STORM SURGE WATCH SCHEME

(Submitted by the WMO Secretariat)

Summary and Purpose of Document

This document provides background information related to statements made by the WMO EC-LX (June 2008) addressing the need for the provision of storm surge guidance information to Members exposed to these risks as a matter of priority.

ACTION PROPOSED

The Workshop participants are invited to:

(a) Note and comment on the information contained in this document as appropriate;

(b) Provide guidance on further actions to be taken towards the development and inclusion of the storm surge watch scheme into the tropical cyclone advisory arrangements and in the Tropical Cyclone Operating Plans.

Appendices:

A. Storm Surge Forecasting Systems
B. Wave Forecasting Systems
C. ECMWF wave products disseminated to WMO Members
DISCUSSION

Background Information

1. Noting that storm surges associated to the recent tropical cyclones Sidr and Nargis in the Bay of Bengal, which caused widespread flooding in the exposed coasts of Bangladesh and Myanmar, were the major cause of devastation and loss of lives in the most populous and low-lying areas of these countries, the WMO Executive Council addressed the need for the provision of storm surge guidance information to Members exposed to these risks as a matter of priority. The Council therefore agreed that a storm surge scheme attached to the tropical cyclone advisory arrangements would help to increase advisory lead-time and thus contribute to saving lives and properties, and would be the first step towards a comprehensive and integrated marine multi-hazard forecasting and warning system for improved coastal risk management.

2. The following paragraphs are included in the EC-LX (June 2008) General Summary:

   4.1.17 The Council recognized that storm surge warnings are a national responsibility. The Council noted that some tropical cyclone RSMC advisories did not include storm surge information. It agreed that a storm surge watch scheme would help to increase advisory lead-time and thus contribute to saving lives and properties, and would be the first step towards a comprehensive and integrated marine multi-hazard forecasting and warning system for improved coastal risk management.

   4.1.18 The Council therefore:

   (a) Requested the Secretary-General, in consultation with UNESCO/IOC to facilitate development of such schemes for regions subject to tropical cyclones;

   (b) Urged regional associations concerned to incorporate a storm surge watch scheme in the tropical cyclone advisory arrangements and in the TCP Regional Operating Plans and/or Manuals;

   (c) Noting that some RSMCs with Activity Specialization in Tropical Cyclones were not equipped to function as a storm surge forecast producing centres, requested the Secretary-General, based on the technical advice of JCOMM, to examine the capabilities and willingness of such Tropical Cyclone RSMCs and other storm surge forecast producing centres to participate in regional storm surge watch schemes, and to develop proposals for consideration by the concerned regional Tropical Cyclone Programme bodies and regional associations;

   […]

   4.1.20 The Council recognized that sea level observations are critical for enhancing storm surge forecasting and invited the Members to continue efforts to collect routinely and share such observations.

   […]

   4.1.22 The Council noted that the Fifth TCP/JCOMM Regional Workshop on Storm Surge and Wave Forecasting would be convened in Melbourne, Australia, from 1 to 5 December 2008. […] With reference to the JCOMM Guide to Storm Surge Forecasting, the Council urged the completion and publication of the Guide and the expansion of training workshops on storm surge and wave forecasting for the benefit of all Members exposed to these risks.
Outcomes of the RA V Tropical Cyclone Committee (RA V TCC) for the South Pacific and the South-East Indian Ocean, Twelfth Session, Niue, July 2008

3. In support of this objective, the Regional Association V Tropical Cyclone Committee (RA V TCC), in its twelfth session (RA V/TCC-XII, Niue, July 2008), discussed the implementation of a storm surge watch scheme in RA V and decided to establish an Action Team to address the issue of coastal flooding in the RA V region, in particular to review:

- the level of threat from storm surge and waves;
- the user defined requirements for warning information;
- gaps in the observation network and scientific knowledge of the threats;
- the capability of specialist centres to provide adequate warning information; and
- make recommendations to president of RA V as soon as possible.

4. The RA V TCC pointed out that in its area of responsibility, dangerous coastal flooding is mainly caused by large swell waves, and noted that RSMC-Nadi typically provides qualitative information about these phenomena in their Special Weather Bulletins.

5. The Storm Surge Watch Scheme Action Team meeting will be held from 15 to 16 December 2008, at the Bureau of Meteorology in Melbourne, Australia.

Outcomes of the RA I Tropical Cyclone Committee (RA I TCC) for the South-West Indian Ocean, Eighteenth Session, Malawi, October 2008

5. The Regional Association I Tropical Cyclone Committee (RA I TCC), in its eighteenth session (RA I/TCC-XVIII, Malawi, October 2008), noted that an extensive discussion on an implementation of a storm surge watch scheme was made by the RA V/TCC at its 12th session held in Niue in July 2008. Noting the guidance provided by WMO EC-LX and in consideration of the serious impact of the storm surge in this region and useful advice from RA V, the RA I TCC decided to establish an ad-hoc group to address the issue related to storm surge in the region. The RA I TCC recommended that this issue should be considered in the broad sense, i.e. not only on surges resulting from tropical storms but also from mid-latitude storms. In this regard, the RA I TCC noted that some Members have undertaken bathymetric studies of their coastal or near coastal areas. Gauging coastal stations are also being installed. However, the RA I TCC had the view that there is a need for a global approach to storm surge monitoring and forecasting.

6. The RA I TCC had also a view that capacity building is indispensable for a successful implementation of the storm surge watch scheme in this region. It therefore requested the WMO Secretariat to provide the RA I/TCC Members with training opportunities for storm surge forecasting and warning.

Possible Concept for a Global Storm Surge Watch Scheme

7. Storm surges and extreme wind-induced waves associated with severe tropical and extratropical cyclones, and its combined effect leading to coastal inundation, stand out as by far the most damaging among natural hazards. These marine-related hazards can be generated by meteorological forcing fields (mainly surface wind and atmospheric pressure) somewhere in the ocean, be it locally or thousands of kilometres away, crossing different regions, requiring global coordinated capabilities to monitor and provide forecasts and warning guidance of marine-related hazards’ events, particularly for improved coastal risk management. The purpose of a worldwide coordinated system is to make available to all Members the daily marine processed data and information they require for real-time uses. Making use of the existing frameworks, a possible concept for a Global Storm Surge Watch Scheme is presented in Figure 1.
Storm Surge Watch Scheme

• Regional Specialized Meteorological Centres with Activity Specialization in Tropical Cyclones can act as the Regional Storm Surge Forecast Producing Centres
• Specialized Products – data analysis and model forecast outputs
  Watch products to be incorporated in the Tropical Cyclone Advisory Arrangements

Figure 1: Possible concept for a Global Storm Surge Watch Scheme

8. JCOMM inventoried the existing operational wind-induced wave and storm surge models and forecasting systems, and that these are widely available among the existing network of Regional Specialized Meteorological Centres (RSMCs) of the Global Data-Processing and Forecasting System (GDPFS) and could eventually act as the Regional Storm Surge Forecast Producing Centres. Appendices A and B provide information on existing storm surge and wave forecasting systems, respectively, based on the responses received of the survey. Appendix C provides information on the ECMWF wave products disseminated to WMO Members. FNMOC and NOAA/NCEP have similar products available in their public websites: https://www.fnmoc.navy.mil/public/ and http://polar.ncep.noaa.gov/waves/index2.shtml, respectively.

9. Based on the above-mentioned concept, Regional Storm Surge Forecast Producing Centres (RSSFPC) would be only responsible for the provision of timely storm surge (and wave) forecasting guidance (specialized products) for use in preparation and issuing of regional watch products by RSMCs with activity specialization in Tropical Cyclones. Regional watch products would only be sent to NMHSs, who are responsible for issuing storm surge warnings at national level (as described in the TCP Regional Operating Plans). In this context, it should be clearly defined the roles and responsibilities of RSSFPCs and RSMCs with activity specialization in Tropical Cyclones on storm surge (and wave) forecasting, and the content of watch products to be incorporated in the Tropical Cyclone Advisory Arrangements must be described in the TCP Regional Operating Plans.

10. Sea level observations are critical for enhancing storm surge forecasting. UNESCO/IoC has developed in collaboration with the Flanders Marine Institute (VLIZ) a web-based global sea level station monitoring facility for viewing sea level data received in near real time from different network operators through a number of different communications channels (http://www.vliz.be/gauges/). The
particular aims of this service are: (i) to provide information about the operational status of global and regional networks of near real time sea level stations; and (ii) to provide a display service for quick inspection of the raw data stream from individual stations. Even not considering this as an ideal solution, it would help some countries in getting access to sea level data.

11. The Workshop participants are invited to provide guidance on further actions to be taken towards the development of a global storm surge watch scheme.

Appendices: 3
Operational / Pre-operational Numerical Models

1. Only 25% of the responses reported not running an operational / pre-operational storm surge model. The information collected on storm surge models in use is extensive, complete and detailed in tables below. A wide variety of uses of sea level observations in real-time, in conjunction with the numerical prediction, is also presented: forecast bias correction, initial conditions (assimilation), blending in bulletins with the forecasts, application of regression and empirical methods, and model validation.

Models Characteristics

2. It is noted that about 75% of applications are 2-D models (finer nested grids not considered). Resolution ranges from 10 / 20 km for regional models and 3-D applications to 1 km or finer nested grids. Table 1 compiles the information received.

Table 1. Operational / Pre-operational storm surge models features.

<table>
<thead>
<tr>
<th>Model</th>
<th>Area</th>
<th>Type</th>
<th>Grid</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAMSOM/Nivmar</td>
<td>Med.sea and Iberian Peninsula</td>
<td>Vertically integrated barotropic</td>
<td>10 minutes</td>
<td>Spain</td>
</tr>
<tr>
<td>Mike 21 pre-op. 3-D</td>
<td>North Sea, Baltic Sea</td>
<td>2-D hydrodynamic</td>
<td>finite diff. 9nm-3nm-1nm-1/3nm</td>
<td>Denmark</td>
</tr>
<tr>
<td>MOG2D</td>
<td>North Sea, Baltic Sea</td>
<td>2-D finite element</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coupled Ice-Ocean</td>
<td>Grand Banks, Newfoundland, Labrador</td>
<td>3-D circulation</td>
<td>20 km x 20 km approx.</td>
<td>Canada</td>
</tr>
<tr>
<td>JMA Storm Surge</td>
<td>23.5 N-46.5 N</td>
<td>2 D linearized shallow water</td>
<td>staggered Arakawa C-grid 1 min. latitude/longitude</td>
<td>Japan</td>
</tr>
<tr>
<td>KMA Storm Surge</td>
<td>20 N-50 N 115E-150E</td>
<td>2-D barotropic surge and tidal current based on Princeton Ocean Model</td>
<td>8 km x 8 km approx. finite diff. curvilinear c-grid 1/12 deg.</td>
<td>Korea</td>
</tr>
<tr>
<td>NIVELMAR</td>
<td>Portuguese mainland coastal</td>
<td>Shallow water</td>
<td>1 min. latitude/longitude</td>
<td>Portugal</td>
</tr>
<tr>
<td>SMARA storm surge</td>
<td>shelf sea 32-55 S 51-70 W Rio de la Plata</td>
<td>2-D depth averaged</td>
<td>geographical Arakawa C 1/3 degree longitude/latitude 1/20 degree,</td>
<td>Argentina</td>
</tr>
<tr>
<td>BSH circulation (BSHcmod)</td>
<td>NE Atlantic, North</td>
<td>3-D hydrostatic circulation</td>
<td>Reg. spherical North Sea, Baltic 6 nm</td>
<td>Germany</td>
</tr>
<tr>
<td>Model</td>
<td>Area</td>
<td>Type</td>
<td>Grid</td>
<td>Country</td>
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</tr>
<tr>
<td>BSH surge (BSHsmod)</td>
<td>Sea, Baltic Sea</td>
<td>2-D barotropic surge</td>
<td>Western Baltic, 1nm Surge North Sea, 6nm</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Caspian Storm Surge</td>
<td>Caspian Sea 36-48.5 N, 45-58 E North Caspian Sea 44.2 48-N, 46.5-55.1 E</td>
<td>2-D hydrodynamic, based on MIKE 21 (DHI Water &amp; Environment)</td>
<td>10km 2 km</td>
<td>Kazakhstan</td>
</tr>
<tr>
<td>HIROMB/NOAA</td>
<td>NE Atlantic, Baltic</td>
<td>3-D baroclinic</td>
<td>C-grid, 24nm</td>
<td>Sweden</td>
</tr>
<tr>
<td>WAQUA-in-Simona/DCSM98</td>
<td>continental shelf 48N-62N, 12W-13 E</td>
<td>2-D shallow water, ADI method, Kalman filter data assimilation</td>
<td>latitude/longitude, 1/8 degree longitude x 1/12 degree latitude</td>
<td>Netherlands</td>
</tr>
<tr>
<td>derived from MOTHY oil spill drifts model</td>
<td>Near Europe Atlantic (Gulf of Biscay, Channel and North Sea) 8°30' W - 10° E, 43°N - 59°N; West Mediterranean basin (from the Gibraltar Strait to Sicily); Restricted area in overseas departments and territories</td>
<td>shallow water equations</td>
<td>Arakawa c grid; finer meshes</td>
<td>France</td>
</tr>
<tr>
<td>SLOSH (Sea, Lake and Overland Surges from Hurricanes)</td>
<td>sea south of Hong Kong within 130 km</td>
<td>finite difference</td>
<td>Polar, 1km near to 7 km South China Sea</td>
<td>Hong Kong, China</td>
</tr>
<tr>
<td>Short-Term Sea Level and Current Forecast</td>
<td>Caspian Sea and near shore low lying zones</td>
<td>3-D Hydrodynamic baroclinic</td>
<td>3 nm horizontal, 19 levels</td>
<td>Russia</td>
</tr>
<tr>
<td>IIT Delhi, IIT Chennai, NIOT Chennai</td>
<td>east and west coasts of India and high resolution areas</td>
<td>non-linear finite element explicit finite element</td>
<td>Eg. for inundation model average spacing of 12.8 km offshore direction and 18.42 km along shore</td>
<td>India</td>
</tr>
<tr>
<td>CS3 tide-surge</td>
<td>NW European shelf waters</td>
<td>Finite difference, vertically averaged</td>
<td>C grid 12 km nested finer resolution</td>
<td>United Kingdom</td>
</tr>
</tbody>
</table>


**Products / Dissemination**

3 The forecast ranges of most of the operational applications are from 36 to 72 hours, although a forecast range as long as 120 hours has been reported. The predictions of surges generated by tropical cyclones have shorter ranges, usually within 12 hours.

3 Products derived from the numerical models are diverse: time varying sea level (surge) forecasts at specified locations and/or charts, local peaks and maxima charts, outputs for flooded areas, currents, oil drift and spread. There was one report of the application of a statistically derived scale of risk degree for set up (floods) as well as for abatement (navigation risk). On the enquiry about additional requirements received from community, flooded areas, oil spill evolution and surface currents are mentioned.

<table>
<thead>
<tr>
<th>Model output</th>
<th>Range, time interval</th>
<th>Real-time data use (routinely)</th>
<th>Applications</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>storm surge</td>
<td>72 hrs</td>
<td>assimilation</td>
<td>water level forecast</td>
<td>Spain</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><a href="http://www.puertos.es">http://www.puertos.es</a></td>
<td></td>
</tr>
<tr>
<td>water level and currents</td>
<td>54 hrs, hourly 4 times a day</td>
<td>remove bias of local forecast. Autoregressive filter</td>
<td>water level oil drift calculations</td>
<td>Denmark</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td><a href="http://www.dhi.dk">http://www.dhi.dk</a></td>
<td></td>
</tr>
<tr>
<td>water level at locations surface height anomaly local time series</td>
<td>2 days 48 hours 6 hourly</td>
<td>real time height anomalies from gauges, comparisons</td>
<td>water level, surface currents, drift</td>
<td>Canada Further info <a href="http://www.mar.dfo-mpo.gc.ca/science/ocean/icemodel/ice_ocean_forecast.html">http://www.mar.dfo-mpo.gc.ca/science/ocean/icemodel/ice_ocean_forecast.html</a></td>
</tr>
<tr>
<td>time series of sea level and surges</td>
<td>33 hours</td>
<td>under development</td>
<td>time series of sea level and surges</td>
<td>Japan</td>
</tr>
<tr>
<td>Time series of sea level</td>
<td>2 days 48 hours 12 hourly</td>
<td>empirical methods combine model and real-time data.</td>
<td>Time series of sea level</td>
<td>Korea</td>
</tr>
<tr>
<td>sea level and currents</td>
<td>120 hours</td>
<td></td>
<td>sea level and currents</td>
<td>Portugal</td>
</tr>
<tr>
<td>water level and mean current, surge</td>
<td>48 hours</td>
<td></td>
<td>water level forecasts</td>
<td>Argentina</td>
</tr>
<tr>
<td>currents, water level, temp. salinity, ice thickness and compactness</td>
<td>circulation: 72, starting from 12 hour met. forecast once a day, Surge:2 per day, 84 hs water level</td>
<td>empirical methods combine model and real-time data.</td>
<td>water level and current forecasts drift, oil spreading calculations</td>
<td>Germany</td>
</tr>
<tr>
<td>current and water level</td>
<td></td>
<td>initial conditions with empirical</td>
<td>local predictions</td>
<td>Kazakhstan</td>
</tr>
</tbody>
</table>

Table 2. Products and dissemination of operational storm surge numerical predictions.
<p>| maps of water depth, P and Q fluxes, time series | methods | weekly bulletins Further details provided |
| seal level maps, time series, web presentations for internal use | comparisons, internal use | water level forecasts, drift calculations, currents |
| seal level maps and selected locations | 48 hours, maps every 3 hours, 10 minutes at selected points | data assimilation | water level/surge forecasts for the coast |
| GRIB and BUFR data files | 48 hours fields hourly 5 min. at ports | water level forecasts | France |
| max. sea level and tides at locations, table of hourly sea levels. | 18 hours before and 12 hrs. after the closest approach of the cyclone | combination in bulletins | storm surge forecasting Hong Kong, China |
| sea level 3-D currents flooded areas | 48 hs. 1hour | forecast regression based positive/negative surge | water level forecasts, flooding, others |
| surge, peak cyclone, inundation | | Forecasts for the case of tropical cyclone |
| STFS | 36 hours | validation | hindcast, forecasts United Kingdom |
| | | | Bulletins Marine forecasts El Salvador |</p>
<table>
<thead>
<tr>
<th>Country</th>
<th>Name of model</th>
<th>Area</th>
<th>Grid</th>
<th>Type of model</th>
<th>Products</th>
<th>Source of wind information</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUSTRALIA</td>
<td>WAM</td>
<td>Global</td>
<td>3° x 3°</td>
<td>Deep water, coupled spectral</td>
<td>Forecast (+12 to +48 h), significant wave, swell and wind-sea height, period, direction</td>
<td>Australian global NWP model, GASP</td>
</tr>
<tr>
<td></td>
<td>WAM</td>
<td>Australian region</td>
<td>1° x 1°</td>
<td></td>
<td>Forecast (+12 to +36 h)</td>
<td>Australian regional NWP model RASP</td>
</tr>
<tr>
<td>CANADA</td>
<td>Ocean Wave Model</td>
<td>North Atlantic</td>
<td>Coarse mesh (1.08° long.)</td>
<td>Deep water, 1st generation spectral</td>
<td>4-panel charts (t + 0, 12, 24, 36) plots of swell height and period, wind-wave height and period, surface wind speed and direction, contours of significant wave height</td>
<td>Regional Finite Element (RFE) model surface wind applicable at 10 m level</td>
</tr>
<tr>
<td></td>
<td>CSOWM</td>
<td>North Pacific</td>
<td>Coarse mesh (1.08° long.)</td>
<td>Deep water, 1st generation spectral</td>
<td>4-panel charts (t + 0, 12, 24, 36) plots of swell height and period, wind-wave height and period, surface wind speed and direction, contours of significant wave height</td>
<td>Global spectral model 1 000 kPa winds</td>
</tr>
<tr>
<td>EUROPE</td>
<td>WAM</td>
<td>Global</td>
<td>1.5° x 1.5°</td>
<td>Deep/shallow water modes, coupled spectral</td>
<td>2-D spectra, significant wave height, mean direction, peak period of 1-D spectra, mean wave period. T=0 to T=120 at 6-h intervals; T=122 to T=240 at 12-h intervals. Outputs coded into FM 82-X Ext. GRIB</td>
<td>Surface winds (10 m) from ECMWF analyses and forecasts</td>
</tr>
<tr>
<td></td>
<td>WAM</td>
<td>Baltic and Mediterranean Sea</td>
<td>0.25° x 0.25°</td>
<td></td>
<td>Same as global model except for T=0 to T=120 at 6-h intervals</td>
<td>Surface winds (10 m) from ECMWF analyses and forecasts</td>
</tr>
<tr>
<td>FRANCE</td>
<td>VAGMED</td>
<td>Western Mediterranean Sea</td>
<td>35 km polar stereographic at 60°N</td>
<td>Deep water, coupled discrete model</td>
<td>Forecast every 3 h up to 48 h. Maps of wave height contours with swell and wind-sea directions. Directional spectra (telex). Archive of analysed 2-D spectra and of forecast height fields</td>
<td>Wind fields from the fine mesh model PERIODOT</td>
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<td>VAGATLA</td>
<td>North Atlantic</td>
<td>150 km polar stereographic at 60°N</td>
<td>Deep water, coupled discrete model, 2nd generation</td>
<td>Forecast every 6 h up to 48 h. Maps of wave height contours with swell and wind-sea directions. Directional spectra (telex). Archive of analysed 2-D spectra and of forecast height fields</td>
<td>Wind fields from EMERAUDE model</td>
</tr>
<tr>
<td>GERMANY</td>
<td>Deutscher Wetterdienst</td>
<td>Atlantic, north of 15°N</td>
<td>Deep water, coupled hybrid</td>
<td></td>
<td>Prognoses for 6 h, then at 12-h intervals to 96 h run daily, verification only</td>
<td>BFK model, 950 kPa level, diagnostically interpolated for about 20 m above sea</td>
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<td></td>
<td>AMT für Wohrgophysik</td>
<td>North-east Atlantic, southern Norwegian Sea, North Sea</td>
<td>50 km</td>
<td>Continental shelf of North Sea, coupled hybrid</td>
<td>(1) Maps of wave and swell direction for south Norwegian Sea and North Sea – 24 h prognoses (2) Wind direction and velocity, significant wave height, swell height, wave period, swell period – 24 h hindcast and forecast for nine geographic positions</td>
<td>Reduced wind components of geopotential fields at 1 000 kPa from meteorological forecast model 7-LPBE</td>
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<tr>
<td>Country</td>
<td>Name of model</td>
<td>Area</td>
<td>Grid</td>
<td>Type of model</td>
<td>Products</td>
<td>Source of wind information</td>
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<tr>
<td>GREECE</td>
<td>Mediterranean</td>
<td>Central and eastern Mediterranean Sea</td>
<td>100 km polar</td>
<td>Deep water, decoupled</td>
<td>Daily wave forecasts for 6-h intervals to 48 h (radio-facsimile broadcasts)</td>
<td>Operational atmospheric numerical model of the ECMWF at 1 000 hPa</td>
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<tr>
<td>HONG</td>
<td>MRI-II</td>
<td>5°-33°N, 165°-135°E</td>
<td>Mercator</td>
<td>Deep water, coupled</td>
<td>Hindcast and 24- and 48-h forecasts of significant waves and swell at grid points every 12 h, charts</td>
<td></td>
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<tr>
<td>KONG</td>
<td></td>
<td>2.5° x 2.5°</td>
<td></td>
<td>discrete</td>
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<td>HK coast</td>
<td></td>
<td>Coastal waters around Hong Kong</td>
<td>4.4 x 4.4 km</td>
<td>Shallow water SMB</td>
<td>6-, 12-, 18- and 24-h forecasts of significant wave height and swells every 12 h, charts</td>
<td>Surface winds at selected coastal stations in Hong Kong</td>
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<tr>
<td>INDIA</td>
<td>Sverdrup-Munk</td>
<td>Indian seas</td>
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<td>Deep water, simple</td>
<td>Wave forecasts</td>
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<td>Breathsneider</td>
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<td>SMB model</td>
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<td>IRELAND</td>
<td>Adapted NOWAMO</td>
<td>North Atlantic</td>
<td>Hybrid</td>
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<td>12-h sea, swell and combined wave heights</td>
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<td></td>
<td>(Norway)</td>
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<tr>
<td>JAPAN</td>
<td>MRI-II</td>
<td>Western North Pacific</td>
<td>381 km 36 x 27</td>
<td>Deep water, spectral</td>
<td>Fax chart of analysis and 24-h forecast, daily</td>
<td>Surface winds from numerical weather prediction model</td>
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<td></td>
<td></td>
<td>model, coupled discrete</td>
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<tr>
<td></td>
<td>MRI-II</td>
<td>Seas adjacent to Japan</td>
<td>127 km 37 x 31</td>
<td>Deep water, spectral</td>
<td>Fax chart of 24-, 36- and 48-h forecast, twice a day</td>
<td>Surface winds from numerical weather prediction model</td>
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<td>model, coupled discrete</td>
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<td>Coastal wave model</td>
<td>Seas of Japan</td>
<td>10 km inshore of 100 km</td>
<td>Hybrid of significant wave and spectral model</td>
<td>Fax chart of 24-, 36-, and 48-h forecast, twice a day</td>
<td>Surface winds from numerical weather prediction model</td>
</tr>
<tr>
<td>MALAYSIA</td>
<td>OONO</td>
<td>Equator to 18°N, 110°-118°E</td>
<td>2° x 2° Mercator</td>
<td>Deep and shallow</td>
<td>Analysis and forecast of 6-h intervals for pre-selected points</td>
<td>Analysis: Grid point wind from subjectively analyzed charts</td>
</tr>
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<td></td>
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<td></td>
<td>coupled hybrid</td>
<td></td>
<td>Forecast Persistence</td>
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<tr>
<td>NETHERLANDS</td>
<td>OONO</td>
<td>North Sea and Norwegian Sea</td>
<td>75 km Cartesian</td>
<td>Deep and shallow,</td>
<td>Analysis and 6-, 12-, 18-, 24-h forecasts of wind-sea charts every 6 h</td>
<td>Numerical atmospheric 4-layer baroclinic model based on air pressures analysis</td>
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<tr>
<td>N.ZEALAND</td>
<td></td>
<td>South-west Pacific (including Tasman Sea</td>
<td>Polar stereographic</td>
<td>coupled hybrid</td>
<td></td>
<td>Regional 10-layer primitive equation NWP model coupled to surface winds with</td>
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<td></td>
<td></td>
<td>and Southern Ocean)</td>
<td>40 x 30 Cartesian</td>
<td></td>
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<td>2-layer diagnostic boundary layer model</td>
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<tr>
<td>NORWAY</td>
<td>WINCH</td>
<td>North Sea, Norwegian Sea, Barone Sea,</td>
<td>75 km polar</td>
<td>Deep water, coupled</td>
<td>Forecast charts of wave parameters at 6-h intervals, time series and wave spectra for selected</td>
<td>10 m winds from Norwegian Meteorological Institute (DNMI) limited area model run up to 48 h.</td>
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<td></td>
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<td>northern parts of northwestern Atlantic</td>
<td>stereographic</td>
<td>discrete, 2nd</td>
<td>points</td>
<td>Also 10 m winds from ECMWF to 165 h</td>
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<td>generation</td>
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<tr>
<td>Country</td>
<td>Name of model</td>
<td>Area</td>
<td>Grid</td>
<td>Type of model</td>
<td>Products</td>
<td>Source of wind information</td>
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<tr>
<td>SAUDI ARABIA</td>
<td>Advective singular wave model</td>
<td>5ºN, 45ºE; 20ºN, 70ºE; 30ºN, 30ºE; 43ºN, 55ºW; Red Sea and Arabian Gulf</td>
<td>28.1 km</td>
<td>Shallow water, advective singular</td>
<td>Charts of significant wave height and period at 6-hour intervals</td>
<td>From numerical analysis model – a numerical sea breeze simulation is used near coast and a gradient wind modified from friction is computed</td>
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<tr>
<td>SWEDEN</td>
<td>NORSWAM</td>
<td>North Sea</td>
<td>100 km</td>
<td>Deep water, coupled hybrid</td>
<td>Wave forecast</td>
<td></td>
</tr>
<tr>
<td>UNITED KINGDOM</td>
<td>European model</td>
<td>North Atlantic, east of 14ºW; 50º45'N–66º45'N including Mediterranean and Black Seas</td>
<td>0.25º lat. x 0.4º long.</td>
<td>To 200 m depth, with 2 m resolution, coupled discrete</td>
<td>12-h hindcast and 36-h forecasts of wind sea and swell sea (height, direction and period), also significant wave height. Fields output on charts or for selected grid points as metsgrams or by printer. Tabulated results of coastal areas are also available.</td>
<td>Forecast winds from lowest level of operational, fine mesh, limited area numerical weather prediction models, every hour</td>
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<td></td>
<td>Global model</td>
<td>Global oceans</td>
<td>1.25º lat. x 0.8333º long.</td>
<td>Deep water, coupled discrete</td>
<td>12-h hindcasts and 120-h forecasts of wind sea and swell sea (height, direction and period), also significant wave height. Fields output on charts for local use or in digitally-coded bulletins (GRID or GRIB) on GTS</td>
<td>Forecast winds from lowest level of operational, coarse-mesh, global numerical weather prediction model, every two hours</td>
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<tr>
<td>USA</td>
<td>NOAA/WAM</td>
<td>Global</td>
<td>2.5º x 2.5º lat./long.</td>
<td>Deep water, coupled spectral</td>
<td>Significant wave height charts for T=12, T=24, T=48 and T=72. Charts of direction of peak energy for Atlantic and Pacific, and period of peak energy for Pacific. Alpha-numeric bulletins of wave spectra, special charts for Gulf of Alaska, Hawaii and Puerto Rico regions</td>
<td>Lowest layer winds corrected to 10 m height from the operational Medium Range Forecast (MRF) model</td>
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<td></td>
<td>GWAM</td>
<td>Global</td>
<td>1º x 1º lat./long.</td>
<td>Deep water, coupled spectral</td>
<td>Significant wave height, sea height, swell height, max. wave height, mean wave direction, sea direction, swell direction, mean period, sea period, swell period, whitecap coverage, T=0 to T=144</td>
<td>Surface winds stress for Navy Operational Global Atmospheric Prediction System (NOGAPS)</td>
</tr>
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<td></td>
<td>IOWAM</td>
<td>Indian Ocean</td>
<td>0.25º x 0.25º lat./long.</td>
<td>Shallow water, coupled spectral, nested in GWAM</td>
<td>As above, T=0 to T=48</td>
<td>Navy Operational Regional Atmospheric Prediction System (NORAPS)</td>
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<tr>
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<td>MEDWAM</td>
<td>Mediterranean Sea</td>
<td>0.25º x 0.25º lat./long.</td>
<td>Shallow water, coupled spectral</td>
<td>As above, T=0 to T=72</td>
<td>NORAPS</td>
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<td></td>
<td>KORWAM</td>
<td>Korea area</td>
<td>0.2º x 0.2º lat./long.</td>
<td>Shallow water, coupled spectral, nested in GWAM</td>
<td>As above, T=0 to T=36</td>
<td>NORAPS</td>
</tr>
</tbody>
</table>
ECMWF wave products disseminated to WMO Members

Following the environmental emergency that has inflicted damage to homes, livelihoods and infrastructure in many parts of the country as a result of large swell waves, which caused widespread flooding in the exposed islands of the Maldives in May 2007 and for the second time in June 2007, WMO has requested ECMWF to consider the immediate provision of wave products to the Maldives in order to support in- and post-emergency operations. The ECMWF Council (Reading, UK, December 2007) considered favourably the request by the WMO on providing additional products to all WMO Members and decided to enhance the set of ECMWF products disseminated to WMO Members on the ECMWF web site (password protected). The improvement is quite significant and includes:

- The provision of a deterministic forecast range of global marine products on 2.5-degree latitude/longitude grids of up to 7 days.
- The provision of global marine products from the Ensemble Prediction System (EPS) on 2.5-degree latitude/longitude grids of up to 6 days, in support of high impact and extreme sea state events. This includes in particular global forecasts of the probability of Significant Wave Height (SWH) above 2, 4, 6, and 8 m based on EPS.

Traditionally marine forecasting is based on parameters describing wind, sea and swell. To capture extreme events it is important to know how high the waves are, how steep they are, how fast they propagate and from which direction they come. For early warning of extreme events at sea, the NMHSs use the parameters: Significant Wave Height (SWH), Mean Wave Direction (MWD) and Mean Wave Period (MWP). The probabilistic forecast of SWH exceeding specific thresholds provides early warning guidance of extreme events. The four thresholds depicted in the ECMWF products are based on requirements of end-users in different parts of the world, which include:

(i) Government department for fisheries;
(ii) Fishermen’s organisations;
(iii) Authorities responsible for safety of life at sea, including coastal waters;
(iv) Authorities responsible for combating marine pollution;
(v) Operators of ferry, hydrofoil, hovercraft, or similar services;
(vi) Oil drilling and shipping companies; and,
(vii) Authorities responsible for protection of the coastal populations from, among others, high waves, storm surges and tsunamis;
(viii) Harbour control authorities.

These products will benefit and guide NMHSs in their official duties dealing with sea state monitoring and forecasting. The enhanced set of ECMWF products is available on the ECMWF web site: http://www.ecmwf.int/products/forecasts/d/charts/medium. Access to the ECMWF Web site for WMO Members is password protected; therefore all requests for access should be made by the Permanent Representative with WMO to the Director of ECMWF (please see www.ecmwf.int). WMO Members are encouraged to submit their request to the ECMWF, with a copy to WMO Secretariat. Feedback regarding these products is welcome.

Figure 2 shows examples of the wave forecast guidance to be made available from the deterministic model. The onset of the high wave’s propagation from the south into the Indian Ocean is well depicted. Figure 3 shows the corresponding probabilistic forecast of significant wave heights exceeding 4m three days prior to the event. The combined use of deterministic and probabilistic forecast guidance will help the NMHSs in their risk assessment at an early stage in forecasting and improving marine-related decision-making processes.
Figure 2: 24h forecast of significant wave height (SWH, top, coloured shading), mean wave direction (MWD, top arrows) and mean wave period (MWP, bottom) valid 12 May 2007. The mean wave direction arrow length is proportional to the significant wave height (by courtesy of the ECMWF).

Figure 3: 72h forecast of the probability that the significant wave height will exceed 4m, valid 12 May 2007 (by courtesy of the ECMWF).