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

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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 buoys-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



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.



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



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



(a) t+0

H_s (m)

buov

all buoys 0806 to 0808

M.S.C.



41001 44138 46036 41010 44139 46059 42001 44140 51001 ENTRIES:

41001 44138 46036 41010 44139 46059 42001 44140 51001 42002 44141 51002

42002 44141 51002 42003 46001 51003 42055 46004 51004 41040 46035 62029 41041 46066 62081 41043 46071 62163

42056 46072 64045 42057 46073 64046

ENTRIES = 0



MODEL MEAN = 0.00 STDEV = 0.000

BUOY MEAN = 0.00 STDEV = 0.000

LSQ FIT: SLOPE = 0.000 INTR = 0.000

RMSE = 0.000 BIAS = 0.000

SYMMETRIC SLOPE = 0.000

CORR COEF = 0.000 SI = 0.000









(b) t+48

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



all buoys 0806 to 0808



Comparison of forecast(t=t+48) DWD wave height with averaged buoy data. fc from 0 and 12Z.



42055 46004 51004 41040 46035 62029 41041 46066 62081 41043 46071 62163 42056 46072 64045 42057 46073 64046 42057 46073 64046 42059 46075 63115 41100 46078 2394AV 41101 46080 23092 44008 46184 23097 44011 46002 23101 44024 46005 62082 44137 46006 ENTRIES = 7172 MODEL MEAN = 1.74 STDEV = 0.694 BUOY MEAN = 1.57 STDEV = 0.768 LSQ FIT: SLOPE = 0.749 INTR = 0.566 RMSE = 0.467 BIAS = 0.172 CORR COEF = 0.829 SI = 0.276 SYMMETRIC SLOPE = 1.073

41001 44138 46036 41010 44139 46059 42001 44140 51001 42002 44141 51002

42003 46001 51003 42055 46004 51004



with averaged buoy data. fc from 0 and 12Z.



41001 44138 46036 41010 44139 46059 42001 44140 51001 42002 44141 51002 42002 44141 51002 42003 46001 51003 42055 46004 51004 41040 46035 62029 41041 46066 62081 41043 46071 62163 42056 46072 64045 42057 46073 64046 42057 460/3 64046 42059 46075 63115 41100 46078 ZSWAV 41101 46080 23092 44008 46184 23097 44011 46002 23101 44024 46005 62082 44137 46006 ENTRIES = 7172 MODEL MEAN = 1.63 STDEV = 0.727 BUOY MEAN = 1.57 STDEV = 0.768 LSQ FIT: SLOPE = 0.879 INTR = 0.248 RMSE = 0.291 BIAS = 0.057 CORR COEF = 0.929 SI = 0.182 SYMMETRIC SLOPE = 1.020

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



all buoys 0806 to 0808







41001 44138 46036 41010 44139 46059 42001 44140 51001 42002 44141 51002 42002 44141 51002 42003 46001 51003 42055 46004 51004 41040 46035 62029 41041 46066 62081 41043 46071 62163 42056 46072 64015 42056 460/2 64045 42057 46073 64046 42059 46075 63115 41100 46078 239AV 41101 46080 23092 44008 46184 23097 44011 46002 23101 44024 46005 62082 44137 46006 ENTRIES = 7172 MODEL MEAN = 1.56 STDEV = 0.812 BUOY MEAN = 1.57 STDEV = 0.768 LSQ FIT: SLOPE = 0.930 INTR = 0.104 RMSE = 0.389 BIAS = -0.006 CORR COEF = 0.880 SI = 0.248 SYMMETRIC SLOPE = 1.008





(a) t+0

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

H_s (m)

buov



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



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



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



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



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



(a) t+0

all buoys 0806 to 0808

ENTRIES = 0

MODEL MEAN = 0.00 STDEV = 0.000

BUOY MEAN = 0.00 STDEV = 0.000

LSQ FIT: SLOPE = 0.000 INTR = 0.000

MODEL MEAN = 8.58 STDEV = 3.097

BUOY MEAN = 8.43 STDEV = 2.845

LSQ FIT: SLOPE = 0.727 INTR = 2.449

MODEL MEAN = 0.00 STDEV = 0.000

BUOY MEAN = 0.00 STDEV = 0.000

LSQ FIT: SLOPE = 0.000 INTR = 0.000

RMSE = 0.000 BIAS = 0.000

SYMMETRIC SLOPE = 0.000

CORR COEF = 0.000 SI = 0.000

RMSE = 2,435 BIAS = 0,148

SYMMETRIC SLOPE = 1.025

CORR COEF = 0.668 SI = 0.288

RMSE = 0.000 BIAS = 0.000

SYMMETRIC SLOPE = 0.000

32012 42055 44018 46072 46229 46063 41001 42099 44024 46073 46232 46089 41004 41040 44025 46075 46002 51001

41004 41040 44025 46075 46002 51001 41008 41041 44027 46078 46005 51003 41096 41041 44027 46078 46005 51003 41010 41046 44137 46882 46012 51004 41012 41047 44138 46084 46014 55039 41012 41047 44138 46084 46014 55039 41025 42066 44140 46056 46015 55005 41086 42057 44141 46132 46023

 41035
 42007
 44141
 49122
 40023

 42001
 42058
 44251
 46147
 46028

 42002
 42059
 44255
 46134
 46029

 42003
 44005
 46001
 42205
 46134
 46029

 42003
 44005
 46001
 42205
 46144
 42017
 46041

 42120
 44009
 46036
 46204
 42209
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 42120
 44045
 46046

 42109
 44011
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42039 44014 46070 46214 46050 42040 44017 46071 46218 46059 ENTRIES = 14856

ENTRIES = 0

CORR COEF = 0.000 SI = 0.000



with averaged buoy data. fc from 0 and 12Z.



MeteoFrance 22 (j20 18 16 Peak Period 2 4 6 8 10 12 14 16 18 20 22 24 Peak Period (sec.) buoy Comparison of forecast(t=t+48) METFR peak period

with averaged buoy data. fc from 0 and 12Z.

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



(a) t+0

MODEL MEAN = 0.00 STDEV = 0.000 BUOY MEAN = 0.00 STDEV = 0.000 LSQ FIT: SLOPE = 0.000 INTR = 0.000 RMSE = 0.000 BIAS = 0.000 CORR COEF = 0.000 SI = 0.000 SYMMETRIC SLOPE = 0.000

MODEL MEAN = 8.87 STDEV = 2.970 BUOY MEAN = 8.45 STDEV = 2.845 LSQ FIT: SLOPE = 0.557 INTR = 4.160 RMSE = 2,840 BIAS = 0,418 CORR COEF = 0.534 SI = 0.332 SYMMETRIC SLOPE = 1.049





2 4 6 8 10 12 14 16 18 20 22 24 Peak Period (sec.) buoy Comparison of forecast(t=t+48) DWD peak period with averaged buoy data. fc from 0 and 12Z.



ENTRIES = 0 MODEL MEAN = 0.00 STDEV = 0.000 BUOY MEAN = 0.00 STDEV = 0.000 LSQ FIT: SLOPE = 0.000 INTR = 0.000 RMSE = 0.000 BIAS = 0.000 CORR COEF = 0.000 SI = 0.000 SYMMETRIC SLOPE = 0.000



Peak Period (sec.) buoy Comparison of forecast(t=t+48) BoM peak period with averaged buoy data. fc from 0 and 12Z.





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

Number of common observations	for Hawaiian buovs	(HW) from	200806 to 200808	(wind.	Hs.	Tr	ונ
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1	51001	177 177 182 Hawaii North West	4	51004	15	1	5 15	5 Hawaii South East
2	51002	176 176 181 Hawaii South West	5	51202	0	0	179	Hawaii Mokapu Point (scripps 098)
3	51003	177 177 182 Hawaii West						



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.



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.



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

0.3.3 Comparison for North Pacific buoys

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1	46001	180 180 182 Gulf of Alaska	12	46082	0	0	56	Gulf of Alaska, Cape Suckling
2	46004	179 179 181 Canada West Coast, Middle Nomad	13	46083	0	0	182	Gulf of Alaska, Fairweather Grounds
3	46035	180 179 181 Bering Sea	14	46084	0	0	182	Gulf of Alaska, Cape Edgecumbe
4	46066	180 179 182 Gulf of Alaska, S Aleutians	15	46085	0	0	179	Central Gulf of Alaska
5	46070	0 0 173 Southwest Bening Sea	16	46132	0	0	182	Canada West Coast, South Brooks
6	46071	163 163 165 North Pacific, Western Aleutians	17	46147	0	0	182	Canada West Coast, South Moresby
7	46072	13 180 182 North Pacific, Central Aleutians	18	46184	178	17	8 18	1 Canada West Coast, North Nomad
8	46073	180 175 177 Southeast Bening Sea	19	46205	0	0	182	Canada West Coast, W. Dixon Entrance
9	46075	59 177 180 North Pacific, Shumagin Islands	20	46207	0	0	182	Canada West Coast, East Dellwood
10	46078	0 176 177 Gulf of Alaska, Albatross Banks	21	46208	0	0	182	Canada West Coast, West Moresby
11	46080	64 66 67 Gulf of Alaska, Kennedy Entrance						

Number of common observations for North Pacific buoys (NPC) from 200806 to 200808 (wind, Hs, Tp)



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.



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 .



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

1	46002	134 135 135 US West Coast, Oregon	13	46042	0	0	145	US South-West Coast, Monterey
2	46005	132 132 132 US North-West Coast, W Astoria	14	46047	0	0	182	US South-West Coast, Tanner Banks
3	46006	17 17 17 US West Coast, SW Astonia	15	46050	0	0	182	US West Coast, Yaquina Bay
4	46012	0 0 170 US South-West Coast, Half Moon Bay	16	46059	179	179) 18	2 US West Coast, California
5	46013	0 0 182 US South-West Coast, Bodega	17	46063	0	0	182	US West Coast, Pt Conception
6	46014	0 0 181 US South-West Coast, Point Arena	18	46089	0	0	128	US West Coast, Tillamook, OR
7	46015	0 0 116 US West Coast, Port Orford	19	46213	0	0	182	US South-West Coast, Cape Mendocino (scripps 094)
8	46023	0 0 182 US South-West Coast, Point Arguello	20	46214	0	0	176	US South-West Coast, Point Reyes (scripps 029)
9	46028	0 0 180 US South-West Coast, Cape St Martin	21	46218	0	0	182	US South-West Coast, Harvest (scripps 071)
10	46029	0 0 182 US West Coast, Columbia River Bar	22	46229	0	0	182	US West Coast, Coos Bay (scripps 126)
11	46036	178 179 181 Canada West Coast, South Nomad	23	46232	0	0 1	81	US South West Coast, Coranado Islands MX (scripps 133)
12	46041	0 0 182 US North-West Coast, Cape Elisabeth						

Number of common observations for US West Coast buoys (USWC) from 200806 to 200808 (wind, Hs, Tp)



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.



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 .



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

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1	41001	78 78 82 US East Coast, E Hatteras	12	44008	180	0 180 182 US North-East Coast, Nantucket
2	41004	0 0 177 US South-East Coast, Edisto	13	44009	0	0 182 US North-East Coast, Delaware bay
3	41008	0 0 180 US South-East Coast, Grays reef	14	44011	175	5 176 180 US North-East Coast, Georges Bank
4	41009	0 0 126 US East Florida , Cape Canaveral	15	44014	0	0 120 US East Coast, Virginia Beach
5	41010	179 179 182 US East Florida , Cape Canaveral East	16	44017	0	0 182 US North-East Coast, Momauk Point
6	41012	0 0 155 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	8 178 181 US North East Coast, Northeast Channel
8	41025	0 0 171 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 0 179 W Bermuda	21	44037	0	0 181 US North East Coast, Jordan Basin
11	44005	0 0 76 US North East Coast, Gulf of Maine				

Number of common observations for US East Coast buoys (USEC) from 200806 to 200808 (wind, Hs, Tp)



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.



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 .



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

1	42001	179 178 174 Mid Gulf of Mexico	6 4	2036	0 0 165 Gulf of Mexico W Tampa
2	42002	180 176 171 Western Gulf of Mexico	7 4	2039	0 0 173 Gulf of Mexico Pensacola S
3	42003	177 177 178 East Gulf of Mexico	8 4	2040	0 0 173 Gulf of Mexico Mobile S
4	42019	0 0 181 Gulf of Mexico Lanelle	9 4	2055 1	178 178 178 Bay of Campeche
5	42020	0 0 179 Gulf of Mexico Corpus Christi	10 4	2099	0 0 173 Gulf Mexico, St Peterburg (scripps 144)

Number of common observations for Gulf of Mexico buoys (GM) from 200806 to 200808 (wind, Hs, Tp)



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.



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 .



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

1	44137	102 178 180 Nova Scotia, East Scotia slope	5	44141	24	17	5 17	6 Nova Scotia, Laurentian Fan
2	44138	180 180 182 Newfoundland, SW Grand Bank	6	44150	180	0	0	Nova Scotia, La Have Bank
3	44139	179 178 181 Newfoundland, Banquerau	7	44251	0	0	153	Newfoundland, Nickerson Bank
4	44140	166 17 17 Newfoundland, Tail Of The Bank	8	44255	0	0	175	Newfoundland, NE Bugeo Bank

Number of common observations for Canadian East Coast buoys (CANEC) from 200806 to 200808 (wind, Hs, Tp)



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.



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 .



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 buovs	(NEATL) from 200806 to 2	200808 (wind.	Hs. T	(a)

1	62029	175 179 0 UK Celtiic Sea shelf break (K1)	5 62163 130 179 0 UK Cettic Sea shelf break (Brittany)
2	62081	180 180 0 UK East Atlantic (K2)	6 64045 81 176 0 UK North-East Atlantic (K5)
3	62082	55 55 0 Estaca de Bares (Spain)	7 64046 171 163 0 UK North-East Atlantic (K7)
4	62095	120 0 0 West Ireland (M6), West Coast	



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.



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 .



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

Number of common observations for North Sea (NSEA) from 200806 to 200808 (wind, Hs, Tp)

1 63115 175 175 0 North Sea shelf break (?????)



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.



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.



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

Number of common observations for South Africa (SA) from 200806 to 200808 (wind, Hs, Tp)

1 ZSWAV 0 118 0 SA Agulinas Bank



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.



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.



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 200806 to 200808 (wind, Hs, Tp)

1	23092	73	74	C) Arabian Sea	4	23101	22	17	0	Bay of Bengal
2	23097	4	4	0	Arabian Sea	5	23170	26	0	0	Arabian Sea
3	23098	13	0	0	Arabian Sea						



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.



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.



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