Operational ocean forecasting for German coastal waters
Overview

- Introduction
- Model system (at BSH)
- Validation
- Results of actual events
  - Elbe flood 2013
  - Xaver
- Outlook
Introduction
Introduction
Why do we run operational models?

BSH provides daily forecasts for a variety of customers and applications.

Main applications:
- water level prediction and storm surge warning service
- drift calculations for oil, other substances & SAR
- offshore industry & coastal engineering
- German navy
- fisheries
- tourism
Introduction
Model history at BSH

- Operational modelling (BSHcmod) since the early 80s
- One BSHcmod version has been sent to SMHI -> HIROMB
- Another version has been sent to DMI -> DMIcmod
- Within MyOcean DMIcmod + BSHcmod => HBM
Model system
(at BSH)
Operational model system at BSH

### Meteorological Models
(GME + COSMO-EU)
- forecasts up to 7 days
- wind, air pressure, air temperature, cloud coverage, specific humidity

### Wave Model
(EWAM)
- forecasts up to 84 hrs
- wave data

### Other forcing data:
tidal predictions, external surges (BSHsmod.na), river input (BfG, SMHI)
- external surge, tidal constituents, river runoff

### Circulation Model
(BSHcmod => HBM)
- for North Sea and Baltic Sea (3D, baroclinic) + biochemistry

### Circulation + Wave Model
(BSHcmod.w => HBM+CWAM)
- for North Sea and Baltic Sea (3D, baroclinic)

### Surge Model
(BSHsmod => HBM)
- for North Sea (2D, barotropic)

### Model data archive:
currents, water levels, eddy coefficients, salinity, temperature, ice data, wave data, meteo. data

### Lagrangian Drift and Dispersion Model
(BSHdmod.L => SeatrackWeb)
- for oil, drifting objects and conservative substances

### Eulerian Dispersion
(BSHdmod.E)
- for conservative substances, suspended matter and biochemistry

### Local Circulation Models
(HBM, UnTRIM)
- for estuaries (Elbe, Weser, Ems)

### Surge data
Circulation model: BSHcmod V4 => HBM

- 3D baroclinic, prognostic
- generalised, adaptive vertical co-ordinates (Kleine, 2004); optionally z-co-ordinates with free surface could be chosen
- 2-way fully dynamical nesting
- k-omega turbulence model
- drying and flooding of tidal flats
- sea ice dynamics (Hibler, 1979 ⇒ going to be replaced by BSH in-house development) and thermodynamics
- driven by meteo. forecasts of DWD, tides (14 constituents) and river inputs
- obc (T+S sponge layer)
Grid nesting V4 – part 1

1-way nesting

1-way nesting

2-way nesting

dx = 10 km

dx = 5 km

dx = 900 m
Grid nesting V4 – part 2

1-way nesting

\(dx = 900 \text{ m}\)

\(dx = 90 \text{ m}\)
Validation of BSH-HBM (period 1.1.2008 – 1.1.2009)
Validation – water levels

• North Sea
  • Tides
  • High water / Low water (only peaks)

• Baltic Sea
  • Total water level
Validation - Tides in the North Sea

Introduction
Model system

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Borkum</td>
<td>107.6</td>
<td>2.8</td>
<td>278</td>
<td>8</td>
<td>28.1</td>
<td>1.0</td>
<td>338</td>
<td>5</td>
</tr>
<tr>
<td>Helgoland</td>
<td>113.2</td>
<td>4.6</td>
<td>312</td>
<td>0</td>
<td>30.8</td>
<td>1.9</td>
<td>13</td>
<td>-5</td>
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<tr>
<td>Cuhaven</td>
<td>147.9</td>
<td><strong>13.5</strong></td>
<td>340</td>
<td>-4</td>
<td>37.1</td>
<td>2.7</td>
<td>46</td>
<td>-7</td>
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<tr>
<td>Buesum</td>
<td>154.7</td>
<td>-1.5</td>
<td>341</td>
<td>4</td>
<td>41.0</td>
<td>-1.1</td>
<td>47</td>
<td>0</td>
</tr>
</tbody>
</table>
Validation – total water level in the North Sea

<table>
<thead>
<tr>
<th>Station</th>
<th>Total water level</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High water</td>
<td>Low water</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bias [cm]</td>
<td>RMSD [cm]</td>
<td>Bias [cm]</td>
<td>RMSD [cm]</td>
</tr>
<tr>
<td>Borkum</td>
<td>-3</td>
<td>11</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Helgoland</td>
<td>3</td>
<td>14</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Cuxhaven</td>
<td>19</td>
<td>18</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Buesum</td>
<td>15</td>
<td>18</td>
<td>6</td>
<td>17</td>
</tr>
</tbody>
</table>

After bias correction:

With an error of ±10 cm BSH-HBM reproduced 39% of the high and 49% for low waters.
With an error of ±20 cm BSH-HBM reproduced 69% of the high and 85% for low waters.
With an error of ±30 cm BSH-HBM reproduced more than 90% of both high and low waters.
Validation – water level in the Baltic Sea

<table>
<thead>
<tr>
<th>Station</th>
<th>N</th>
<th>$\sigma$ [m]</th>
<th>mean [m]</th>
<th>Bias [m]</th>
<th>$\sigma$ [m]</th>
<th>RMSD [m]</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiel-Holtenau</td>
<td>8158</td>
<td>0.25</td>
<td>0.05</td>
<td>0.07</td>
<td>0.28</td>
<td>0.12</td>
<td>0.90</td>
</tr>
<tr>
<td>Koserow</td>
<td>8301</td>
<td>0.21</td>
<td>0.10</td>
<td>0.18</td>
<td>0.23</td>
<td>0.10</td>
<td>0.90</td>
</tr>
<tr>
<td>Sassnitz</td>
<td>5792</td>
<td>0.21</td>
<td>0.13</td>
<td>0.15</td>
<td>0.22</td>
<td>0.10</td>
<td>0.89</td>
</tr>
<tr>
<td>Travemuende</td>
<td>8472</td>
<td>0.24</td>
<td>0.07</td>
<td>0.08</td>
<td>0.28</td>
<td>0.12</td>
<td>0.90</td>
</tr>
<tr>
<td>Warnemuende</td>
<td>7477</td>
<td>0.22</td>
<td>0.08</td>
<td>0.11</td>
<td>0.25</td>
<td>0.11</td>
<td>0.89</td>
</tr>
</tbody>
</table>
Validation – currents

- Very difficult to validate
  - Only few measurements
  - High variability due to local topographic effects -> resolution not sufficient / difficult to find the corresponding grid point

- Data from a few Baltic stations were analysed
  - BSH-HBM reproduces variability of currents rather good (STD of BSH-HBM is nearly the same than STD of measurements)
  - Bias at bottom lower than 10 cm/s at all places
  - Bias at surface lower than 10 cm/s at most stations
Validation – current speed

Arkona 54° 53,11′ N, 13° 51,64′ E, depth: 46m
Validation – current speed

Darsser Sill 54° 41,9′ N, 12° 42′ E, depth: 21m

![Graph showing current speed measurements over time. The graph compares observations and BSH-HBM predictions.]
Validation – current speed

Vengeance Grund in the Great Belt

![Graph showing current speed over time with dates from 01/01/08 to 26/12/08. The x-axis represents dates, and the y-axis represents current speed in m/s. Two lines are shown: one for observations and one for BSH-HBM.]
Validation – sea surface temperature

SST L3

BSH-HBM

Jan - Dec 2008

mean [° C]

-2 0 2 4 6 8 10 12 14 16 18 20 22 24
Validation – sea surface temperature
Validation – temperature at stations

- **Surface:**
  In all places: Bias and RMSD $< 0.7^\circ$ C, Correlation $> 97\%$

- **Depths between surface and 80 m**
  At most and especially all German stations:
  Bias: 0.2 - 2° C, RMSD: 0.5 - 1° C, Correlation: $> 90\%$

- **Water depth $> 80$ m in the Baltic**
  Bottom temperature at Huvudskar Ost in the central Baltic
  Bias: -0.77° C, RMSD: 0.36° C, Correlation: 33 %
Validation – temperature at stations

Station UFS Deutsche Bucht in the German Bight / North Sea

[Graph showing temperature changes over time and depth]
Validation – temperature at stations

Station Fehmarn Belt in the Western Baltic

![Graph showing temperature depth profile over time for Station Fehmarn Belt in the Western Baltic. The graph displays data from 01/01/08 to 26/12/08, with depth in m on the y-axis and date on the x-axis. Temperature values range from 3°C to 21°C.]
Validation – temperature at stations

Station Huvudskar Ost in the central Baltic
Validation – salinity at stations

• Only few observations available
• Good agreement in deeper water depths (> 60 m)
• Sufficient correlation at surface, but potential for improvements
• At depths above the permanent halocline and below the surface measurements show generally stronger fluctuations than BSH-HBM

This is most probably owed to a combination of the complicated bathymetry of the Baltic Sea and the (probably too) coarse vertical resolution of the applied model setups
Validation – salinity at stations

Station Fehmarn Belt in the Western Baltic

![Graph showing salinity over time at the Fehmarn Belt station in the Western Baltic Sea. The graph displays two lines: one representing observations and another representing BSH-HBM predictions. The x-axis represents dates from January 1, 2008, to December 26, 2008, and the y-axis represents salinity in PSU (P部件每单位海里).]
Validation – salinity at stations

Station Arkona in the Western Baltic

Salinity [PSU]

Date

01/01/08 31/03/08 29/06/08 27/09/08 26/12/08

Salinity [PSU]

Date

01/01/08 31/03/08 29/06/08 27/09/08 26/12/08

observations

BSH-HBM
Validation – salinity at stations

Station Huvudskar Ost in the central Baltic
Validation – Sea Ice
Validation – Sea Ice

2008.03.01 - BSH-HBM

2008.03.01 - Observation

Sea ice concentration [%]

65°N

60°N

20°E  25°E  30°E

20°E  25°E  30°E
Elbe flood
(May / June 2013)
Elbe flood

- Heavy rainfall in south-east Middle Europe in May and June 2013 caused a flood at various rivers in that region.

- Along the river Elbe water levels which never occurred before were measured.

- Very high water levels in the tidal influenced part of the Elbe estuary between St. Pauli and the weir in Geesthacht.
Elbe flood

- The forecast of the river discharge was characterized by high uncertainties and therefore a high variability from forecast to forecast.
- Best estimate forecast of BSH-HBM works with discharge calculations from water levels in Neu Darchau (outside the EL-model region).
- Calculated river discharges of more than 4000 m³/s (nearly five times as high as the medium discharge) were also fraught with uncertainty.
Elbe flood

Zollenspieker

Geesthacht

sealevel [m]

01/06/2013 08/06/2013 15/06/2013 22/06/2013 29/06/2013
date

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7

BSH-HBM
Observation

01/06/2013 08/06/2013 15/06/2013 22/06/2013 29/06/2013
date

0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6 6.5 7

BSH-HBM - UP
BSH-HBM - OP
Observation - UP
Xaver
(5th to 7th December 2013)
Xaver

- Very high middle wind speeds between 45 and 55 knots (9-10 Beaufort) from north-westerly directions in the German Bight.

- Up to four storm surges and up to two strong storm surges in a row at almost all German North Sea stations.

- Highest water level elevation at station St.Pauli with 3.98 m above the mean high water, i.e. 6.09 m above mean sea level – a very strong storm surge and the second highest value ever.
Cuxhaven

St. Pauli

sealevel [m]

04/12/2013 05/12/2013 06/12/2013 07/12/2013 08/12/2013
date

04/12/2013 05/12/2013 06/12/2013 07/12/2013 08/12/2013
date
Three times as high as compared to a situation with stable wind conditions of 4-5 Beaufort from one direction over a whole day.
Outlook
Biogeochemical module (under development)

- Internal coupling interface (F90 modules)
- Development in co-operation with DMI
- Combined „North Sea/Baltic Sea model“
  → Online coupling of HBM + ERGOM (DMU)

**Goal:** Operational model with data assimilation

Will go pre-operational this summer!!
Development of pre-operational coupled current/wave model system by BSH & DWD

Coupling of

HBM circulation model and

WAM wave model

based on OASIS3 coupler

with 900m resolution

products for

- weather
- waves
- Currents+sea level+ice

Meteorological Models
GME + COSMO-EU (7km) + COSMO-DE (2,8 km)

wind, air pressure, air temperature, cloud coverage, specific humidity

Circulation + Wave Model (HBM + CWAM)
for German Bight and Western Baltic Sea
(3dim., 900 m)

Model data archive:
waveheight, -period, -direction, currents, water level, sea ice met. data
Model domain and resolution

Model domain cWAM: 53.2292° N – 56.4458° N
6.1736° O – 14.9097° O

Coarse resolution EWAM
(„Europäisches wave model“)
Grid spacing:
Lon.: 0.1°, Lat.: 0.05°

fine resolution c(K)WAM
(„coastal wave model“)
Grid spacing:
Lon.: 0.01388°, Lat.: 0.00833° (ca. 900 m)
Prospects

Coupling of COSMO-CLM and HBM via OASIS within the KLIWAS-project to

→ Generate a regional coupled atmosphere-ocean-model
→ Extend the multi-model ensemble of coupled atmosphere-ocean-models
→ Effective and sustainable use of professional expertise at DWD and BSH
BSH model system: (potential) coupling
Thank you!