Predicting and measuring waves, long waves and winds

A high-resolution weather forecasting tool for marine operations management in ports and harbors

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Introduction

Many ports and harbors experience occasions when energetic weather conditions lead to operational issues. These may relate to underkeel clearance for the entrance or exit transit, agitation at the berth due to swell penetration or longwave surge and high winds influencing vessel management for example. Other activities, such as dredging, survey or construction typically require low energy conditions for safe execution. Effective planning for these activities requires reliable quantification of site specific weather parameters over short and medium (five to seven days) forecast range.

To meet this need, a set of web-based tools (MOVs – MetOceanView) has been developed to allow access and management of harbor-scale weather.

The core forecast system architecture is founded on modern high-resolution ocean and atmospheric models, customized at appropriate scales for the actual port or harbor location as well as the shipping approaches. The numerical models allow the detailed transformation of waves from offshore and into the entrance regions, as well as the coastal currents and water levels. The wind fields influenced by the regional topography can also be resolved.

Ingestion of real-time measured wave and wind data into MOV allows the forecast accuracy and trends to be co-plotted and therefore assessed on a daily basis. The core forecast configurations also assimilate observed data where possible to improve short range forecasts. Examples of the forecast system are presented here for four operational situations. Port Taranaki and Port Geraldton lie within complex reef and near-shore bathymetry, and experience high energy swell conditions and occasions with problematic longwaves. Das Island in the Persian Gulf provides a lower energy example for the management of dredging operations, while the Port of Los Angeles application shows the benefit of spatial overlay maps of the local marine conditions.

Forecast system overview

The operational forecast system is configured at global, regional and local scales; allowing a truly customized solution to be established for any location. The high-resolution domains can be rapidly deployed, and a typical port system can be established within two to three days of notification. Full access to the forecast data is provided by an innovative set of web-based tools, and through delivery by email, as discussed in subsequent sections.

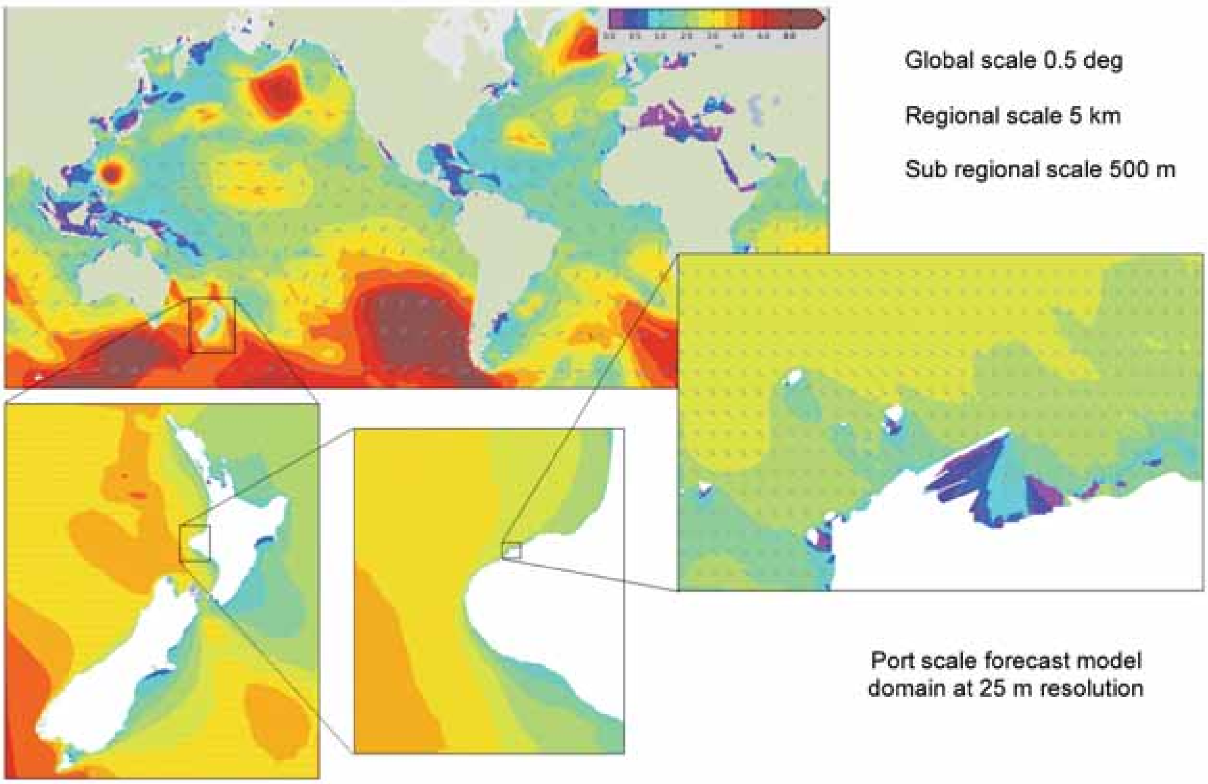

Figure 1. Example of the multi-nested forecast domain implemented for Port Taranaki in New Zealand.

Global scale model

An in-house global WaveWatch3 (WW3) domain is run four times per day at 0.5o resolution using wind fields from NCEP's Global Forecast System (GFS). Remote-sensed wave data are assimilated into each cycle. Forecasts produced with a seven-day horizon. As part of the WW3 implementation, full spectral boundaries are also generated for the nested regional domains.

Regional and local scale models

A series of multi-nested SWAN [2] wave model domains provide detailed resolution at the necessary regional and local scales. For a port location, a three-stage nest from the global domain is typically prescribed, although an additional level may be required in regions with highly complex bathymetric settings. An example of the nested wave domains used for the operational Port Taranaki implementation is shown in Figure 1.

Wind fields within these nested domains are sourced from either the NOAA GFS or from customized WRF atmospheric model domains. Local validation is initially performed to determine if increased resolution over the GFS scale is warranted. A 6–8km WRF domain is often beneficial in coastal regions with significant topographic influence, such as New Zealand waters or the Bass Strait (see Figure 2).

Effective marine forecasting requires data sources that suit the local topographic complexity and wave generation characteristics.

Regional current models are run in some domains, with resolution of between 1km and 5km. A 2D implementation of POM [5] is used for current modeling, with wind velocity components and atmospheric pressure interpolated in space and time onto the model grid. The TPXO7.2 global inverse tidal solution [1] is used to prescribe the tidal elevation and current velocity boundaries.

Any number of reporting sites can be set within the domain, producing hourly site-specific data over the seven-day forecast horizon.

Calibration and validation

The wave physics within the forecast domain are usually calibrated against the available historical wave data in the vicinity of the port, or from the nearest offshore buoy source. The calibration process ensures the appropriate bed friction and grid resolution has been applied to the domain. Once operational, data from within the nested domains can be directly compared with real-time wave measurements and ongoing model adjustment applied as necessary. Forecast accuracy and short-term weather trends can also be assessed at any time. An example from an offshore wave buoy in New Zealand is provided in Figure 3.

All site-specific forecast data are archived. This allows forecast accuracy analysis to be post-processed; determining the statistical measures of accuracy at forecast horizons up to seven days ahead.

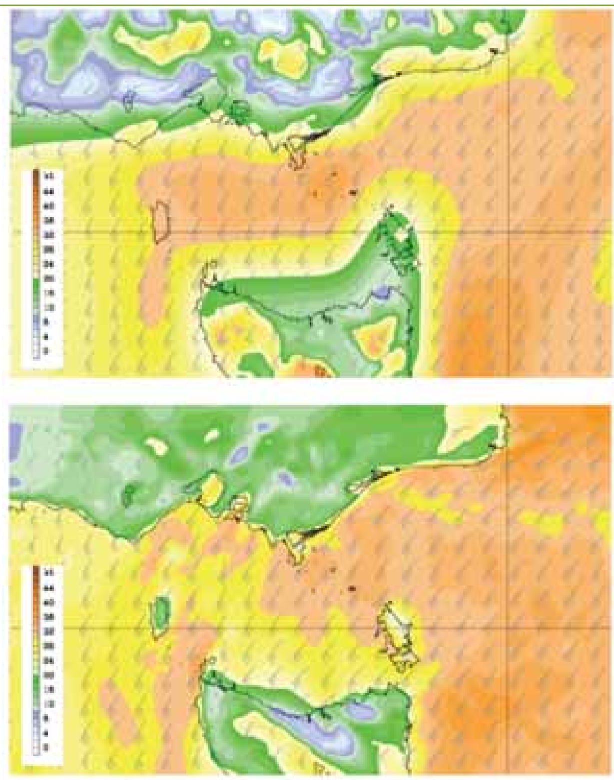

Figure 2. Comparison of the wind field during a strong south-westerly event the Bass Strait. Upper map is from GFS, lower map is a local WRF domain at 8km resolution.

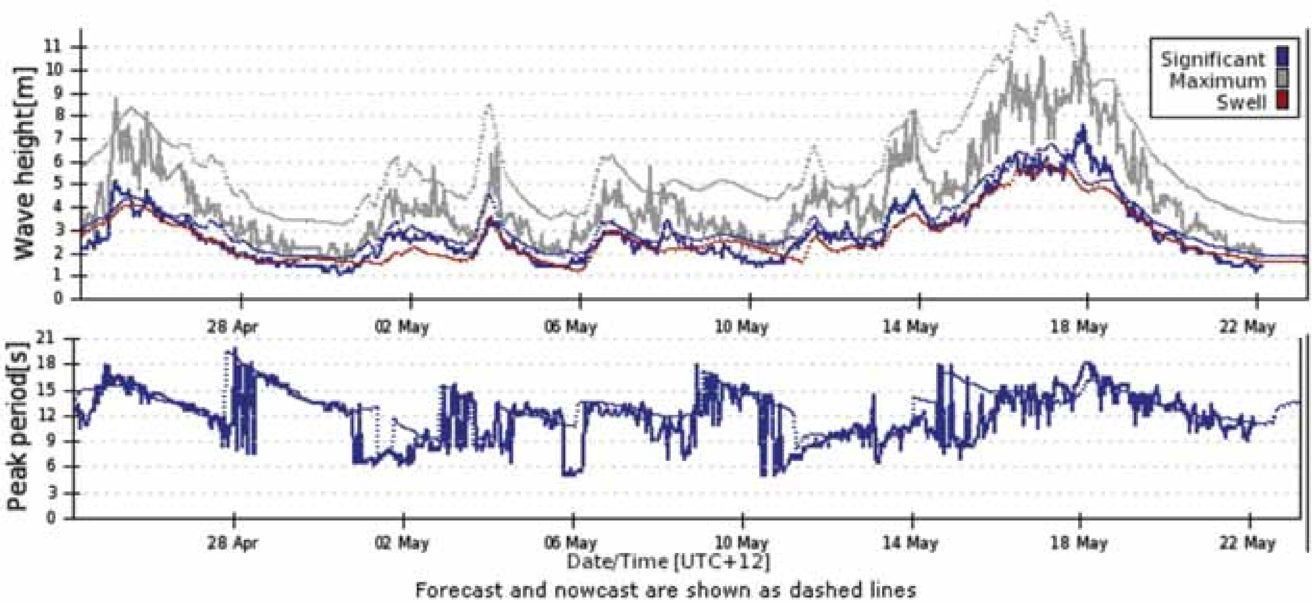

Figure 3. Real-time wave data are ingested into the forecast system, providing an instant comparison of the measured and forecast values – useful for interpreting weather trends and providing guidance for short range operational decisions. Shown here are the measured (solid) and forecast / nowcast (dashed) wave height and peak period from a site west of Cape Farewell, New Zealand.

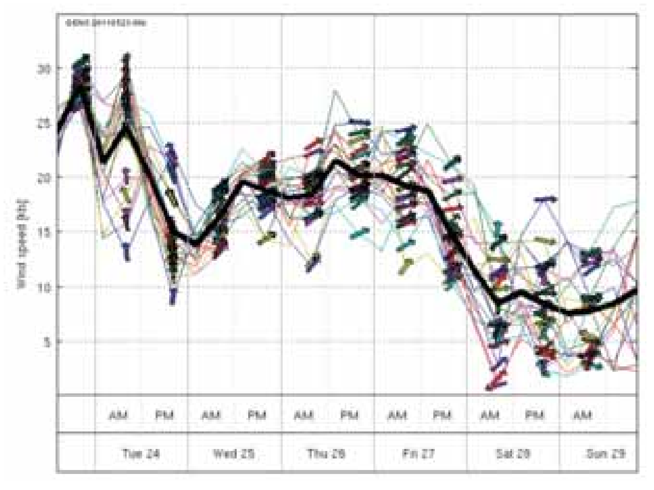

Figure 4. The spread of the wind forecast ensembles provides guidance on the forecast confidence and stability. Example shown here for the Port of Melbourne.

Long period wave (LPW) forecasting

Problematic surging and agitation of berthed vessels can be directly related to long period waves (LPW) that penetrate a harbor defenses. Both the LPW and the surge events can be reliably forecast at discrete locations within a harbor basin [3]. This LPW energy lies in the 25–150s period range, and is released during the swell wave transformation process.

Accordingly, bathymetric features in the vicinity of a harbor entrance tend to govern the LPW energy distribution and also the degree of penetration into the harbor. Once inside the harbor, the internal geometry often plays an important role in LPW energy regime and vessel surging dynamics. Resonance (or seiche) effects may amplify the signal, often within very discrete areas of the harbor.

Analysis by the authors of data from 11 different harbors has confirmed that berth LPW conditions are highly correlated to swell wave spectra parameters from outside the harbor. While the LPW generation process is location-specific, complex and highly non-linear, a robust semi-empirical technique can be used to transform the swell wave spectra from a representative location outside the harbor to the LPW conditions at discrete berths inside the harbor. The forecast accuracy of this method is equivalent to that achieved for the swell waves at the harbor entrance. LPW data from inside the port is needed for calibration of the technique, and a period of at least three months duration is normally specified.

2.5 Data access and delivery

A full suite of forecast data and interactive tools is available from a website login for clients. The seven-day marine forecast data include;

- Maps of wave height, direction, period, wind speed and direction
- Site data presented as graphs and tables
- User-defined hazard alerts

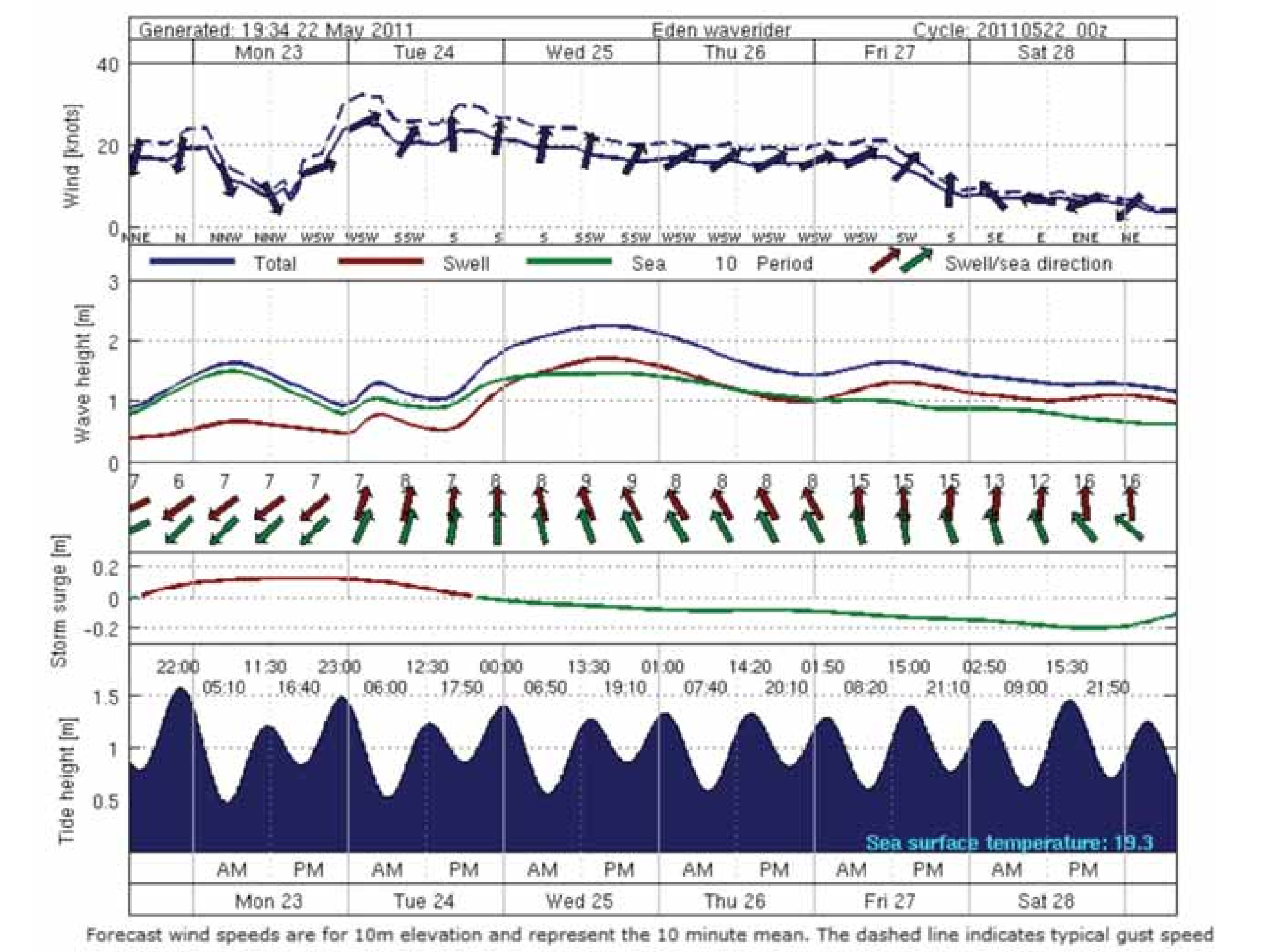

Figure 5. Forecast graphs are updated four times per day. These graphs, along with data tables and synoptic maps, are auto-emailed as PDF files to the client distribution list. Shown here is the waverider location offshore of Eden, NSW.

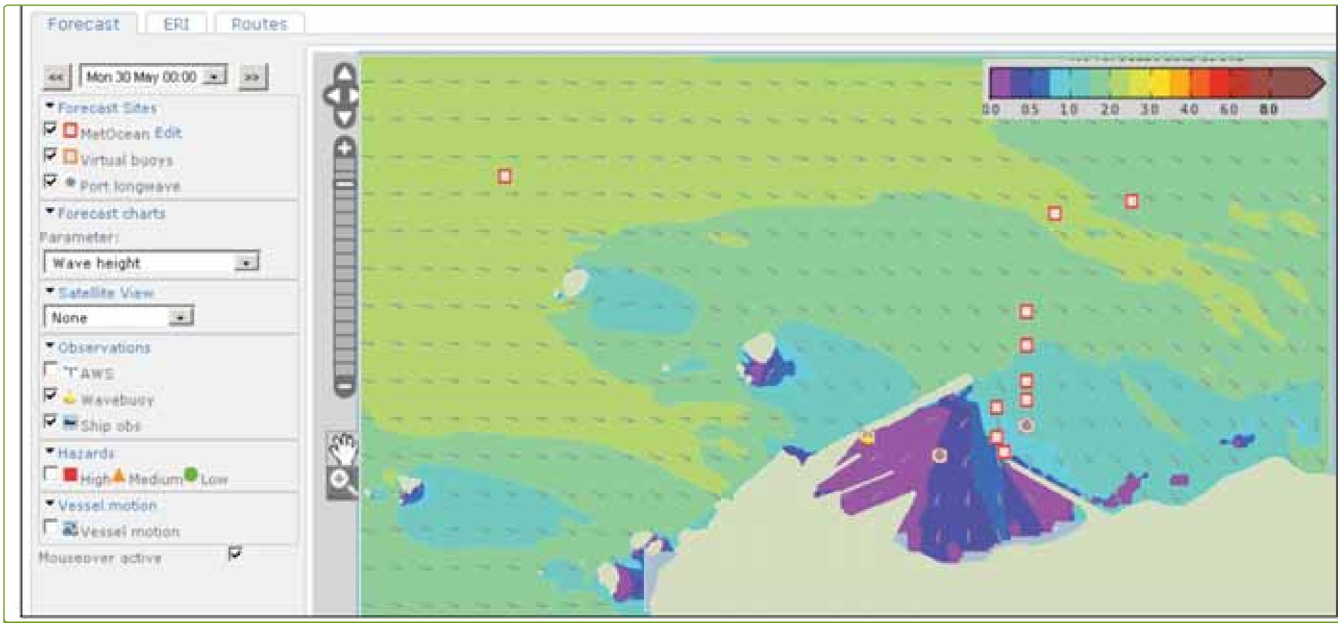

Figure 6. The MOV interface to the wave domain for Port Taranaki. High resolution in the wave model is needed to account for the local complexity including adjacent islands. Measured and forecast site-specific data are accessed from this interface, including site along the channel for underkeel clearance and berth locations for surge and vessel agitation.

- Observed wave and wind data from local stations plotted alongside forecast values
- Wind ensembles from GFS and WRF
- Report generation including statistics.

The 7-day wind ensembles provide a valuable guide to forecast confidence, as indicated by the spread in speed and direction, as shown on Figure 4. Other data, such as rainfall, sea and air temperature and wind gusts are also available. The first six hours of each cycle are archived into a readily available 'nowcast' of the metocean conditions over the previous 12 months, which can be downloaded as a text file. Site-specific reports are generated every forecast cycle, and include graphs (Figure 5) and tables as well as regional synoptic charts. The forecast reports are auto-emailed in PDF format to the client distribution list at the user-specified frequency.

Example MOV implementations

Port Taranaki, New Zealand

Port Taranaki, on the west coast of the North Island of New Zealand, is situated in an energetic wave climate with complex

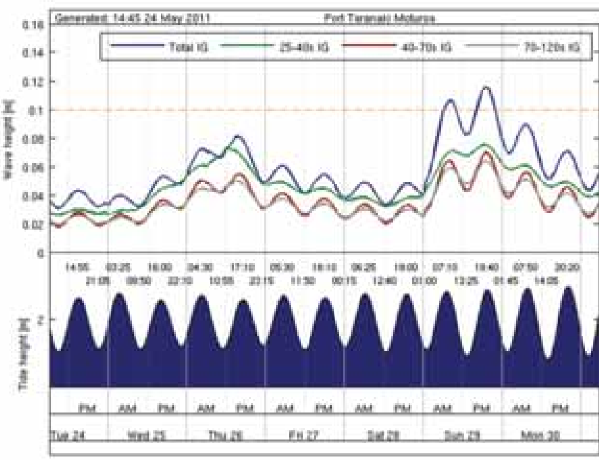

Figure 7. Example of the forecast long wave heights at the Moturoa Berth, Port Taranaki. Note the modulation of the wave heights by tide level. A 0.1m-long wave height threshold is set as the warning level for vessel surge, displayed as a dashed line on the forecast graph.

near-shore bathymetry. The MOV implementation here features a three-stage SWAN nest, with the final stage at 25m resolution (Figure 6). Wave and wind data are ingested from four discrete locations (wave buoy, two long wave gauges, one wave platform and two wind sensors). Forecast data is produced for sites along the leads as well as at the main berths and the offshore anchorages.

The LPW energy that enters Port Taranaki is strongly modulated by tide level, as can be seen in the forecast example provided in Figure 7. The tidal modulation is of particular interest; causing a near doubling of the long wave heights over a spring tide. Also provided on the LPW forecasts are thresholds for guidance. These vary slightly from port-to-port, but many years of operational experience confirms that 0.1m is the initial threshold for concern (i.e. problematic moored vessel motion and surging do not usually occur below 0.1m). Active management strategies are typically employed from 0.15m, while at 0.20m and above, safe berth conditions are likely to be compromised.

Within MOV the forecast long wave heights are compared with real-time measured values from the Moturoa berth, allowing the trends to be actively monitored. Consideration of the timing of the long wave height peak relative to the tide level is an effective management strategy at this port.

Shown on Figure 8 are the measured LPW heights along with the forecast values from the T+6-12 hour forecast horizon. During this energetic event the measured LPW heights peaked at 0.20–0.25m, while the co-temporal forecast offshore swell conditions were Hs=2.7 m with Tp=15 s. Notably, LPW events of this magnitude are clearly evident in the forecast guidance some five to seven days in advance, allowing management plans to be developed and adopted accordingly.

Port Geraldton, Western Australia

The approaches to Port Geraldton in Western Australia pass through a 3km-wide reef platform – a zone featuring significant wave transformation and long wave generation, along with bathymetric focusing of the swell and long wave energy toward the harbor entrance [4]. Tide level does not modulate LPW energy in Geraldton Harbor, and the adjacent cross-shore profile/morphology is considered by [6] to be influential on that process.

An extensive SWAN domain (resolution approximately 50m) is required to forecast wave heights from around 30m depth in to the harbor entrance. The Geraldton wave climate is

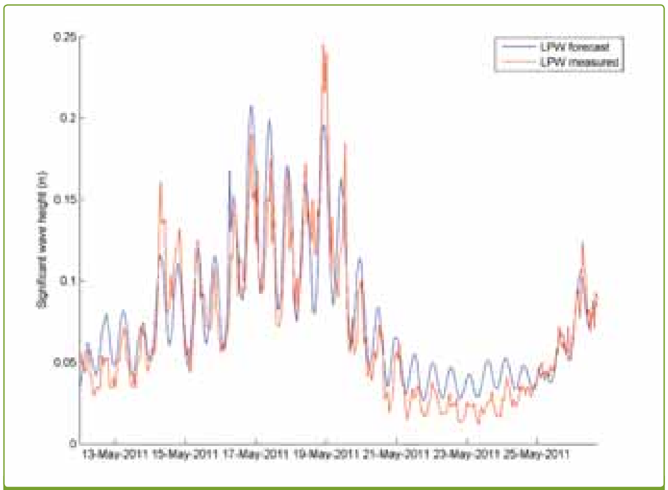

Figure 8. Comparison of the measured and forecast (T+6-12 hours) significant long wave heights at the Moturoa Berth, Port Taranaki. Data from May 2011.

affected by the offshore Abrolhos Island group, necessitating a regional SWAN nest at around 2km resolution and extending some 100km offshore. Long wave and swell wave forecasts are produced for specific berths within the harbor. As for Port Taranaki, operational thresholds have been developed for surge management of moored vessels. Evaluation of real-time LPW berth data alongside the forecast guidance provides additional confidence when adopting proactive management strategies.

Das Island Terminal, Persian Gulf

The Persian Gulf forecast domain provides 3km resolution of the wave climate, while Das Island (UAE) is smaller than that scale at 1.5 km by 3km.

To support dredging operations at the island, a high-resolution (50m) nest was established to resolve the topographic sheltering and wave refraction processes for the operational areas. Island wave climates are strongly influenced by the directionality of the prevailing weather; subtle changes in direction can have operational implications and customized modeling at the appropriate scale is an effective tool to manage this variability. Because the wave conditions in the Persian Gulf closely follow the local and regional wind developments, interpretation of the primary wave guidance (e.g. Figure 5) alongside the wind ensemble data (e.g. Figure 4) provides an effective technique to gauge the forecast uncertainly.

Port of Los Angeles, USA

A two-stage nest is deployed for the Port of Los Angeles, with the first stage extending over Southern California and capturing the offshore islands. Forecast validation within the domain is available from 28 NDBC wave and weather buoys. In this implementation, the forecast wave data (height, period and direction) plus the wind speed and direction data are supplied as ESRI GIS layers at six-hourly increments over the seven-day forecast horizon. An example is shown for a Google Earth export in Figure 9.

Summary

The MetOceanView System (MOV) provides marine managers and operational personnel with site-specific data and forecast information. The system architecture uses the latest ocean and

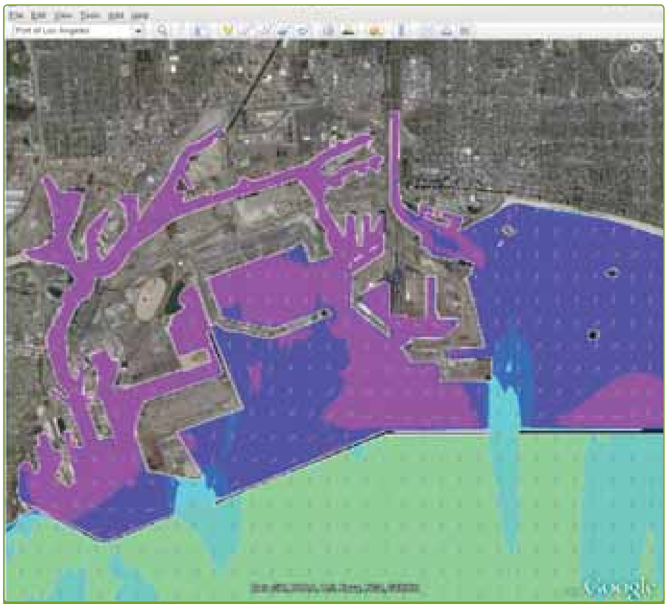

Figure 9. All MOV forecast data products are available as industry-standard GIS layers. Shown above is wave height and direction at the Port of Los Angeles; projected here using Google Earth.

atmospheric forecast models, customized at the most appropriate scale for a port or harbor situation.

The transformation of waves along the shipping approaches and into the entrance region is captured, along with the coastal currents, water levels and winds. With data for calibration, long wave surging at the berths can also be predicted with good accuracy. Integration of real-time measured waves, long waves and winds into MOV allows the forecast accuracy and short range weather trends to be monitored.

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ABOUT THE COMPANY

MetOcean Solutions Ltd (MSL) is a provider of high quality environmental data and analysis for coastal, ports and offshore engineering projects throughout Australia, New Zealand, Asia Pacific and the Middle East. As a science-based consultancy, MSL assists clients and project teams by providing the environmental information needed to make good decisions and maximize operational efficiencies.

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