Observation and Modeling of High Individual Ocean Waves and Wave Groups caused by a variable Wind Field

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Motivation

To explain Rogue Waves in the Southern North Sea and to find possibilities for warning systems.

Method

Simulate overlay of different statistical ensembles in a numerical sea state model.
Summary

Rogue waves are explained by the overlay of two wave ensembles with different Rayleigh distributions.

Rogue Waves belong to a Rayleigh distribution with an Hs about 1.6 larger than the background waves.
Rayleigh distribution (exceeding value)

N is the number of wavegroups from an ensemble with a given $H_s$ for which on average the wave height $H_N$ is reached or exceeded one time.

$$H_N = H_s \left(0.5 \ln (N)\right)^{0.5}$$

$$N = \exp \left(2 \left(\frac{H_N}{H_s}\right)^2\right)$$
<table>
<thead>
<tr>
<th>N</th>
<th>$H_{N}/H_{S}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4</td>
<td>1</td>
</tr>
<tr>
<td>1000</td>
<td>1.86</td>
</tr>
<tr>
<td>3000</td>
<td>2.07</td>
</tr>
</tbody>
</table>

Average observed number $N$ of wave groups for a significant wave height $H_{S}$ until the encounter occurs with a group height $H_{N}$ or larger.
Time Series Wave Height at Draupner, Jan, 1st 1995 15:20

Significant Waveheight 11.9m
Peak Period 16.7 sec
Maximum crest Height 18.5 m
Adjacent trough -7.1m and -6.5m
Depth 70m

Kona, 3.Nov.2011

Figur 4. Lavtrykksoirvelen som vi ser vest for fylland på satellittbildet fig. 2, har vi kunnet følge på tidligere bilder. Irvelen passerer ikke øst for Stenalid tidlig om morgenen, og øket vinden i vestlige Nordøya på sin veg sorover, slik som vist på figur.
Fig. AAA1: AVHRR NOAA Thermal Infrared on 1.1.1995 at 8.50 UTC and at 20.34 UTC

Kona, 3. Nov. 2011

12th International Workshop on Wave Hindcasting and Forecasting and 3rd Coastal Hazards Symposium
Draupner
58, 11 N / 2,28 E

FINO

Storm event of the 1st Nov. 2006

SKN + 15 m
Mean HW + 12.5 m
Kona, 3.Nov.2011

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MSG-1 image acquired on Nov 1, 2006, 10:30 UTC

MERIS FR LEVEL 2 acquired on Nov 01, 2006

ASAR WSM acquired on Nov 1, 2006 10:26 UTC with overlayed windfield
Measurement at FINO-1 Platform. The times of rogue waves entry, Qscat and ENVISAT acquisition are shown.
Wind field from A SAR and from QuickSCAT Scatterometer wind field (05:42 UTC, 25x25km) (left), HIRLAM – High Resolution Limited Area Hydrostatic Model, 11x11km Gitter HIRLAM 01.11.2006 09:00 UTC (middle) and wind field from DWD (right). The gustiness are visible in QuickSCAT data. In HIRLAM and DWD wind fields the gustiness is not present.

Significant wave heights $H_s$ in November 2007, measured using WAMOS (black) and ADCP (red) on the FINO 1 offshore platform. The averaging period used to determine the statistical wave parameters significant wave height, peak wave direction and peak wave period is 30 min with the wave radar system, and 20 min with the ADCP (AWAC).
Numerical simulation of a single idealized cell passing across the North Sea. Wind field is updated each 5 min, the results are presented in 4 h time steps. The cell enters the sea at time $t=2h$ and need about 15 h to make land fall again. Local wave height reaches 3 m within the footprint of the cell.
Fig.X3. Simulation of a group of idealized cells moving with a speed of 15m/s across the North Sea (no wind and waves in the background). Significant wave height reaches a value of 2.5m under the first cell and 3.5m under the second cell within an area of about 5x5 kilometers. The wave height time series from location N54°0.86’ E6°35.26’ (FINO-1) is shown for every 10min. The cell’s strongest influence lasts for a time of 10min.
Fig. X5. Simulation of a group of cells, moving with a speed of 25m/s across the North Sea (constant wind 20m/s with going to direction south-east and corresponding sea state pre-simulated with spin-up time of 24h). The wind speed again reaches 40m/s inside the cells. Significant wave height reaches 10m within the cells. The difference between $H_s$ (with cell) and $H_s$ (without cell) reaches the value of 3.9 m-
Ratio between maximal $H_s$ under cell group footprint and $H_s$ simulated without cells (left) for three locations in the North Sea along cell group trajectory (right).
L (Return period in years for the Fino Wave) = 4 years

M (groups per storm at FiNO with Hs=17 m) = 6 groups/storm

N (storms like Britta per year) = 2

G = 48 groups with Hs = 17 m in 4 years

\[ H_G = H_s \left(0.5 \ln (G)\right)^{0.5} \]

\[ H_{48} = 23.7 \text{ m} \]
Conclusions

• To determine the characteristics of extreme individual wave groups and small scale wind variability, satellite data have been used. Since the wind field resolution is too coarse in the present operational numerical wave models, they cannot simulate the ocean surface waves of extreme wind gusts.

• We showed, that fast travelling small scale gusts, embedded in larger depressions, are an effective source for extraordinary high energy wave fields, that travel at the propagation speed of the gusts. They can be described by a Rayleigh distribution with larger Hs than the background wave field.

• With higher resolved wind fields and finer spatial resolution the present wave models should be able to issue warnings for extreme individual waves.
Draupner Plattform

e1_18115_2421_slc
01-01-1995, 10:49 h UTC
100 x 100 km

position:
58, 11 N / 2,28 E
70 m water depth

Kona, 3.Nov.2011
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Wind gusts in the German Bight/ North Sea on 9. Nov. 2007 as a time series (above).

Max. Gusts at different stations (below)

<table>
<thead>
<tr>
<th>Station</th>
<th>Max. Gust (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Sea</td>
<td></td>
</tr>
<tr>
<td>Spiekeroog</td>
<td>146.5</td>
</tr>
<tr>
<td>UFS Deutsche Bucht</td>
<td>127.4</td>
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<tr>
<td>Strucklahnungshörn</td>
<td>124.6</td>
</tr>
<tr>
<td>List auf Sylt</td>
<td>120.2</td>
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<tr>
<td>Norderney</td>
<td>115.9</td>
</tr>
<tr>
<td>Hallig Hooge</td>
<td>111.6</td>
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<tr>
<td>Helgoland</td>
<td>110.5</td>
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<tr>
<td>Sankt Peter-Ording</td>
<td>108.7</td>
</tr>
<tr>
<td>Büsum</td>
<td>108.4</td>
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<tr>
<td>Bremerhaven</td>
<td>100.4</td>
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<tr>
<td>Borkum-Süderstraße</td>
<td>96.8</td>
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<tr>
<td>Brunsbüttel (Schleuse)</td>
<td>95.4</td>
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<tr>
<td>Cuxhaven</td>
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<tr>
<td>Leck</td>
<td>90.4</td>
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<tr>
<td>Emden</td>
<td>86.4</td>
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</tbody>
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