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
October 2016 to December 2016

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February 7, 2017
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 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.
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.
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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 analysed ECMWF wave height with averaged buoy data. Forecasts from 0 and 12Z.

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

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

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

Comparison of forecast(t=48) FNMOC 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.
Comparison of analysed AES wave height with averaged buoy data. forecasts from 0 and 12Z.

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

Comparison of analysed NCEP wave height with averaged buoy data. forecasts from 0 and 12Z.

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

Comparison of analysed METFR wave height with averaged buoy data. forecasts from 0 and 12Z.

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

Figure 3.5: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
Comparison of forecast(t=t+48) DWD wave height with averaged buoy data. forecasts from 0 and 12Z.

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

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

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

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

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

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

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

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

Comparison of analysed KMA wave height with averaged buoy data. forecasts from 0 and 12Z.

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

Comparison of analysed PRTOS wave height with averaged buoy data. forecasts from 0 and 12Z.

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

Figure 3.7: Scatter diagrams for wave height at step 0 and 48 for the displayed centres at all buoys.
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Comparison of analysed DWD 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 analysed SHOM wind speed with height corrected averaged buoy data. forecasts from 0 and 12Z.

Figure 3.10: Scatter diagrams for wind speed at step 0 and 48 for the displayed centres at all buoys.
Comparison of analysed JMA wind speed with height corrected averaged buoy data. forecasts from 0 and 12Z.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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.
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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

Number of common observations for North West Atlantic buoys (NWATL) from 201610 to 201612 (wind, Hs, Tp)

<table>
<thead>
<tr>
<th>Buoy Identifier</th>
<th>Count</th>
<th>Count</th>
<th>Count</th>
<th>Location Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>41062</td>
<td>177</td>
<td>177</td>
<td>177</td>
<td>US South-East Coast, S Hatteras</td>
</tr>
<tr>
<td>41064</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>US South-East Coast, Edisto</td>
</tr>
<tr>
<td>41048</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>W Bermuda</td>
</tr>
<tr>
<td>44065</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>US North East Coast, Gulf of Maine</td>
</tr>
<tr>
<td>44066</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>US South East Coast, Cape Henry (scripps 147)</td>
</tr>
<tr>
<td>44025</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>US North East Coast, Long Island</td>
</tr>
<tr>
<td>44037</td>
<td>164</td>
<td>163</td>
<td>164</td>
<td>US North East Coast, GMOOS M0102 Jordan Basin</td>
</tr>
<tr>
<td>44066</td>
<td>0</td>
<td>18</td>
<td>18</td>
<td>US North East Coast, Nantucket</td>
</tr>
<tr>
<td>44011</td>
<td>0</td>
<td>177</td>
<td>177</td>
<td>US South East Coast, Cape Henry (scripps 147)</td>
</tr>
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<td>44014</td>
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<td>178</td>
<td>178</td>
<td>US South East Coast, Jeffrey's Ledge, N(Scripps 160)</td>
</tr>
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<td>44045</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>US South East Coast, GMOOS M0102 Jordan Basin</td>
</tr>
<tr>
<td>44057</td>
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<td>164</td>
<td>US North East Coast, Long Island</td>
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<td>178</td>
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<td>US South East Coast, Cape Henry (scripps 147)</td>
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<td>44137</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>Nova Scotia, East Scotia slope</td>
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<td>44139</td>
<td>178</td>
<td>178</td>
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<td>Newfoundland, Banquereau</td>
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<td>140</td>
<td>140</td>
<td>140</td>
<td>Nova Scotia, Laurentian Fan</td>
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<td>44150</td>
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<td>94</td>
<td>94</td>
<td>Nova Scotia, La Have Bank</td>
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<td>44132</td>
<td>94</td>
<td>94</td>
<td>94</td>
<td>Nova Scotia, La Have Bank</td>
</tr>
</tbody>
</table>

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

![Buoy locations diagram]

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

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

<table>
<thead>
<tr>
<th>Buoy ID</th>
<th>UK Celtic Sea shelf break (K1)</th>
<th>UK Celtic Sea shelf break (Brittany)</th>
<th>UK East Atlantic (K4)</th>
<th>UK North-East Atlantic (K5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>62029</td>
<td>176 176</td>
<td>175 175</td>
<td>177</td>
<td>178</td>
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<td>62365</td>
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<td>168 168</td>
<td>177</td>
<td>178</td>
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<tr>
<td>62165</td>
<td>155 177</td>
<td>168 178</td>
<td>177</td>
<td>178</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Buoy ID</th>
<th>Wind</th>
<th>Hs</th>
<th>Tp</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>62024</td>
<td>181</td>
<td>182</td>
<td>0</td>
<td>Bilbao (Spain)</td>
</tr>
<tr>
<td>62047</td>
<td>0</td>
<td>183</td>
<td>0</td>
<td>UK East Atlantic, Blacknorwe, CEFAS</td>
</tr>
<tr>
<td>62069</td>
<td>0</td>
<td>112</td>
<td>0</td>
<td>CANDHIS Les Pierres Noires</td>
</tr>
<tr>
<td>62082</td>
<td>181</td>
<td>181</td>
<td>0</td>
<td>Estaca de Bares (Spain)</td>
</tr>
<tr>
<td>62083</td>
<td>180</td>
<td>182</td>
<td>0</td>
<td>Villano-Sisargas (Spain)</td>
</tr>
<tr>
<td>62084</td>
<td>68</td>
<td>179</td>
<td>0</td>
<td>Silleiro (Spain)</td>
</tr>
<tr>
<td>62085</td>
<td>0</td>
<td>181</td>
<td>0</td>
<td>Cadiz (Spain)</td>
</tr>
</tbody>
</table>

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

![Map of North Sea buoys with buoy locations marked]

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

[Map and table showing buoy locations and number of common observations]

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 Baltic 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 Baltic Sea buoys.
Figure 3.48: Forecast root mean square error (RMSE) and linear correlation coefficient at common Baltic Sea buoys.
3.13 Comparison for English Channel and Irish Sea

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 English Channel and Irish Sea.
Figure 3.51: Forecast root mean square error (RMSE) and linear correlation coefficient at common English Channel and Irish Sea.
3.14 Comparison for Western Mediterranean Sea buoys

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 Western Mediterranean Sea buoys.
Figure 3.54: Forecast root mean square error (RMSE) and linear correlation coefficient at common Western Mediterranean Sea buoys.
3.15 Comparison for 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 Mediterranean Sea buoys.
Figure 3.57: Forecast root mean square error (RMSE) and linear correlation coefficient at common Mediterranean Sea buoys.
3.16 Comparison for Korean buoys

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 Korean buoys.
Figure 3.60: Forecast root mean square error (RMSE) and linear correlation coefficient at common 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 Japanese buoys.
Figure 3.63: Forecast root mean square error (RMSE) and linear correlation coefficient at common Japanese buoys.
3.18 Comparison for Australian South East Coast 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 Australian South East Coast buoys.
Figure 3.66: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian South East Coast buoys.
3.19 Comparison for Australian Great Barrier Reef buoys

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 Australian Great Barrier Reef buoys.
(a) R.M.S.E.

(b) Correlation Coefficient

Figure 3.69: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian Great Barrier Reef buoys.
3.20 Comparison for Australian South West facing 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 West facing Coast buoys.
Figure 3.72: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian South West facing Coast buoys.
3.21 Comparison for Australian North West 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 North West Coast buoys.
Figure 3.75: Forecast root mean square error (RMSE) and linear correlation coefficient at common Australian North West Coast buoys.
3.22 Comparison for New Zealand buoy

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 New Zealand buoy.
Figure 3.78: Forecast root mean square error (RMSE) and linear correlation coefficient at common New Zealand buoy.
3.23 Comparison for Brazilian buoys

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 Brazilian buoys.
Figure 3.81: Forecast root mean square error (RMSE) and linear correlation coefficient at common Brazilian buoys.