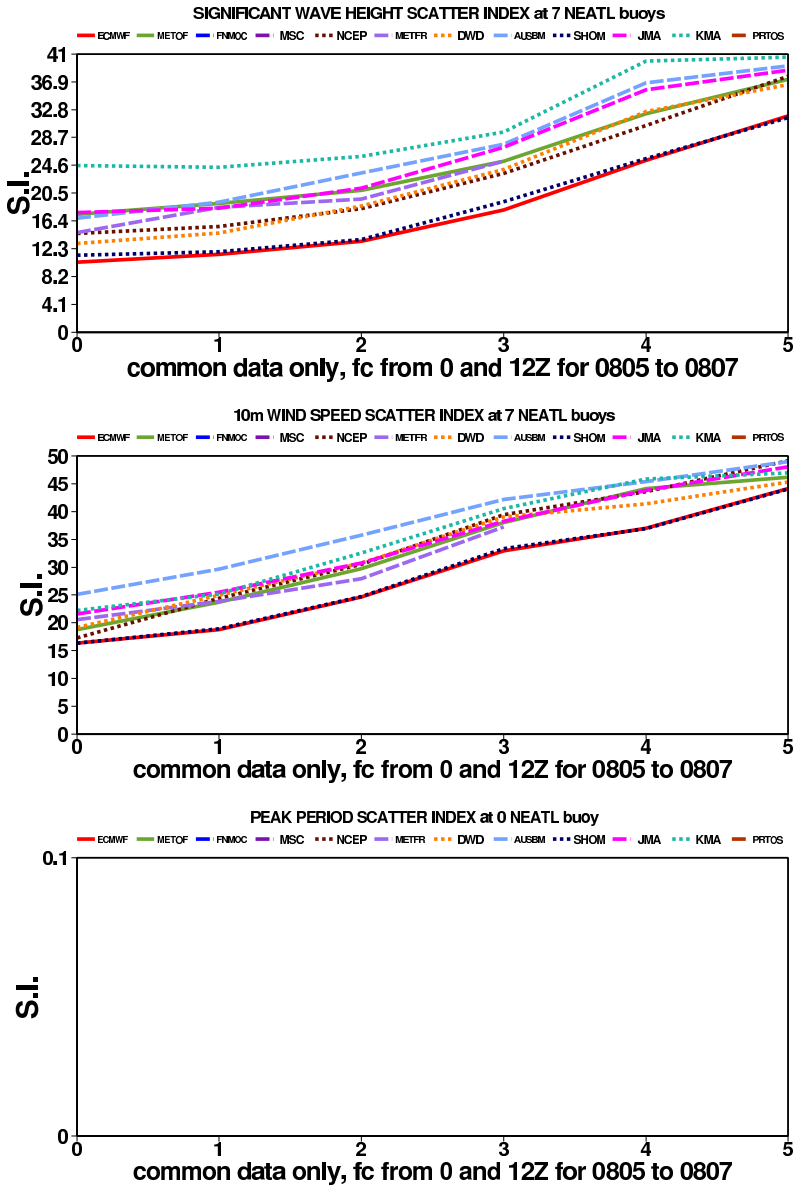
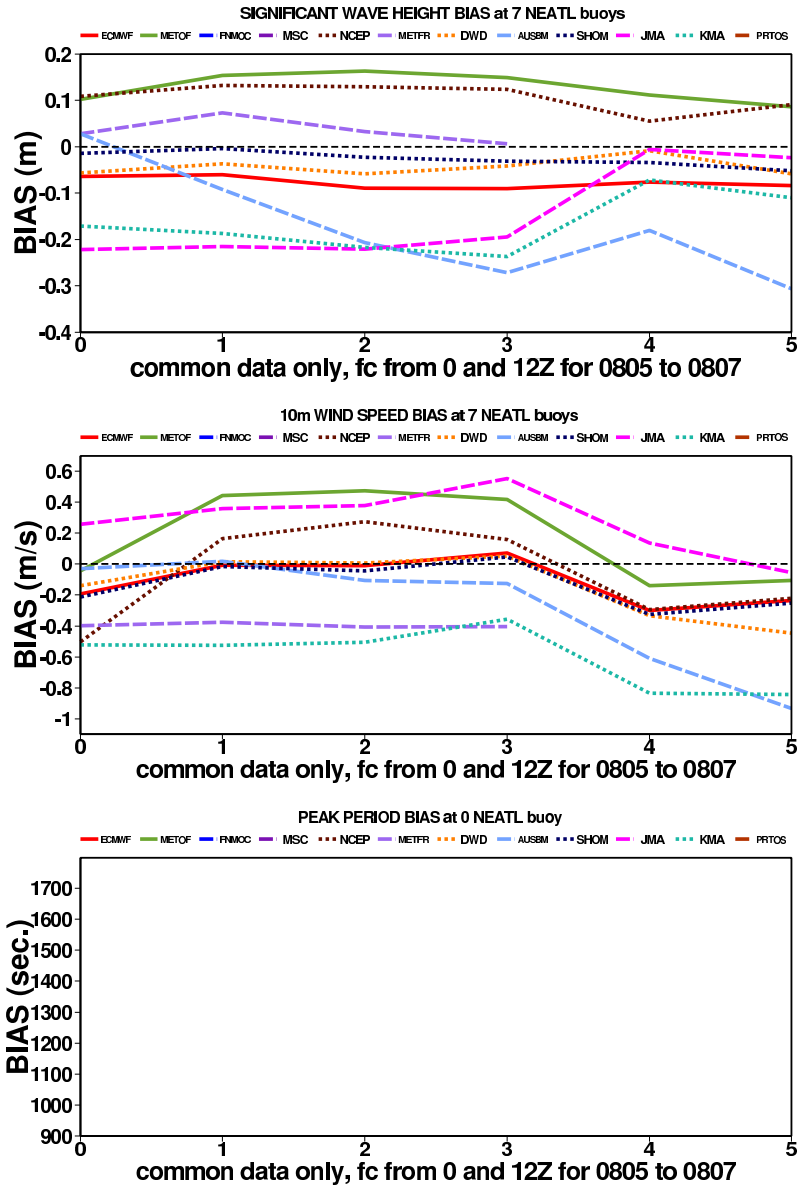


Figure 34: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

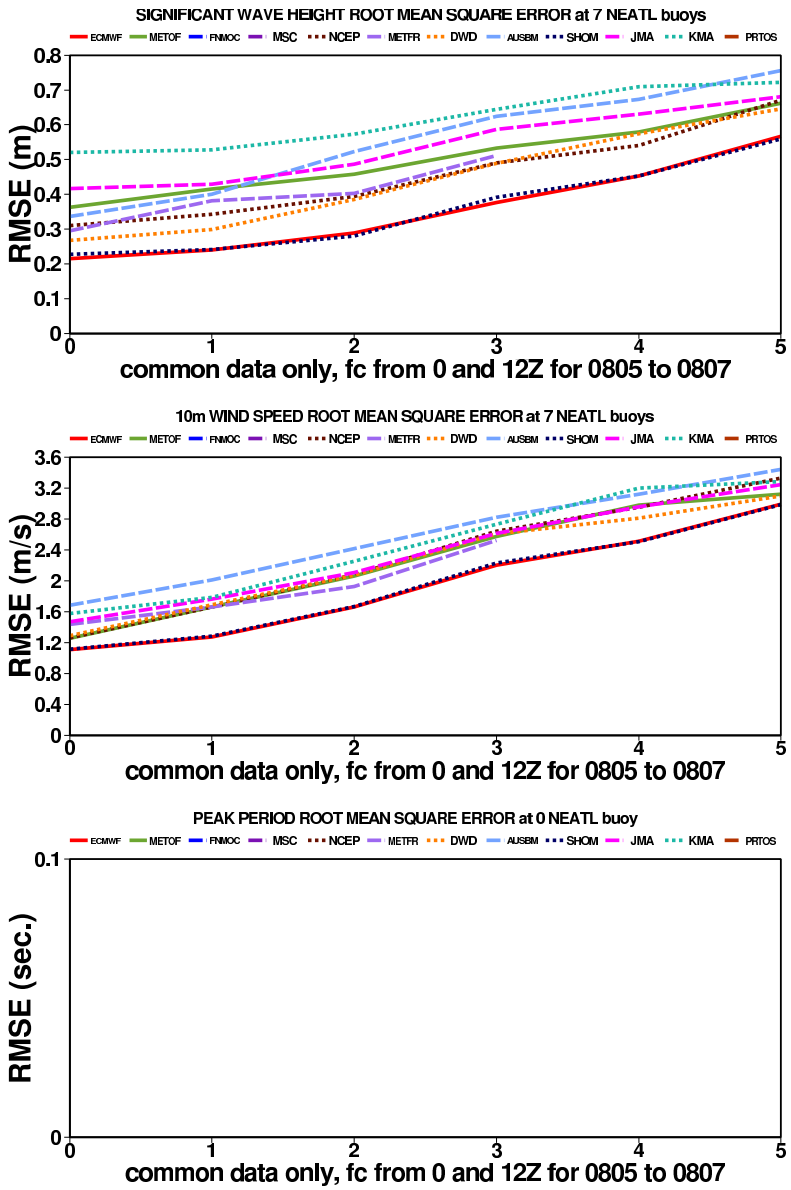


(a) Scatter Index (%)

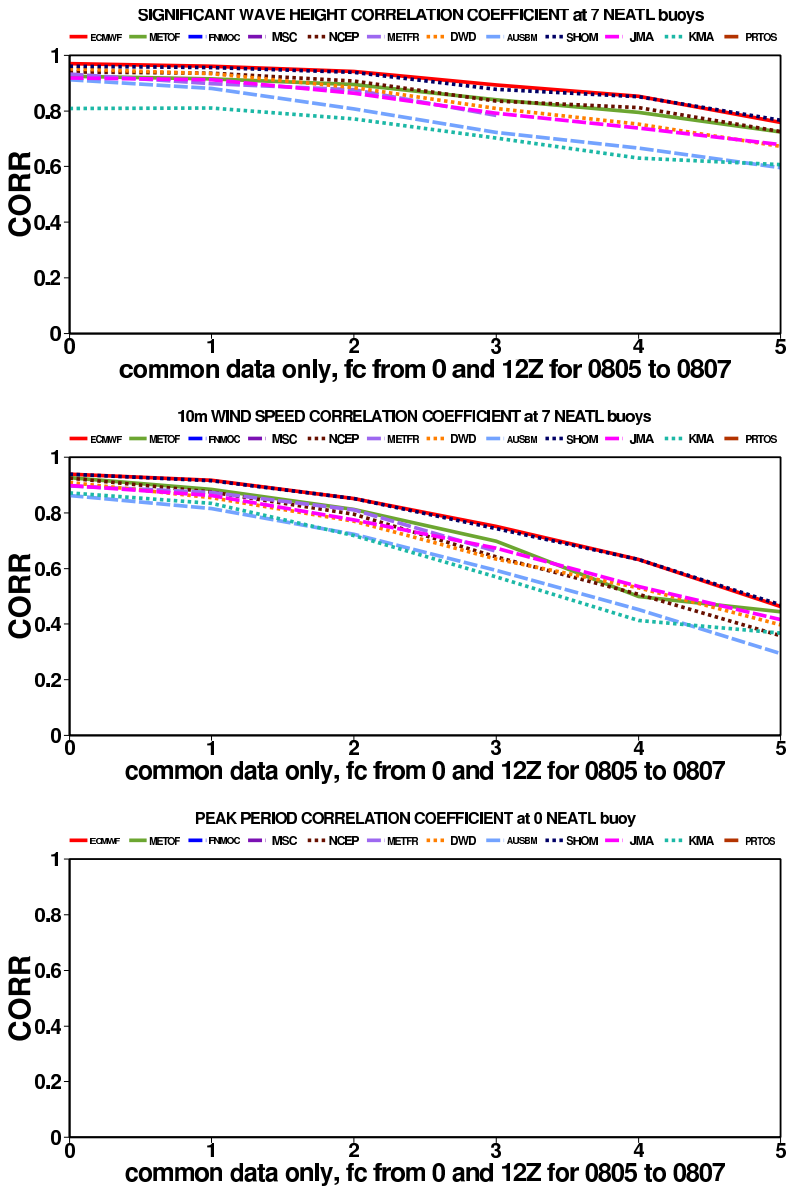


(b) Bias (model-buoy)

Figure 35: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North East Atlantic buoys .



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 36: Forecast root mean square error (RMSE) and linear correlation coefficient at common North East Atlantic buoys .

0.3.9 Comparison for North Sea platforms

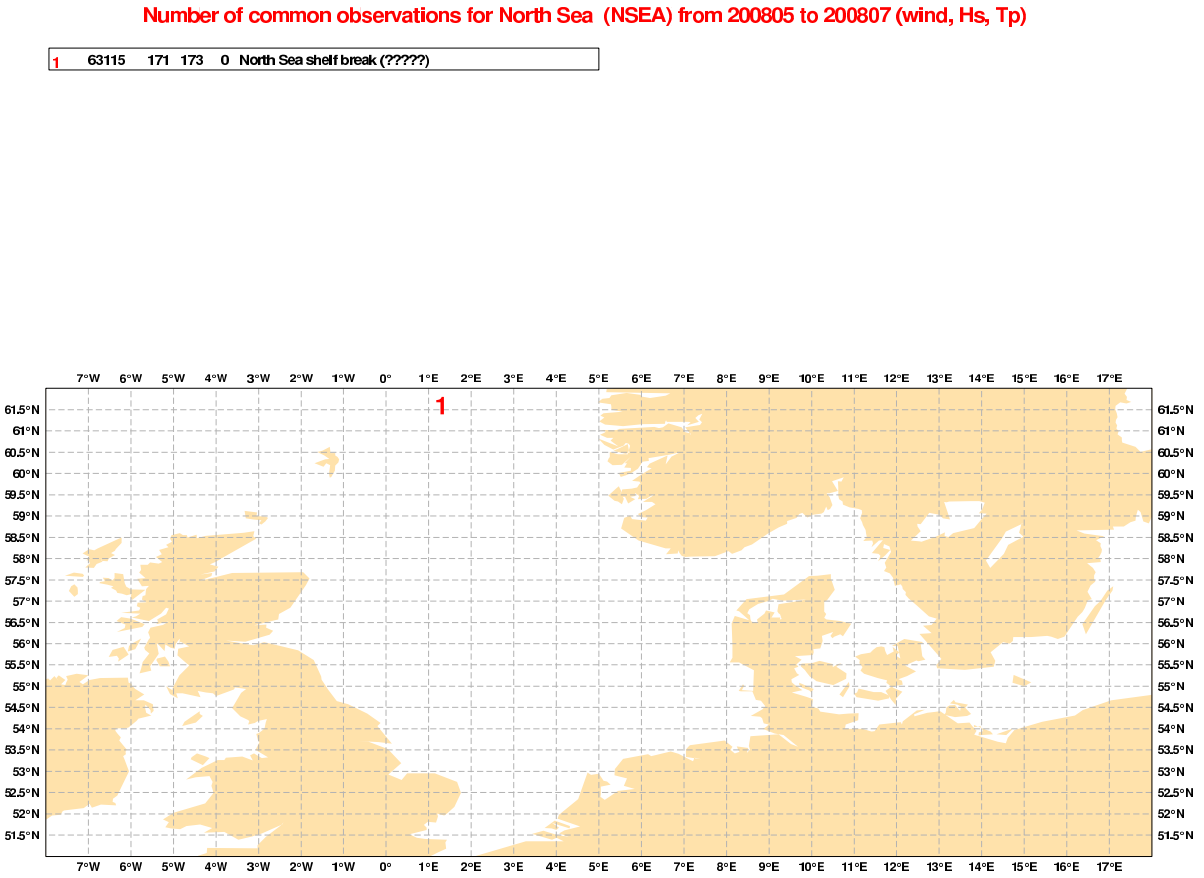
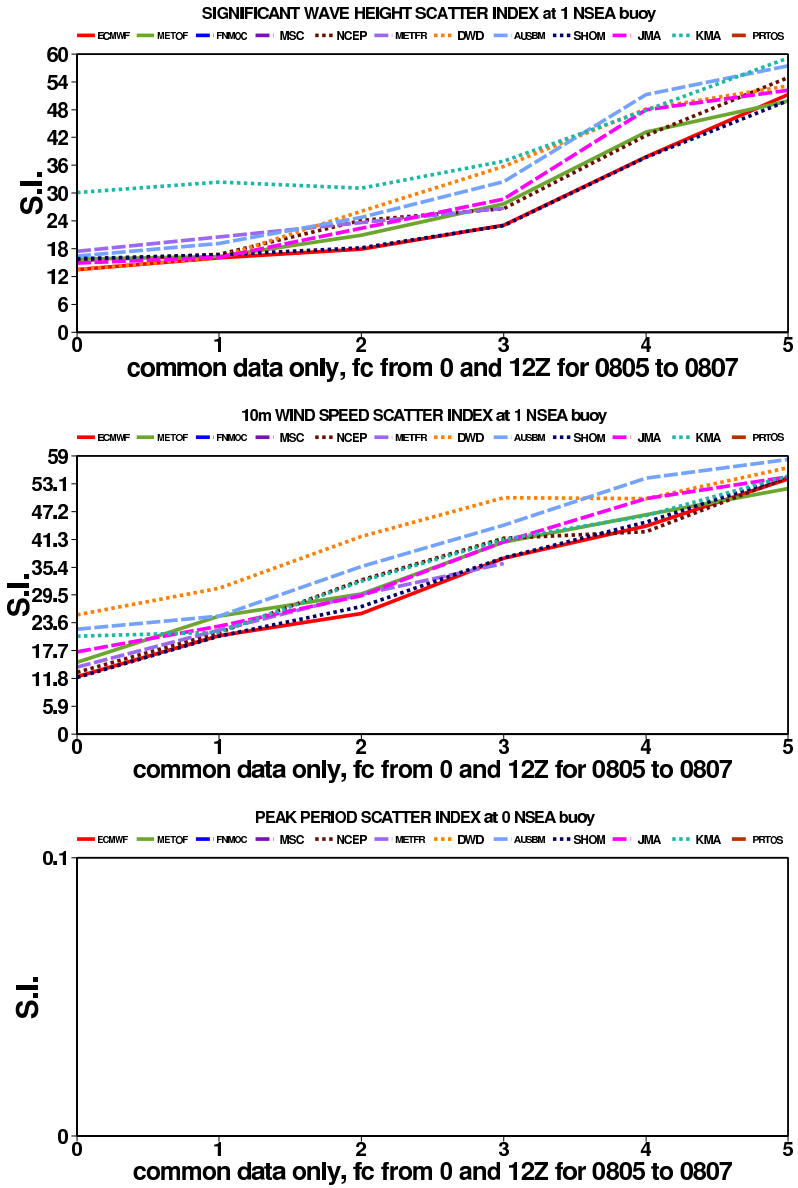
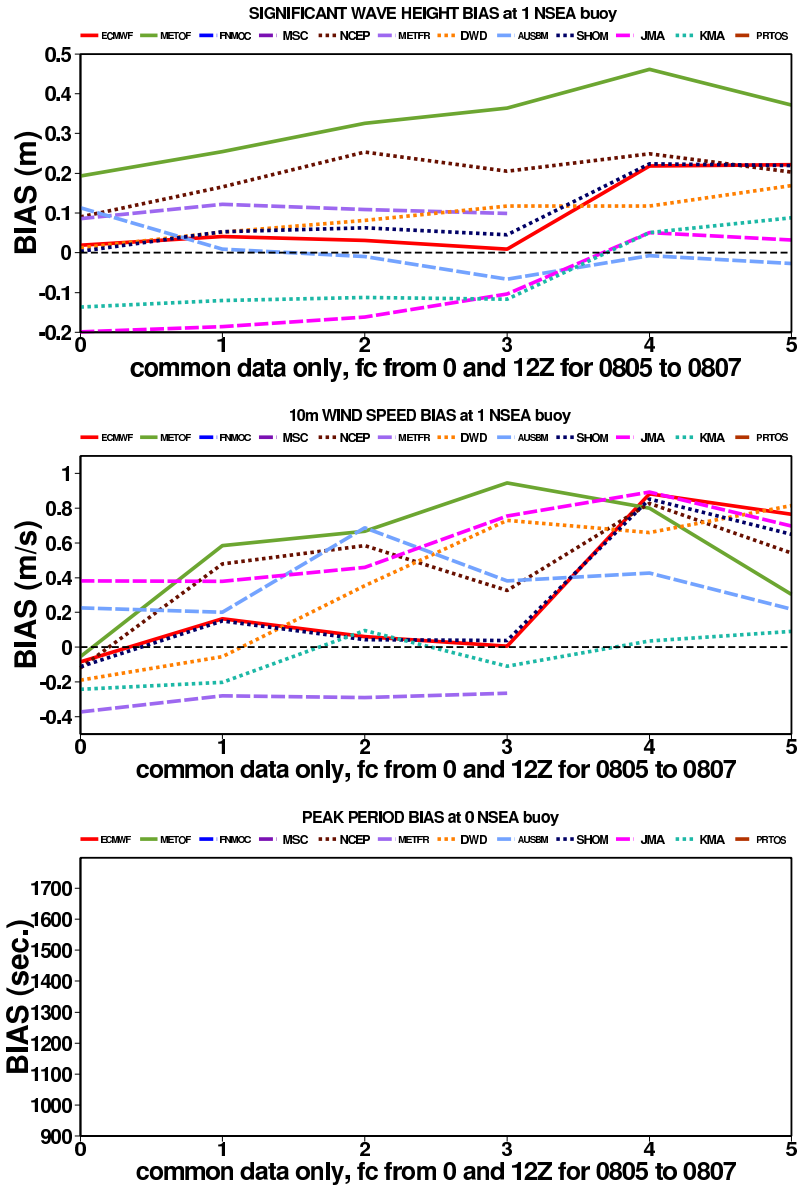


Figure 37: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

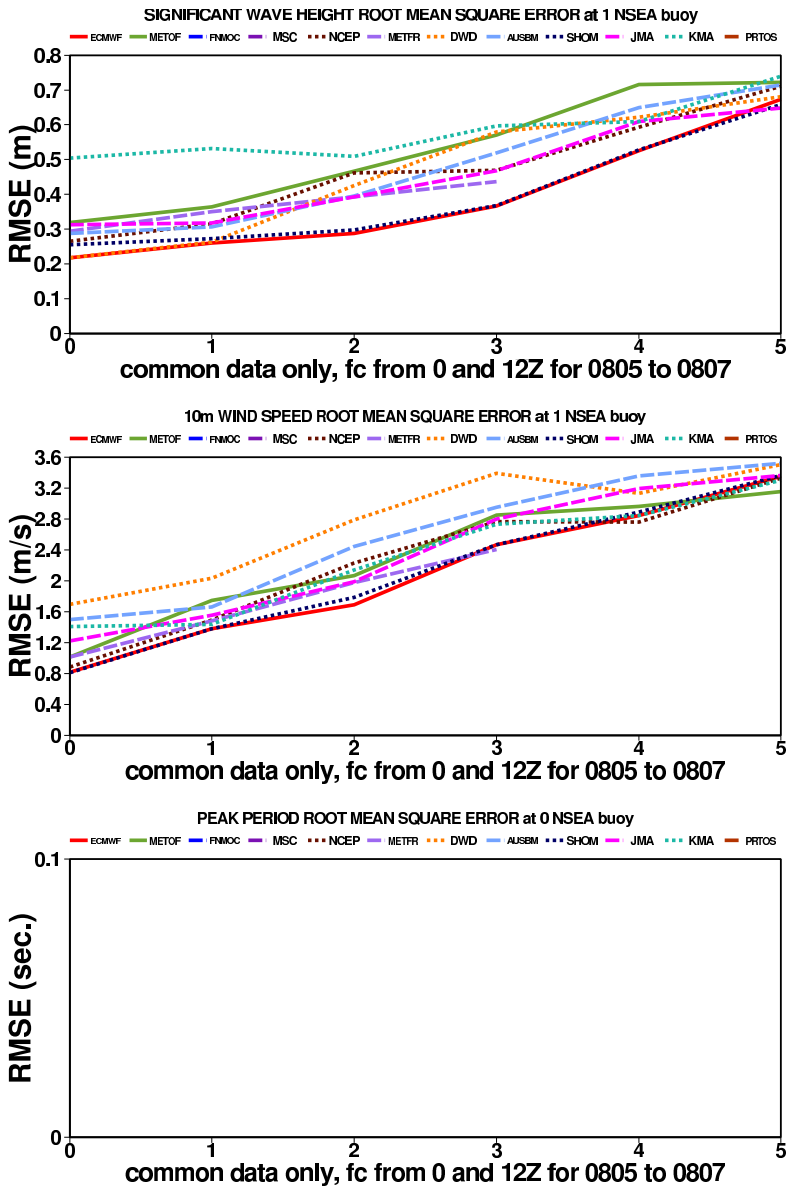


(a) Scatter Index (%)

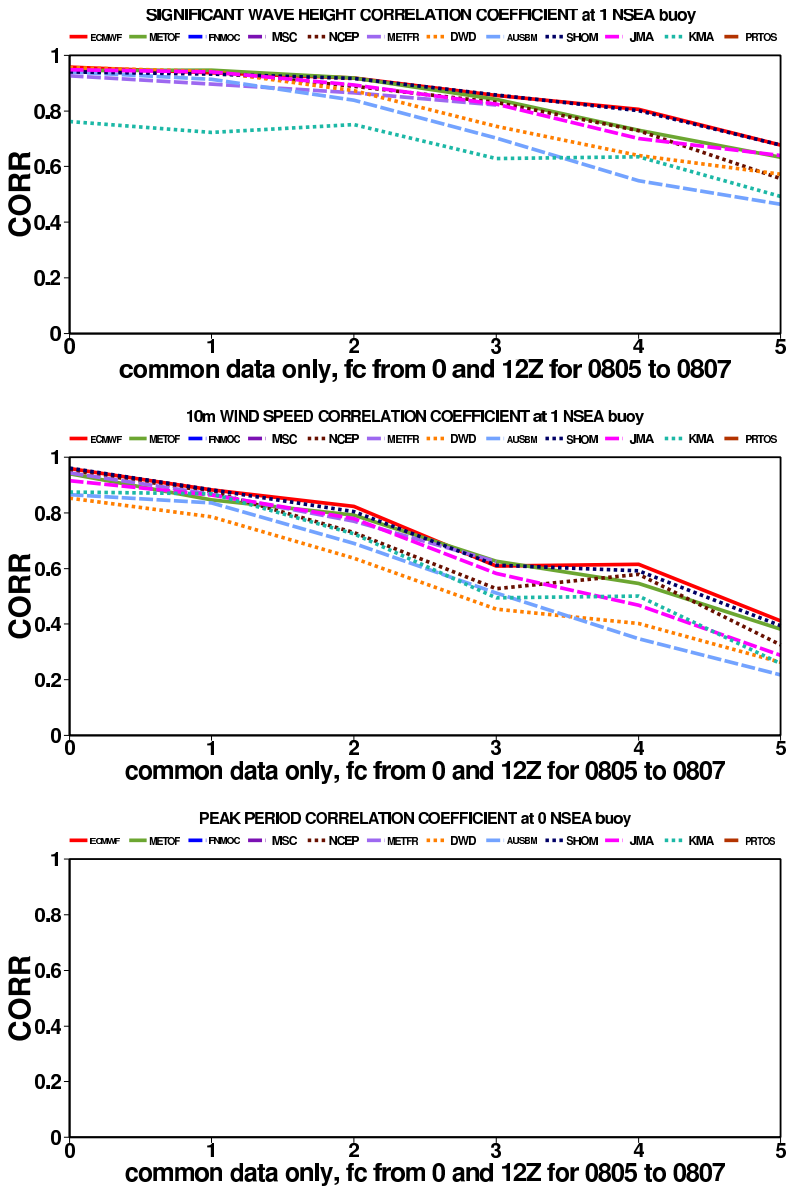


(b) Bias (model-buoy)

Figure 38: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North Sea platforms.



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 39: Forecast root mean square error (RMSE) and linear correlation coefficient at common North Sea platforms.

0.3.10 Comparison for South African platform

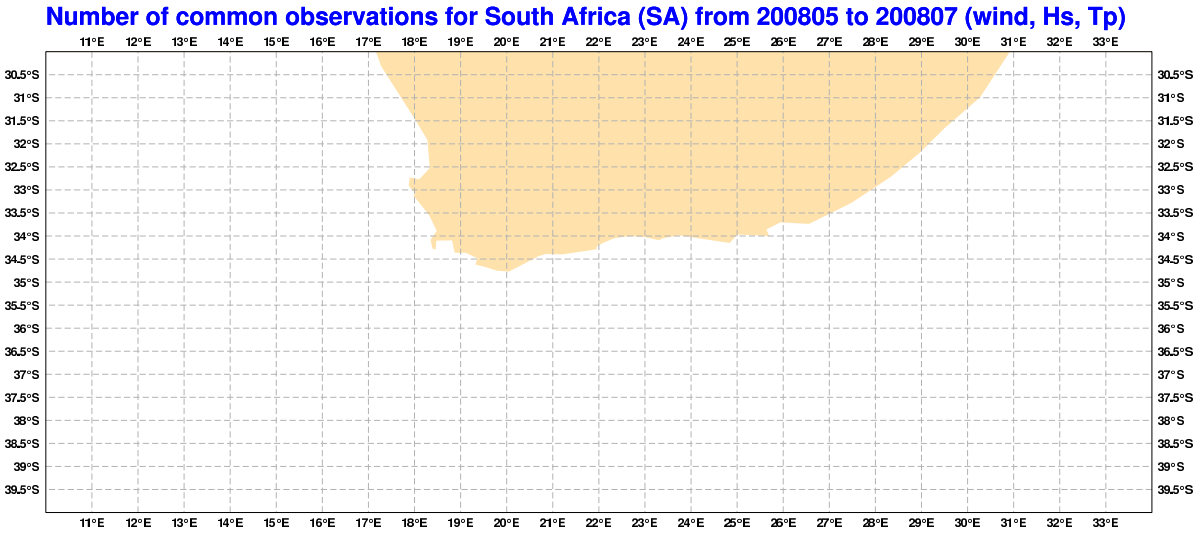
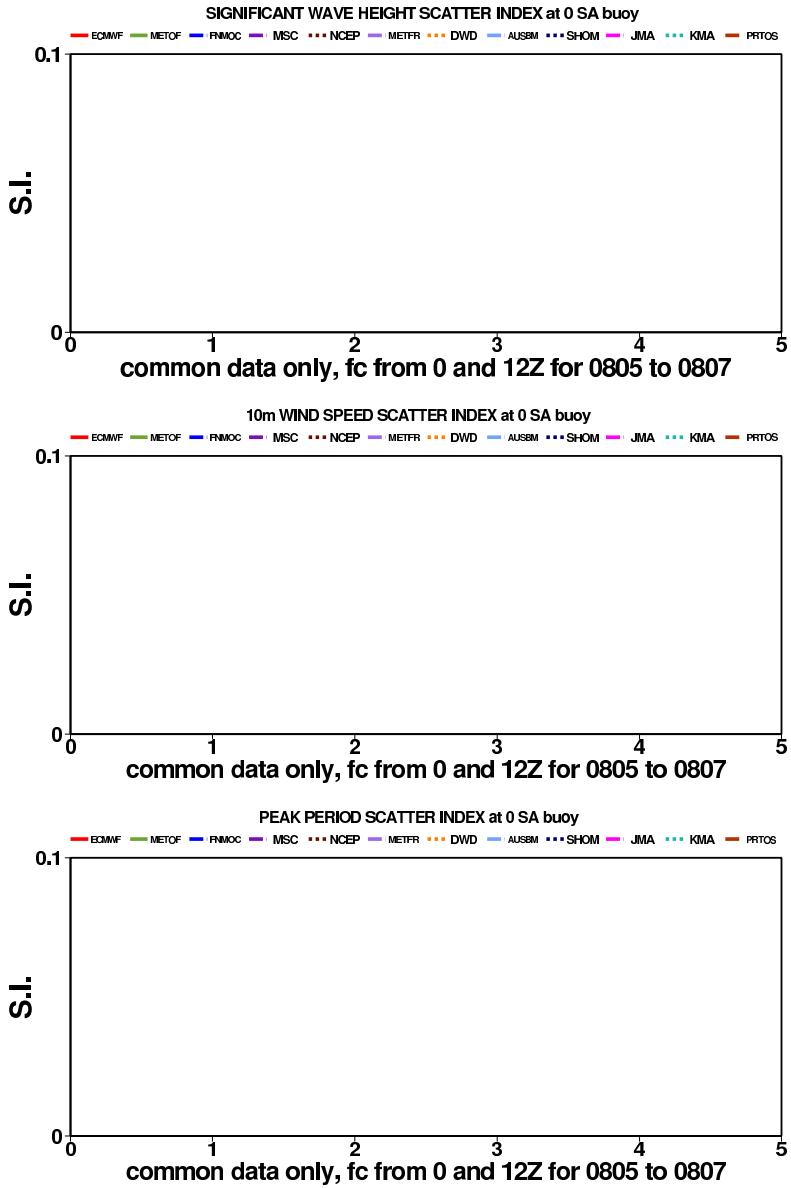
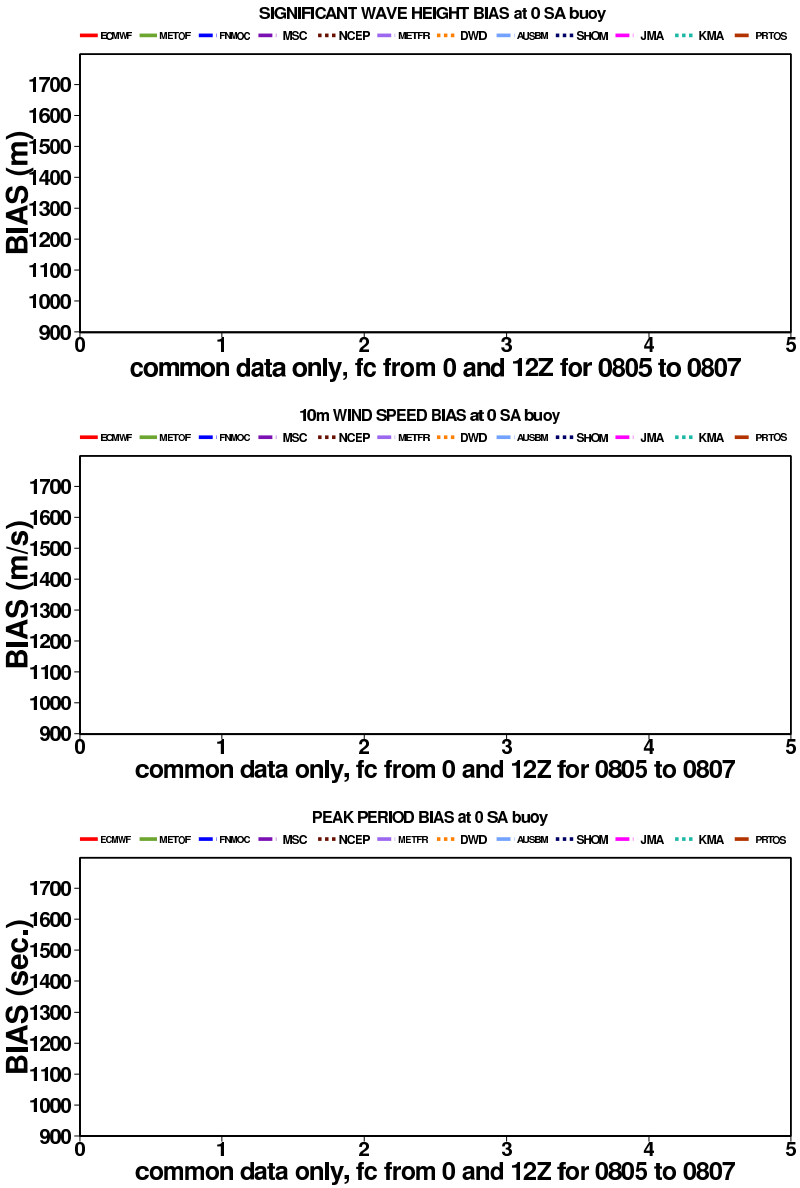


Figure 40: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

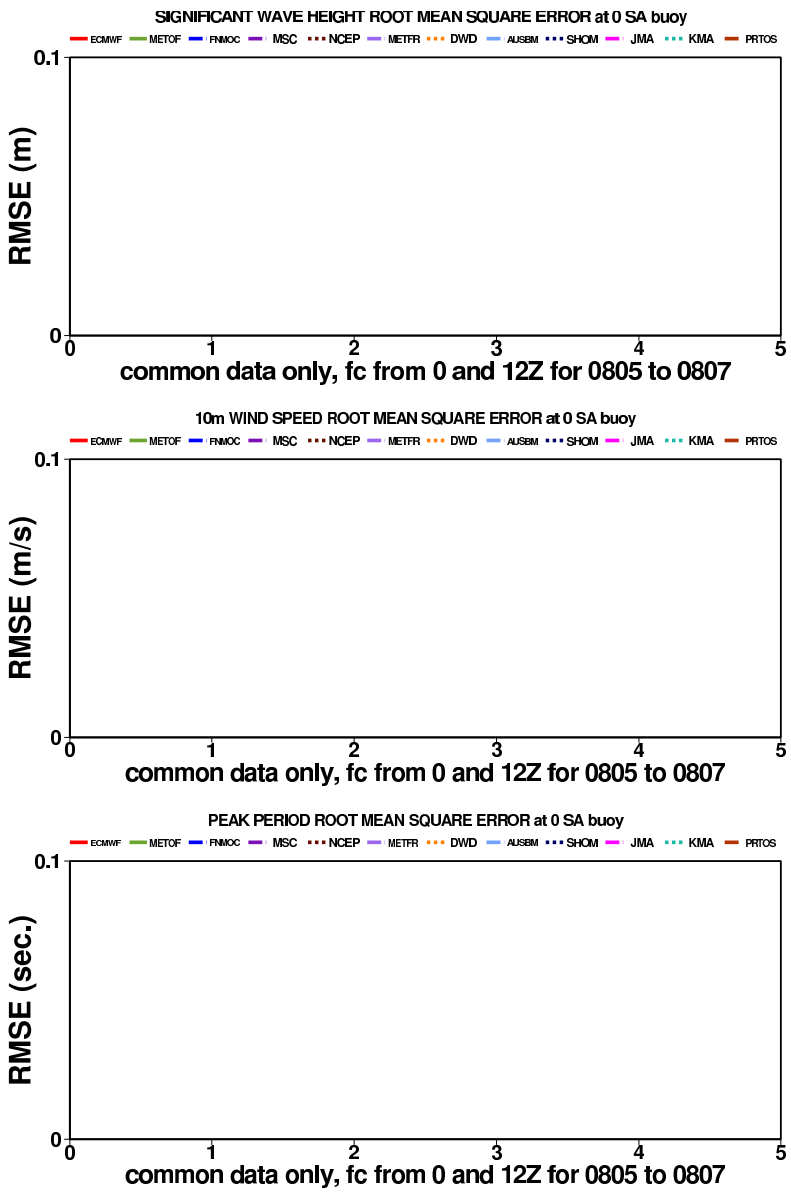


(a) Scatter Index (%)

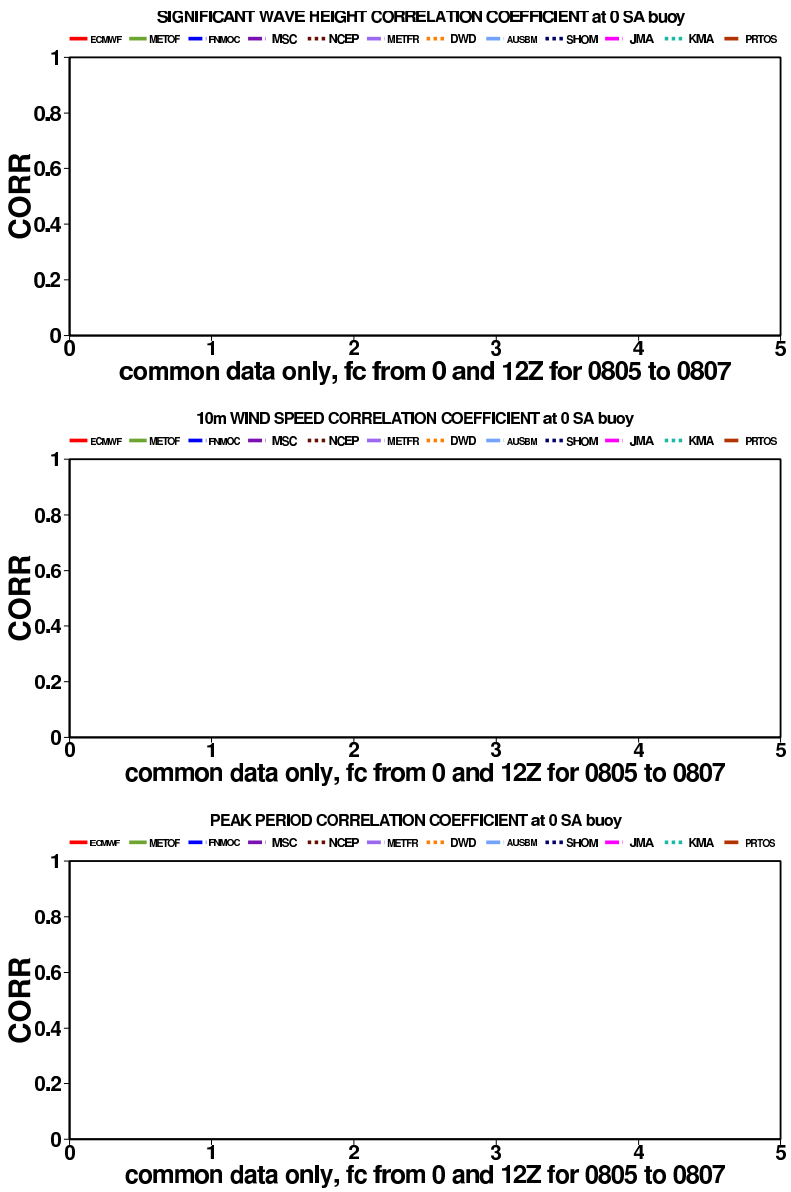


(b) Bias (model-buoy)

Figure 41: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common South African platform.



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 42: Forecast root mean square error (RMSE) and linear correlation coefficient at common South African platform.

0.3.11 Comparison for Indian buoys

Number of common observations for India (INDIA) from 200805 to 200807 (wind, Hs, Tp)

1	23092	94	72	0	Arabian Sea	5	23101	65	65	0	Bay of Bengal
2	23097	56	41	0	Arabian Sea	6	23170	24	0	0	Arabian Sea
3	23098	13	0	0	Arabian Sea	7	23172	52	0	0	Arabian Sea
4	23100	0	43	0	Bay of Bengal	8	23174	15	0	0	Bay of Bengal

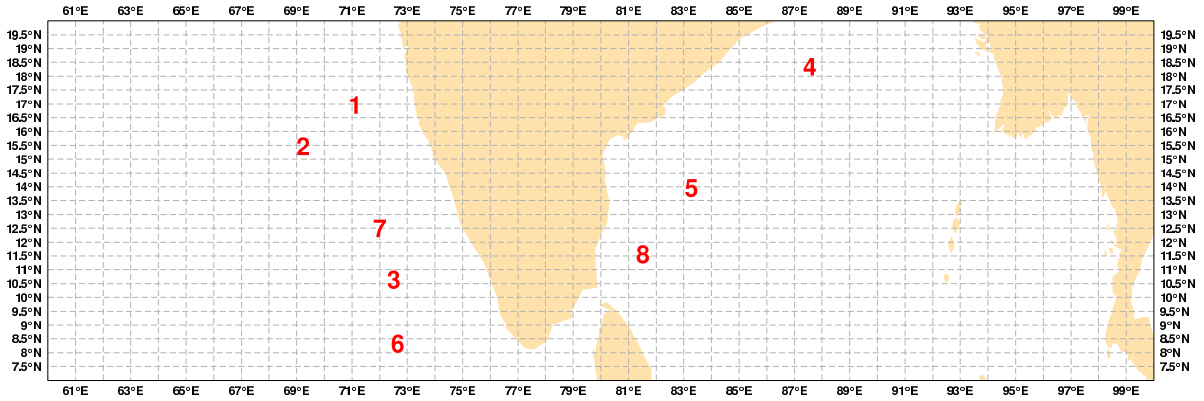
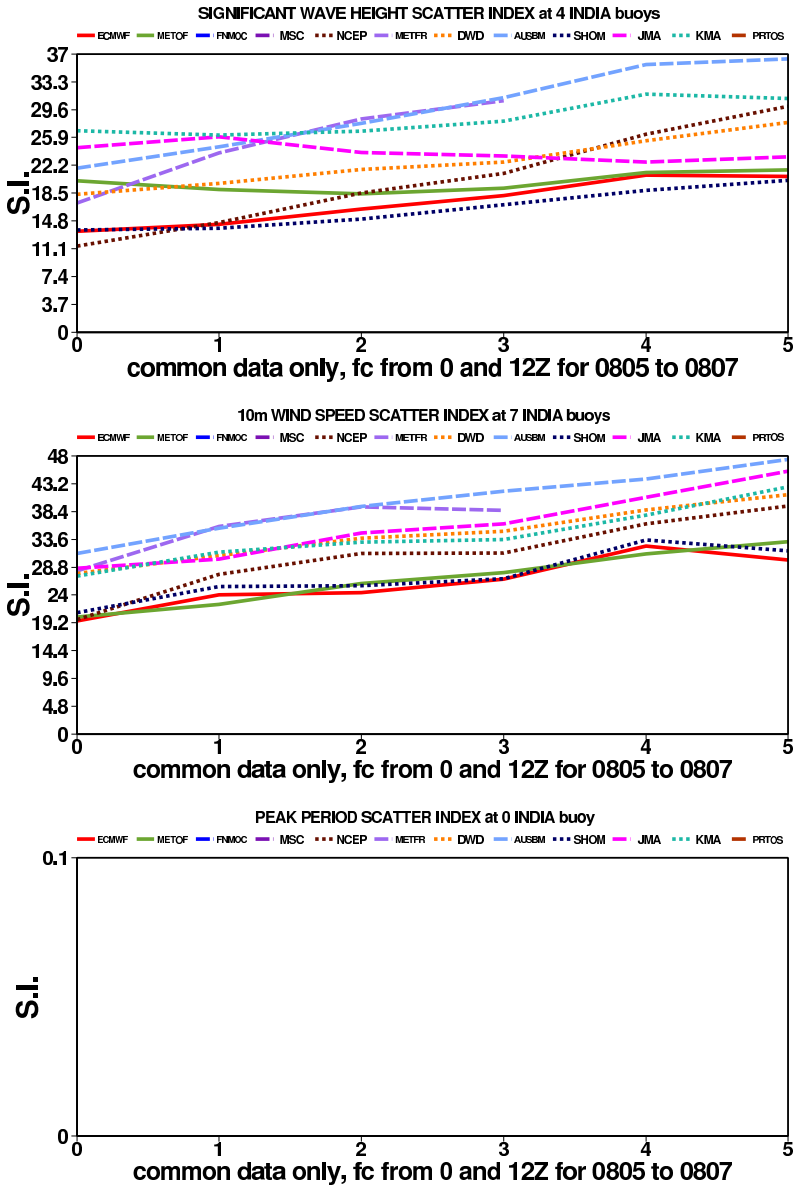
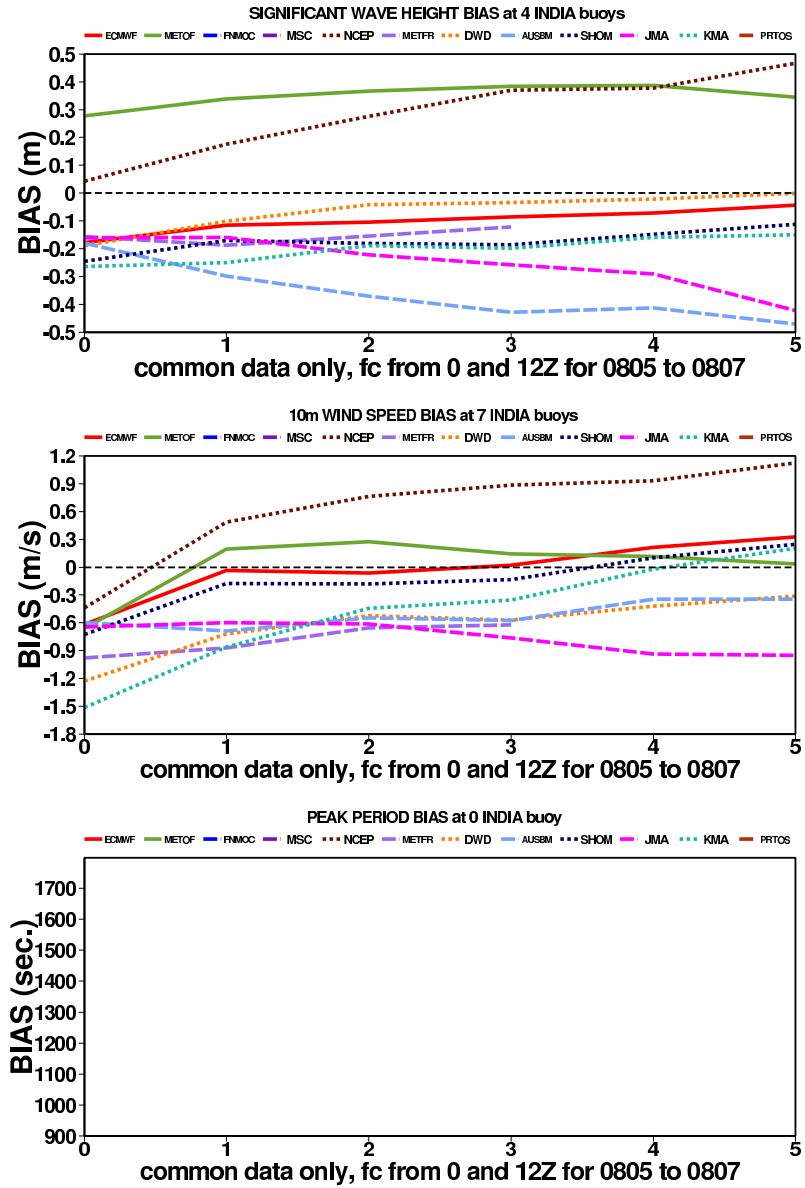


Figure 43: Buoy locations. The numbers in the table following each buoy identifier are the number of collocations between models and buoy wind speed, wave height and peak period.

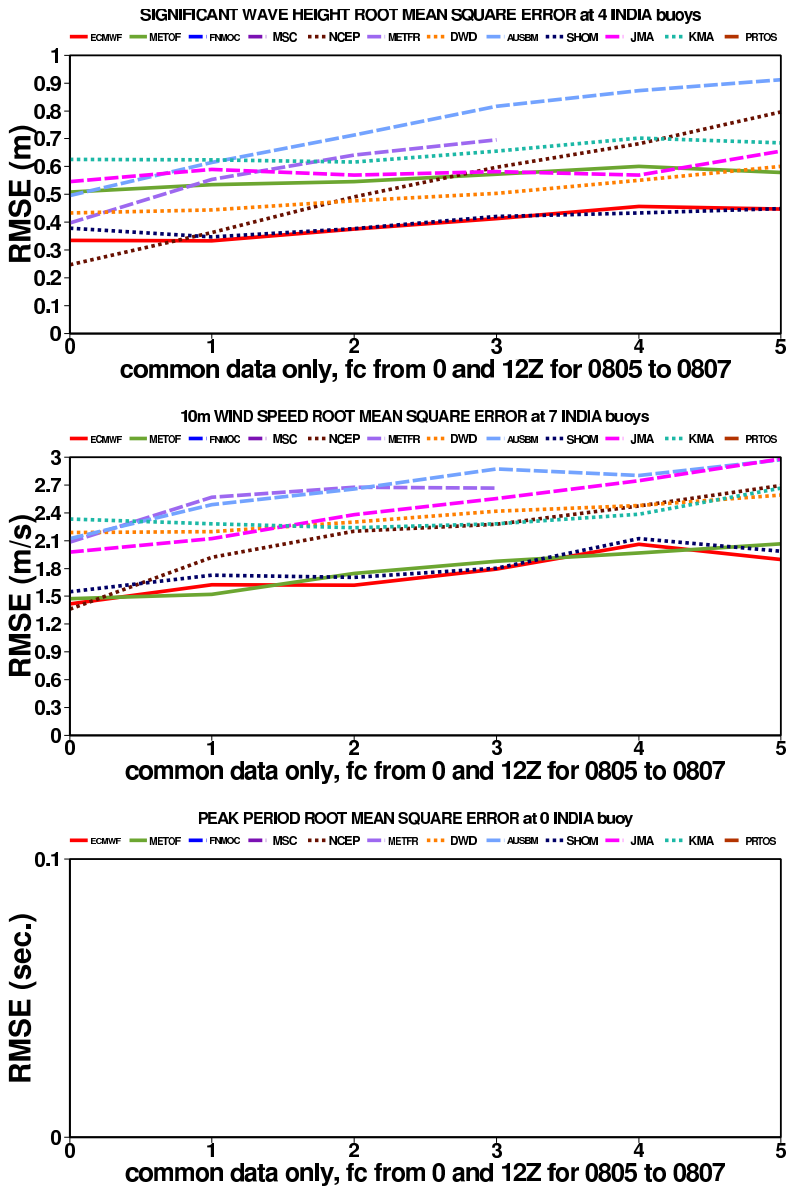


(a) Scatter Index (%)

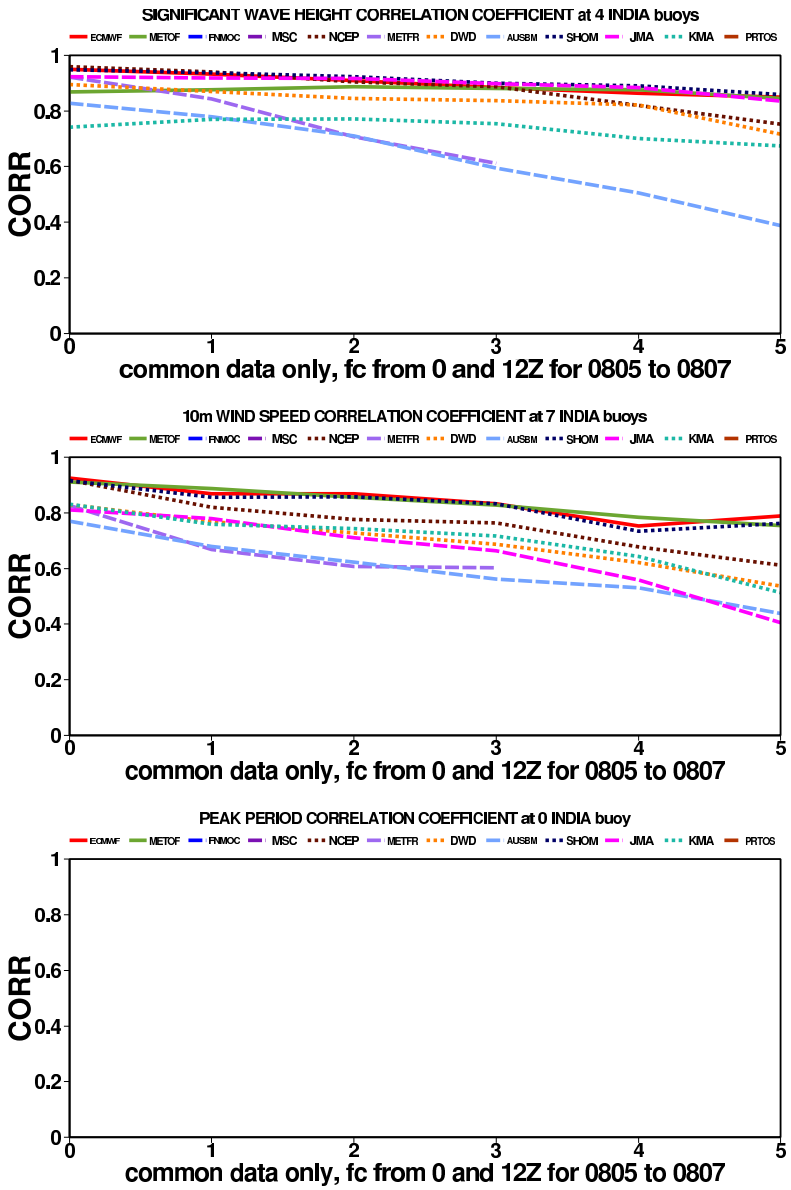


(b) Bias (model-buoy)

Figure 44: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Indian buoys.



(a) R.M.S.E.



(b) Correlation Coefficient

Figure 45: Forecast root mean square error (RMSE) and linear correlation coefficient at common Indian buoys.