Intercomparison of operational wave forecasting systems against buoys: data from ECMWF, MetOffice, FNMOC, MSC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA, KMA, Puerto del Estado, DMI, CNR-AM, METNO, SHN-SM
February 2014 to April 2014

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Chapter 1

Forewords

Outputs from different fully 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 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 document, examples, in graphical and tabular forms, are shown. These results have been processed at ECMWF and should serve 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.
Chapter 2

Data

Before using observations for verification, care has to be taken to process the data to remove any erroneous observations. Moreover, extra care has to be taken 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, MSC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA, KMA, Puerto del Estado, DMI, CNR-AM, METNO, SHN-SM are used whenever available. Some sub-areas might only have some of the participants and when all locations are considered, the limited models are left out. The other participants are left blank in the plots below.
References


Contents

1 Forewords ......................................................... 1

2 Data ........................................................................ 2

3 Results ..................................................................... 5

   3.1 Comparison for all buoys .................................. 6
   3.2 Comparison for Hawaiian buoys ......................... 21
   3.3 Comparison for North East Pacific buoys ................. 24
   3.4 Comparison for North West Atlantic buoys ............... 27
   3.5 Comparison for Gulf of Mexico buoys ................. 30
   3.6 Comparison for Caribbean Sea buoys .................... 33
   3.7 Comparison for North East Atlantic buoys .............. 36
   3.8 Comparison for Euro-Atlantic Coast buoys .............. 39
   3.9 Comparison for North Sea platforms ..................... 42
   3.10 Comparison for North Sea buoys ......................... 45
   3.11 Comparison for Icelandic buoys and Norwegian platforms 48
   3.12 Comparison for Barents Sea buoys ...................... 51
   3.13 Comparison for Baltic Sea buoys ......................... 54
   3.14 Comparison for English Channel and Irish Sea ....... 57
   3.15 Comparison for Western Mediterranean Sea buoys .. 60
   3.16 Comparison for Mediterranean Sea buoys ............. 63
   3.17 Comparison for Korean buoys ............................ 66
   3.18 Comparison for Japanese buoys ......................... 69
   3.19 Comparison for Marshall Islands buoy ................. 72
   3.20 Comparison for Australian South East Coast buoys .. 75
3.21 Comparison for Australian South West facing Coast buoys ........................................ 78
3.22 Comparison for Australian North West Coast buoys ........................................ 81
3.23 Comparison for New Zealand buoy ................................................................. 84
3.24 Comparison for Brazilian buoys ..................................................................... 87
Chapter 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, MSC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA, KMA, Puerto del Estado, DMI, CNR-AM, METNO, SHN-SM are used.

This report was generated automatically, which explains its very generic appearance.
3.1 Comparison for all buoys

Figure 3.1: Buoy locations
Figure 3.2: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common all buoys.
Figure 3.3: Forecast root mean square error (RMSE) and linear correlation coefficient at common all buoys.
Comparison of forecast \( t=t+48 \) FNMOC wave height with averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed FNMOC wave height with averaged buoy data. Forecasts from 0 and 12Z.

Wave height (m)     buoy

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

Comparison of analysed UKMO wave height with averaged buoy data. Forecasts from 0 and 12Z.

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

Comparison of analysed ECMWF wave height with averaged buoy data. Forecasts from 0 and 12Z.

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

Comparison of analysed FNMO wave height with averaged buoy data. Forecasts from 0 and 12Z.

(a) \( t+0 \)

(b) \( t+48 \)

Figure 3.4: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
Figure 3.5: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
Comparison of analysed SHOM wave height with averaged buoy data. Forecasts from 0 and 12Z.

Wave height (m)     buoy

140

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

Figure 3.6: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.

Figure 3.7: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
Comparison of forecast(t=t+48) FNMOC wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed FNMOC wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Wind Speed (m/s)     buoy
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

Comparison of analysed ECMWF wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) ECMWF wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed UKMO wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) UKMO wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed FNMOC wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) FNMOC wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

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

Figure 3.8: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.
Figure 3.9: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.
Comparison of forecast(t=t+48) SHOM wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed SHOM wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Wind Speed (m/s)     buoy

Comparison of forecast(t=t+48) AUSBM wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed AUSBM wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) DWD wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

Comparison of analysed DWD wind speed with height corrected averaged buoy data. Forecasts from 0 and 12Z.

(a) t+0

(b) t+48

Figure 3.10: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.
Figure 3.11: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.
Comparison of forecast(t=t+48) FNMOC peak period with averaged buoy data. forecasts from 0 and 12Z.

Comparison of analysed FNMOC peak period with averaged buoy data. forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) UKMO peak period with averaged buoy data. forecasts from 0 and 12Z.

Comparison of analysed UKMO peak period with averaged buoy data. forecasts from 0 and 12Z.

Comparison of forecast(t=t+48) ECMWF peak period with averaged buoy data. forecasts from 0 and 12Z.

Comparison of analysed ECMWF peak period with averaged buoy data. forecasts from 0 and 12Z.

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

Figure 3.12: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.
Figure 3.13: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.
Comparison of analysed SHOM peak period with averaged buoy data. Forecasts from 0 and 12Z.

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<tr>
<td>2</td>
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Comparison of analysed AUSBM peak period with averaged buoy data. Forecasts from 0 and 12Z.

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Comparison of forecast(t+48) DWD peak period with averaged buoy data. Forecasts from 0 and 12Z.

<table>
<thead>
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<th>Peak Period (s)</th>
<th>Buoy</th>
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<tr>
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<tr>
<td>20</td>
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</table>

Figure 3.14: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.
Figure 3.15: Scatter diagrams for peak period at step 0 and 48 for the displayed centres at all buoys.
### 3.2 Comparison for Hawaiian buoys

<table>
<thead>
<tr>
<th>Buoy Identifier</th>
<th>Location</th>
<th>Number of collocations</th>
</tr>
</thead>
<tbody>
<tr>
<td>51063</td>
<td>Hawaii West</td>
<td>176 176 176</td>
</tr>
<tr>
<td>51064</td>
<td>Hawaii South East</td>
<td>176 170 169</td>
</tr>
<tr>
<td>51100</td>
<td>Northern Hawaii</td>
<td>165 25 24</td>
</tr>
<tr>
<td>51101</td>
<td>North West Hawaii</td>
<td>176 176 176</td>
</tr>
</tbody>
</table>

Figure 3.16: 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 3.17: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Hawaiian buoys.
Figure 3.18: Forecast root mean square error (RMSE) and linear correlation coefficient at common Hawaiian buoys.
3.3 Comparison for North East Pacific buoys

Figure 3.19: 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 3.20: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North East Pacific buoys.
Figure 3.21: Forecast root mean square error (RMSE) and linear correlation coefficient at common North East Pacific buoys.
3.4 Comparison for North West Atlantic buoys

**Figure 3.22:** 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 3.23: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North West Atlantic buoys.
Figure 3.24: Forecast root mean square error (RMSE) and linear correlation coefficient at common North West Atlantic buoys.
3.5 Comparison for Gulf of Mexico buoys

Figure 3.25: 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 3.26: 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 3.27: Forecast root mean square error (RMSE) and linear correlation coefficient at common Gulf of Mexico buoys.
3.6 Comparison for Caribbean Sea buoys

Number of common observations for Caribbean Sea buoys (CRB) from 201402 to 201404 (wind, Hs, Tp)

<table>
<thead>
<tr>
<th>Buoy Identifier</th>
<th>Number of Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>41040 166 165 166 Tropical Atlantic, West Atlantic</td>
</tr>
<tr>
<td>2</td>
<td>41041 167 167 167 Tropical Atlantic, Middle Atlantic</td>
</tr>
<tr>
<td>3</td>
<td>41043 0 170 170 South Western Atlantic</td>
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<tr>
<td>4</td>
<td>41044 169 169 169 South Western Atlantic</td>
</tr>
<tr>
<td>5</td>
<td>41046 170 170 170 E Bahamas</td>
</tr>
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<td>6</td>
<td>41047 170 170 170 NE Bahamas</td>
</tr>
<tr>
<td>7</td>
<td>41048 170 170 170 South Western Atlantic</td>
</tr>
<tr>
<td>8</td>
<td>42056 169 169 169 Yucatan Basin</td>
</tr>
<tr>
<td>9</td>
<td>42057 169 169 169 Western Caribbean</td>
</tr>
<tr>
<td>10</td>
<td>42058 170 170 170 Central Caribbean</td>
</tr>
<tr>
<td>11</td>
<td>42059 169 169 169 Eastern Caribbean</td>
</tr>
</tbody>
</table>

Figure 3.28: 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 3.29: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Caribbean Sea buoys.
Figure 3.30: Forecast root mean square error (RMSE) and linear correlation coefficient at common Caribbean Sea buoys.
3.7 Comparison for North East Atlantic buoys

Figure 3.31: 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 3.32: 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 3.33: Forecast root mean square error (RMSE) and linear correlation coefficient at common North East Atlantic buoys.
3.8 Comparison for Euro-Atlantic Coast buoys

Figure 3.34: 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 3.35: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Euro-Atlantic Coast buoys.
Figure 3.36: Forecast root mean square error (RMSE) and linear correlation coefficient at common Euro-Atlantic Coast buoys.
3.9 Comparison for North Sea platforms

Figure 3.37: 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 3.38: 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 3.39: Forecast root mean square error (RMSE) and linear correlation coefficient at common North Sea platforms.
3.10 Comparison for North Sea buoys

![Buoy locations map]

Figure 3.40: 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 3.41: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common North Sea buoys.
Figure 3.42: Forecast root mean square error (RMSE) and linear correlation coefficient at common North Sea buoys.
### 3.11 Comparison for Icelandic buoys and Norwegian platforms

**Figure 3.43:** 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 3.44: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Icelandic buoys and Norwegian platforms.
Figure 3.45: Forecast root mean square error (RMSE) and linear correlation coefficient at common Icelandic buoys and Norwegian platforms.
3.12 Comparison for Barents Sea buoys

Figure 3.46: 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 3.47: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Barents Sea buoys.
Figure 3.48: Forecast root mean square error (RMSE) and linear correlation coefficient at common Barents Sea buoys.
3.13 Comparison for Baltic Sea buoys

Figure 3.49: 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 3.50: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Baltic Sea buoys.
Figure 3.51: Forecast root mean square error (RMSE) and linear correlation coefficient at common Baltic Sea buoys.
3.14 Comparison for English Channel and Irish Sea

Figure 3.52: 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 3.53: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common English Channel and Irish Sea.
Figure 3.54: Forecast root mean square error (RMSE) and linear correlation coefficient at common English Channel and Irish Sea.
3.15 Comparison for Western Mediterranean Sea buoys

Figure 3.55: 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 3.56: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Western Mediterranean Sea buoys.
Figure 3.57: Forecast root mean square error (RMSE) and linear correlation coefficient at common Western Mediterranean Sea buoys.
3.16 Comparison for Mediterranean Sea buoys

![Buoy locations map](image)

**Number of common observations for Mediterranean Sea buoys (MEDIT) from 201402 to 201404 (wind, Hs, Tp)**

<table>
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<tr>
<th>Identifier</th>
<th>Number of Common Observations</th>
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<tr>
<td>61300</td>
<td>0 86 88 Mazara (Italy)</td>
</tr>
<tr>
<td>61306</td>
<td>0 78 66 Palermo (Italy)</td>
</tr>
<tr>
<td>61313</td>
<td>0 117 163 Alghero (Italy)</td>
</tr>
<tr>
<td>61314</td>
<td>0 158 143 Ponza (Italy)</td>
</tr>
<tr>
<td>61315</td>
<td>0 171 147 Livorno (Italy)</td>
</tr>
<tr>
<td>61316</td>
<td>0 121 108 Civitavecchia (Italy)</td>
</tr>
<tr>
<td>61317</td>
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<td>61318</td>
<td>0 121 108 E1M3A, North Crete (HCMR)</td>
</tr>
<tr>
<td>61319</td>
<td>0 153 146 E Pylos, Ionian Sea (HCMR)</td>
</tr>
</tbody>
</table>

Figure 3.58: 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 3.59: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Mediterranean Sea buoys.
Figure 3.60: Forecast root mean square error (RMSE) and linear correlation coefficient at common Mediterranean Sea buoys.
3.17 Comparison for Korean buoys

Figure 3.61: 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 3.62: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Korean buoys.
Figure 3.63: Forecast root mean square error (RMSE) and linear correlation coefficient at common Korean buoys.
3.18 Comparison for Japanese buoys

Figure 3.64: 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 3.65: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Japanese buoys.
Figure 3.66: Forecast root mean square error (RMSE) and linear correlation coefficient at common Japanese buoys.
3.19 Comparison for Marshall Islands buoy

Figure 3.67: 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 3.68: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Marshall Islands buoy.
Figure 3.69: Forecast root mean square error (RMSE) and linear correlation coefficient at common Marshall Islands buoy.
3.20 Comparison for Australian South East Coast buoys

Figure 3.70: 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 3.71: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Australian South East Coast buoys.
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<td><strong>10m Wind Speed RMSE</strong></td>
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(a) R.M.S.E.

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<td><strong>Peak Period Correlation Coefficient</strong></td>
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(b) Correlation Coefficient

Figure 3.72: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian South East Coast buoys.
Figure 3.73: 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 3.74: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Australian South West facing Coast buoys.
Figure 3.75: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian South West facing Coast buoys.
Figure 3.76: 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 3.77: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Australian North West Coast buoys.
Figure 3.78: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian North West Coast buoys.
3.23 Comparison for New Zealand buoy

Figure 3.79: 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 3.80: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common New Zealand buoy.
Figure 3.81: Forecast root mean square error (RMSE) and linear correlation coefficient at common New Zealand buoy.
3.24 Comparison for Brazilian buoys

Figure 3.82: 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 3.83: Forecast scatter index (standard deviation of the difference normalised by the mean of the observations) and bias (model-buoy) at common Brazilian buoys.
Figure 3.84: Forecast root mean square error (RMSE) and linear correlation coefficient at common Brazilian buoys.