Inter-comparison of Operational Wave Forecasting Systems

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Motivations:

- Following WISE 1995, a routine inter-comparison of wave model forecasts was set-up.
- It was intended to provide a mechanism for benchmarking wave forecast products.
- Since the early 90’s, more wave observations have been available.
- Wave forecasting is now routine at many operational centres.
- The JCOMM Expert Team on Wind Waves and Storm Surges (ETWS) following ETWS-1 (Halifax, 2003) endorsed the expansion of the project.
- At ETWS-2 (Geneva 2007), it was agreed to continue and expand this activity.
- First results were presented during WAVES97 (Bidlot et al. 1998) and a peer review paper was published (Bidlot et al. 2002).
- It is now opportune to review what has been achieved.
Methodology:

- Each month, model data (analysis and forecasts) are exchanged for a set of prescribed locations where wave and wind observations are made.
- A simple ASCII format is used.
- The data sets are combined at ECMWF and quality controlled in-situ observations of wind speed and direction, wave height and wave period are added to the data set.
- The combined data sets are made available to all participants.
- Summary plots and tables are also produced at ECMWF.
- A technical report is available at:

**Conclusions:**

- This informal inter-comparison of wind and wave model data has worked well for over 12 years.
- It is time to work on extending this exercise.
- By adding wave spectra?
- By comparing to remotely sensed data (Altimeter(s), SARs)?
- By exchanging model fields (High Resolution Diagnostic Data set (HHDR) approach, objective score approach)?
Participants:

1995:
- European Centre for Medium range Weather Forecasts (ECMWF), global model.
- The Met Office, UK, (MO), global model.
- Fleet Numerical Meteorology and Oceanography Centre, USA, (FNMOC), global model.
- Meteorological Service of Canada, Canada, (MSC), 2 limited area models (N Pac. & N Atl.).

1996:
- National Centers for Environmental Prediction, USA, (NCEP), global model.

2001:
- Météo France, France (MF), global model*

2004:
- Deutscher Wetterdienst, Germany, (DWD), global model and limited area models (N Sea & Med.).
- Bureau of Meteorology, Australia, (BoM), global model.
- Service Hydrographique et Océanographique de la Marine, France, (SHOM), global model & N Atl.
- Japan Meteorological Agency, Japan, (JMA), global model.

2006:
- Korea Meteorological Administration, Republic of Korea, (KMA), global model.
- Puetos del Estado, Spain (PRTOS), limited area models (N Atl. & Med.).
In-situ observations from buoys and platforms:

Locations where wind and wave data were collocated with ECMWF model.

Sources: mostly via the WMO GTS, but also from the South African Weather Service, and recently from BoM, Puertos del Estado, Oceanor, and SHOM.

Quality control and processing of the data done at ECMWF
Results based on original list of buoy locations

Wind and wave observations at common locations for all buoys from 200706 to 200708
Analysed significant wave height and averaged buoy data at buoy 46001

Analysed peak period and averaged buoy data at buoy 46001
10th int. workshop on wave hindcasting and forecasting  Slide 9

**Original list**

all buoys 0706 to 0708

**E.C.M.W.F.**

Comparison of forecast(t=t+24) ECMWF wave height with averaged buoy data. fc from 0 and 12Z.

**Statistics for all buoys combined**

- **SIGNIFICANT WAVE HEIGHT SCATTER INDEX at all 34 buoys**
  - ENTRIES = 3456
  - MODEL MEAN = 1.65  STDEV = 0.763
  - BUOY MEAN = 1.66  STDEV = 0.834
  - LSQ FIT: SLOPE = 0.874  INTR = 0.195
  - RMSE = 0.251  BIAS = -0.015
  - CORR COEF = 0.954  SI = 0.151
  - SYMMETRIC SLOPE = 0.976

- **SIGNIFICANT WAVE HEIGHT BIAS at all 34 buoys**
  - ENTRIES = 3456
  - MODEL MEAN = 1.65  STDEV = 0.763
  - BUOY MEAN = 1.66  STDEV = 0.834
  - LSQ FIT: SLOPE = 0.874  INTR = 0.195
  - RMSE = 0.251  BIAS = -0.015
  - CORR COEF = 0.954  SI = 0.151
  - SYMMETRIC SLOPE = 0.976

**ECMWF**
Comparison of forecast($t=t+24$) METOF wave height with averaged buoy data. fc from 0 and 12Z.
Comparison of forecast \((t=t+24)\) FNMOC wave height with averaged buoy data. fc from 0 and 12Z.

**F.N.M.O.C.**

- **ENTRIES:**
  - 1 - 3
  - 3 - 6
  - 6 - 13
  - 13 - 29
  - 29 - 67
  - 67 - 135
  - 135 - 360

**SYMMETRIC SLOPE** = 1.040

**CORR COEF** = 0.938

**SI** = 0.192

**RMSE** = 0.322

**BIAS** = 0.039

**LSQ FIT:**
- **SLOPE** = 1.032
- **INT R** = -0.014

**BUOY MEAN** = 1.66

**ST DEV** = 0.834

**MODEL MEAN** = 1.70

**STDEV** = 0.918

- **ENTRIES** = 3456

**S.I.**

**SIGNIFICANT WAVE HEIGHT SCATTER INDEX at all 34 buoys**

**BIAS (m)**

**SIGNIFICANT WAVE HEIGHT BIAS at all 34 buoys**
Comparison of forecast(t=t+24) NCEP wave height with averaged buoy data. fc from 0 and 12Z.

**ENTRIES:**
- 1 - 3
- 3 - 6
- 6 - 13
- 13 - 29
- 29 - 67
- 67 - 155
- 155 - 360

**VALUES:**
- **BUOY MEAN** = 1.66
- **STDDEV** = 0.834
- **MODEL MEAN** = 1.77
- **STDEV** = 0.898

**LSQ FIT:**
- SLOPE = 1.011
- INTR = 0.087
- RMSE = 0.327
- BIAS = 0.106
- CORR COEF = 0.939
- SI = 0.186
- SYMMETRIC SLOPE = 1.066
Comparison of forecast\((t=t+24)\) METFR wave height with averaged buoy data. fc from 0 and 12Z.

**Significant Wave Height Scatter Index**
- **Entries**: 3456
- **Model Mean**: 1.88, **STDEV**: 0.794
- **Buoy Mean**: 1.66, **STDEV**: 0.834
- **LSQ Fit**: SLOPE = 0.848, INTR = 0.469
- **RMSE**: 0.441, **BIAS**: 0.216
- **Corr Coef**: 0.890, **SI**: 0.231
- **Symmetric Slope**: 1.097

**Significant Wave Height Bias**
- **Entries**: 3456
- **Model Mean**: 1.88, **STDEV**: 0.794
- **Buoy Mean**: 1.66, **STDEV**: 0.834
- **LSQ Fit**: SLOPE = 0.848, INTR = 0.469
- **RMSE**: 0.441, **BIAS**: 0.216
- **Corr Coef**: 0.890, **SI**: 0.231
- **Symmetric Slope**: 1.097
Comparison of forecast(t=t+24) DWD wave height with averaged buoy data. fc from 0 and 12Z.

ENTRIES:
- 1 - 3
- 3 - 6
- 6 - 13
- 13 - 29
- 29 - 67
- 67 - 155
- 155 - 360

D.W.D.

ENTRIES = 3456
MODEL MEAN = 1.71 STDEV = 0.755
BUOY MEAN = 1.66 STDEV = 0.834
LSQ FIT: SLOPE = 0.829 INTR = 0.329
RMSE = 0.339 BIAS = 0.044
CORR COEF = 0.915 SI = 0.202
SYMMETRIC SLOPE = 1.003

SIGNIFICANT WAVE HEIGHT SCATTER INDEX at all 34 buoys

SIGNIFICANT WAVE HEIGHT BIAS at all 34 buoys
Comparison of forecast \(t=t+24\) BoM wave height with averaged buoy data, fc from 0 and 12Z.
Comparison of forecast $t=t+24$ SHOM wave height with averaged buoy data. fc from 0 and 12Z.

Entries:
- 1 - 3
- 3 - 6
- 6 - 13
- 13 - 29
- 29 - 67
- 67 - 155
- 155 - 360

**ENTRIES:** 3456

**MODEL MEAN =** 1.66 **STDEV =** 0.808

**BUOY MEAN =** 1.66 **STDEV =** 0.834

**LSQ FIT:** SLOPE = 0.905 **INT =** 0.158

**RMSE =** 0.300 **BIAS =** 0.001

**CORR COEF =** 0.934 **SI =** 0.180

**SYMmetric SLOPE =** 0.994

**SIGNIFICANT WAVE HEIGHT SCATTER INDEX at all 34 buoys**

**SIGNIFICANT WAVE HEIGHT BIAS at all 34 buoys**
Comparison of forecast \((t=t+24)\) JMA wave height with averaged buoy data. fc from 0 and 12Z.

**Significant Wave Height Scatter Index at all 34 buoys**

- ECMWF
- METOF
- FNMOC
- MSC
- NCEP
- METFR
- DWD
- AUSNM
- SHOM
- JMA
- KMA
- PRTDS

**Significant Wave Height Bias at all 34 buoys**

- ECMWF
- METOF
- FNMOC
- MSC
- NCEP
- METFR
- DWD
- AUSNM
- SHOM
- JMA
- KMA
- PRTDS

**Entries**: 3456

**Model Mean**: 1.48, **STDEV**: 0.839

**Buoy Mean**: 1.66, **STDEV**: 0.834

**LSQ Fit**: Slope = 0.919, **INT R**: -0.049

**RMSE**: 0.394, **BIAS**: -0.183

**CORR COEF**: 0.913, **SI**: 0.209

**Symmetric Slope**: 0.914
Comparison of forecast(t=t+24) KMA wave height with averaged buoy data. fc from 0 and 12Z.

**Entries:**
- 1 - 3
- 3 - 6
- 6 - 13
- 13 - 29
- 29 - 67
- 67 - 135
- 135 - 360

**Symmetric Slope =** 0.986
**Corr Coef =** 0.793
**Si =** 0.305
**RMSE =** 0.510
**Bias =** 0.045

**LSQ Fit:**
- Slope = 0.637
- Intr = 0.649

**Buoy Mean =** 1.66
**St Dev =** 0.834

**Model Mean =** 1.71
**St Dev =** 0.669

**Significant Wave Height Scatter Index at all 34 buoys**

**Significant Wave Height Bias at all 34 buoys**
Original list: wave height scatter index time series

```
SI (%)
```

Analysis

```
KMA +3  JMA +3  SHOM +3  AUSBM +3  DWD +3  METFR +3  FNMOC +3  NCEP +3  UKMO +3  ECMWF +3
KMA +1  JMA +1  SHOM +1  AUSBM +1  DWD +1  METFR +1  FNMOC +1  NCEP +1  UKMO +1  ECMWF +1

fc d+3

months (median of the running averages)

2004  2005  2006  2007
```
Original list: wave height scatter index time series

12-month running average

fc d+3 - - -

Analysis

months (median of the running averages)


ECMWF
12-month running average of wind speed scatter index time series.
Original list: peak period scatter index time series

12-month running Average.

Peak period
**Sub-areas:**

Number of common observations for North West Atlantic buoys (NWATL) from 200706 to 200708 (wind, Hs, Tp)

<table>
<thead>
<tr>
<th>Number</th>
<th>Buoys Code</th>
<th>Observations</th>
<th>Location</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>41001</td>
<td>178 177 177</td>
<td>US East Coast, El Hatteras</td>
</tr>
<tr>
<td>2</td>
<td>41004</td>
<td>101 100 100</td>
<td>US South-East Coast, Edisto</td>
</tr>
<tr>
<td>3</td>
<td>41010</td>
<td>178 179 179</td>
<td>US East Florida, Cape Canaveral East</td>
</tr>
<tr>
<td>4</td>
<td>44004</td>
<td>180 179 179</td>
<td>US North East Coast, Hotel</td>
</tr>
<tr>
<td>5</td>
<td>44005</td>
<td>180 179 179</td>
<td>US East Coast, Cape Canaveral East</td>
</tr>
<tr>
<td>6</td>
<td>44008</td>
<td>180 179 179</td>
<td>US North-East Coast, Nantucket</td>
</tr>
<tr>
<td>7</td>
<td>44009</td>
<td>180 179 179</td>
<td>US North-East Coast, Delaware bay</td>
</tr>
<tr>
<td>8</td>
<td>44014</td>
<td>179 176 176</td>
<td>US East Coast, Virginia Beach</td>
</tr>
</tbody>
</table>

North West Atlantic
Euro Atlantic

Number of common observations for North East Atlantic buoys (NEATL) from 200708 to 200709 (wind, Hs, Tz)

Western Mediterranean Sea

Number of common observations for Western Mediterranean Sea (WMED) from 200708 to 200709 (wind, Hs, Tz)
Euro Atlantic

10m Wind Speed Scatter Index at 14 NEATL buoys

Wind

Tz

Western Mediterranean Sea

10m Wind Speed Scatter Index at 9 WMED buoys

S.I.

Mean Period Scatter Index at 7 WMED buoys

S.I.
Extension: wave spectra?

Normalized 2-D spectrum for eyls 1045 AN, alpha=0.1
21:00Z on 17.08.1969
at xxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 13.54 m, fm= 0.085 Hz, fp= 0.067 Hz
Qp= 1.156, Dir. Spread = -nan

Normalized 2-D spectrum for eyls 1045 AN, alpha=1.0
21:00Z on 17.08.1969
at xxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 16.20 m, fm= 0.079 Hz, fp= 0.067 Hz
Qp= 1.300, Dir. Spread = -nan

Normalized 2-D spectrum for eyls 1045 AN, alpha=0.1
00:00Z on 18.08.1969
at xxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 10.41 m, fm= 0.097 Hz, fp= 0.090 Hz
Qp= 0.968, Dir. Spread = 0.647

Normalized 2-D spectrum for eyls 1045 AN, alpha=1.0
00:00Z on 18.08.1969
at xxxx (29.00°, -88.80°) at depth 220.0 m
Hs= 13.54 m, fm= 0.085 Hz, fp= 0.067 Hz
Qp= 0.853, Dir. Spread = -nan

Normalised 2-D spectrum for eyls: 
Hs= 13.54 m, fm= 0.085 Hz, fp= 0.067 Hz
U10=43.27 m/s, u*= 3.18 m/s, windsea direction = 299°
buoy: Hs= 0.00 m, fm= 0.000 Hz, fp= 0.000 Hz
wind speed = 0.00 m/s, wind direction (ocean.conv.) = 0°

Normalised 2-D spectrum for eyls: 
Hs= 10.41 m, fm= 0.097 Hz, fp= 0.090 Hz
U10=32.30 m/s, u*= 1.66 m/s, windsea direction = 7°
buoy: Hs= 0.00 m, fm= 0.000 Hz, fp= 0.000 Hz
wind speed = 0.00 m/s, wind direction (ocean.conv.) = 0°

### E(f) (m²/s)

<table>
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<tr>
<th>E(f)</th>
<th>freq</th>
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<tr>
<td>0</td>
<td>0.00</td>
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<tr>
<td>100</td>
<td>0.10</td>
</tr>
<tr>
<td>200</td>
<td>0.20</td>
</tr>
<tr>
<td>300</td>
<td>0.30</td>
</tr>
<tr>
<td>400</td>
<td>0.40</td>
</tr>
</tbody>
</table>

### Frequency (Hz)

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>E(f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.10</td>
<td>100</td>
</tr>
<tr>
<td>0.20</td>
<td>200</td>
</tr>
<tr>
<td>0.30</td>
<td>300</td>
</tr>
<tr>
<td>0.40</td>
<td>400</td>
</tr>
</tbody>
</table>
Extension: wave spectra?

Equivalent wave height bias (model-buoy) at all US and Canadian buoys.
Operational analysis
Extension: comparison with altimeter Hs?

model analysis hindcast from 2006-12-01 to 2007-02-28
with data assimilation (ew46)
Extension: comparison with altimeter Hs?

ENVISAT RA-2 SWH St. Dev. Diff. with respect to WAM
Extension: field comparison?

High Resolution Diagnostic Data set (HRDDS) (see Adrian Hines’ presentation)
Extension: field comparison: scores as in atm. forecasting
Conclusions:

- This informal inter-comparison of wind and wave model data has worked well for over 12 years.
- It is time to work on extending this exercise.
- By adding wave spectra?
- By comparing to remotely sensed data (Altimeter(s), SARs)?
- By exchanging model fields (HHDR approach, objective score approach)?