Marine weather forecasting and monitoring at the Port of Sydney and Botany Bay, NSW, Australia

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Abstract
With the increasing number of cargo and cruise ships visiting the ports of Sydney and Botany Bay, the New South Wales Port Authority (NSWPA) recognised a need to increase the capacity for marine weather guidance to ensure safe and efficient operability. The service designed for NSWPA includes high resolution atmospheric and oceanographic forecast solutions, probabilistic model data derivations, real-time weather monitoring and a suite of decision-making tools. All this is delivered from a web platform so the information is readily accessible and fully transparent across their organisation. The focus of the service is to improve the vessel transit safety and cargo transfer efficiency, along with the ability to impose berth risk controls. While the development was customised for the NWSPA, the core infrastructure behind the service leverages more than a decade of R&D into weather intelligence for ports and the marine industry.

Keywords: port safety, custom marine forecast

1. Introduction
Like many harbours around the world, the ports of Sydney and Botany Bay experience occasions when energetic weather conditions can give rise to problematic operational issues. Examples include safe under-keel clearance during entrance or exit transits, agitation at the berths due to swell penetration or long period wave surge, and high winds influencing vessel management and loading operations. Other activities, such as dredging, survey or construction typically require low energy conditions for safe execution. Being respectively Australia's second busiest container facility and premier cruise ship destination, Botany Bay and Port Jackson also present a high level of responsibility for the New South Wales Port Authority (NSWPA) to ensure the safety of the passengers, crews, environment and assets.

Effective planning for all weather-sensitive port operations requires reliable quantification of the site-specific weather conditions over both the short range (24 hour) and medium range (5-7 days) forecast horizons. To meet this need, an atmospheric and marine forecast system was configured to allow access to high-resolution site-specific information for more effective management of the harbour weather conditions.

The core system architecture is founded on modern high-resolution ocean and atmospheric models, customised at appropriate scales for the actual port or harbour location as well as the shipping approaches. The system is called MetOceanView [1] (MOV), visible in Figure 10.

The numerical models allow the detailed transformation of wave spectra from offshore and into the entrance regions – including the effects of coastal currents and water levels, where appropriate, and the wind field as modified by the local topography. Ingestion of real-time measured wave, current, water level and wind data into MOV allows the forecast accuracy and trends to be co-plotted and therefore assessed on a daily basis. The primary forecast configurations also assimilate observed data where possible to improve the short-range forecasts.

2. Forecast system overview
The forecast system starts at a global scale and then uses a variety of techniques to resolve the important weather data right down to the locations of interest.

2.1 Global scale model
An in-house global WaveWatch3 (WW3) domain is run 4 times per day at 0.5° resolution using wind fields from NCEP's Global Forecast System (GFS) as well as those from the ECMWF (European Centre for Medium-Range Weather Forecasts) twice per day. Remote-sensed wave data are assimilated into each cycle, and full 2D spectral boundaries are generated for nested regional domains with WaveWatch3 (WW3) or SWAN (Simulating WAves Nearshore) [2].

2.2 Regional and local scale models
Local wave and wind models were established within the various global domains to appropriately downscale the weather for port operations. A Weather Research and Forecasting (WRF) atmospheric domain was configured at 0.07° resolution, generating realistic wind fields for the Sydney region including coastal areas. These winds are used within a series of multi-nested SWAN wave domains at 0.02° and 0.001° resolution, as shown in Figure 1. This nesting technique - selecting and controlling the best boundary conditions and using the latest bathymetry data - allows the optimal forecast solutions to be found and updated as necessary.

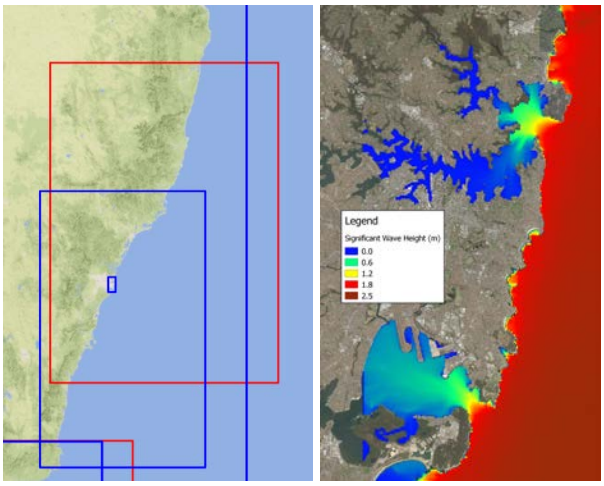

Figure 1 Overview (left) of the wind and wave models over the Sydney region and example of SWAN model output (right). The red box shows the WRF wind domain while the blue boxes represent the extent of the nested SWAN wave models.

2.3 Probabilistic wind forecasting

Increasingly port authorities are seeking to standardise weather-sensitive operations and make use of decision making tools that are tailored to specific thresholds. An addition to the high resolution wind forecasts is an enhanced Probability Distribution (ePD) system that produces Probability of Exceedance (POE) forecasts. For NSWPA these specialist guidance products have been customised to alert the operational team to the likelihood of wind events which exceed 15, 25 and 35 knot values, which represents key thresholds for decision makers. An example POE forecast is shown in Figure 2.

Over 80 individual NWP (Numerical Weather Prediction) forecasts as well as current observational data are fed into the ePD system. Each source is examined for how much information it brings to the forecast situation. The ePD system examines current and past contributions of each information source on a daily basis, and reassigns relative importance accordingly. The ePD system does not assume each information source is equal. The end result is a flow-dependent (including wind direction) probability density function from which a significantly improved forecast can be derived.

The ePD system currently imports model data from: GFS, GFS Ensemble, ECMWF, ECMWF Ensemble, BoM's (Bureau of Meteorology) OCF (Operational Consensus Forecasts) forecast data, BoM's Access model data, MW's (MetraWeather) own mesoscale models (MM5 and WRF) and the Canadian CMC (Canadian Meteorological Center) and CMC Ensemble models. Figure 3 shows a high wind event showing forecast agreement with observations.

Date/Time*		Wind Speed (10-minute mean)**	Prob > 15kt	Prob > 25kt	Prob > 35kt
Sun 26/4/2015	Morning	22	98%	15%	0%
Sun 26/4/2015	Afternoon	29	100%	91%	1%
Sun 26/4/2015	Evening	23	100%	28%	0%
Sun 26/4/2015	Night	15	51%	0%	0%
Mon 27/4/2015	Morning	16	86%	0%	0%
Mon 27/4/2015	Afternoon	16	73%	0%	0%
Mon 27/4/2015	Evening	14	20%	0%	0%
Mon 27/4/2015	Night	13	4%	0%	0%

*	Morning	Afternoon	Evening	Night
AEST	04:00 - 10:00	10:00 - 16:00	16:00 - 22:00	22:00 - 04:00
AEDT	05:00 - 11:00	11:00 - 17:00	17:00 - 23:00	23:00 - 05:00
UTC	18:00 - 00:00	00:00 - 06:00	06:00 - 12:00	12:00 - 18:00

Figure 2 Sample email POE alert issued to operational staff, showing the risk of selected wind speed thresholds being exceeded within the next 48 hours. In this case the alert is colour coded to highlight when these thresholds are exceeded in 6-hourly windows. These alerts can be configured to send only when triggered, or with each model run as desired.

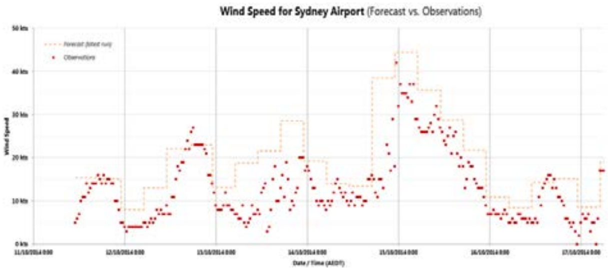

Figure 3 Forecast verification for wind speed at Sydney Airport. Red dots depict observed 10 minute mean wind speed, while the orange dashed line represents the 6-hourly forecast. In this example, the forecast run plotted is the latest for each timestep.

2.4 Validation

Once operational, data from within the nested domains are directly compared with real-time wind and wave measurements, and ongoing model adjustments are applied as necessary. Forecast accuracy and short term weather trends are assessed at any time. Given the extensive network of instruments (wind sensors and wave buoys) across both harbours, a very detailed validation process was possible. Notably, most other port environments do not have such a rich density of quality information, and the availability allows increased confidence in the model outcome and also a better representation of the actual physical processes

All site-specific forecast data received by MOV are archived. This allows forecast accuracy analysis to be post-processed; determining the statistical measures of accuracy at forecast horizons up to 7 days ahead. Intensive verification of the probabilistic wind forecast was performed for specific high wind events, guiding further statistical tuning.

3. Data access and delivery

The MOV web platform is available 24/7 via personalised account logins.

3.1 Forecasting guidance

The forecast guidance is primarily provided in the form of scalable map overlays of multiple variables including: wave height/direction/period, wind speed/direction, surface current, air/sea temperature, visibility, thunderstorm risk and storm surge. A total of 21 site-specific marine and atmospheric forecast locations (Figure 4) were set in order to cover the wide range of conditions both ports may experience. At these sites, the NSWPA access marine or atmospheric forecast graphs (Figure 5) along with wave spectra (Figure 6), nowcast history, user-defined hazard alerts and tidal predictions. Many of these locations also include real-time monitoring instruments.

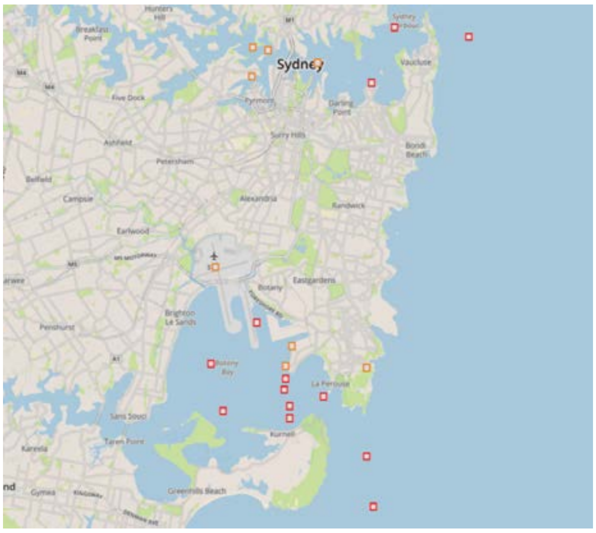

Figure 4 Representation of marine and atmospheric site-specific forecast locations in the Port of Sydney and Botany Bay. These sites were chosen with a collaborative approach to best represent the local weather patterns and navigational channels.

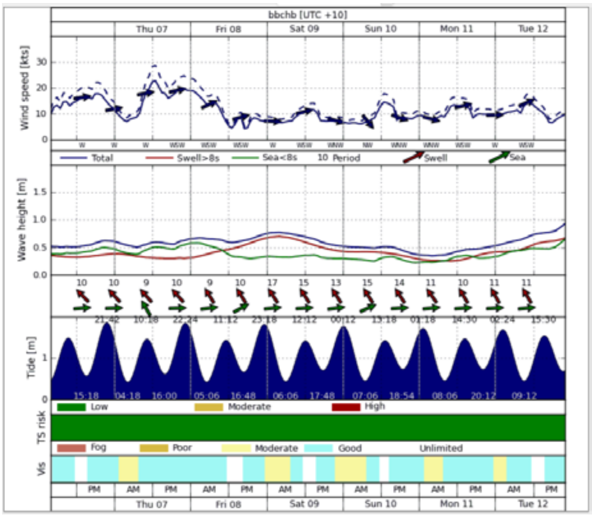

Figure 5 An example of site-specific marine forecast graph. Available for automatic email delivery, this page provides 7-day forecast guidance including wind speed, wave height, tide elevation and visibility.

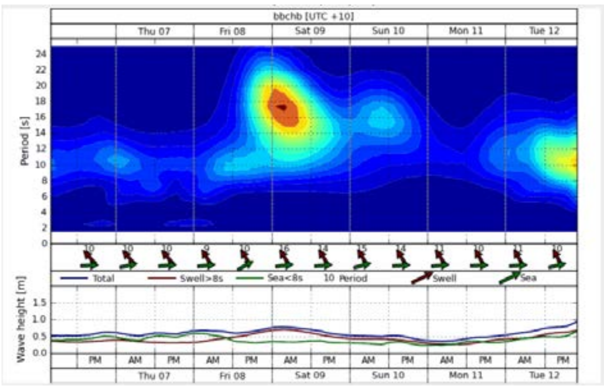

Figure 6 An example of wave spectra at the offshore location. This graph shows the colour-coded sea/swell energy for the upcoming week. The vertical axis represents the significant period. This type of forecast has proven useful in anticipating potential longwave events and getting a clear idea of the sea state to come.

3.2 Real-time monitoring

Ingesting, storing and displaying the NSWPA's extensive instrument network data was customised for their MOV account. This included 2 directional and 5 non-directional wave buoys, 2 tide gauges, 2 current meters, along with 9 wind sensors plus the BoM weather stations. All data can be viewed from MOV (Figure 7). Using mouse hover displays, the marine operations management is able to either get a quick glimpse of the current weather conditions or compare the forecast data alongside the observation feed to judge the quality of the guidance provided.

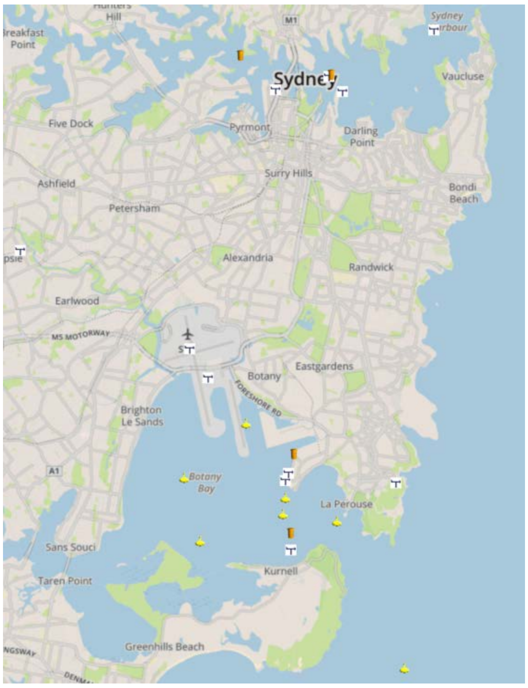

Figure 7 Representation of instrument locations in the Port of Sydney and Botany Bay. An array of wave buoys, wind sensors, current meters and tide gauges are continuously interfaced with MetOceanView to provide a real-time monitoring platform for the Marine Operations Management.

4. Further developments

4.1 Realtime lightning detection

MW has partnered with GPATS (Global Positioning and Tracking Systems), Australia's national lightning detection network provider, to provide realtime lightning detection & alerting to customers. The Australia-wide network of GPATS lightning sensors currently reports lightning detection efficiencies >90% for Australia and surrounding waters (Figure 8).

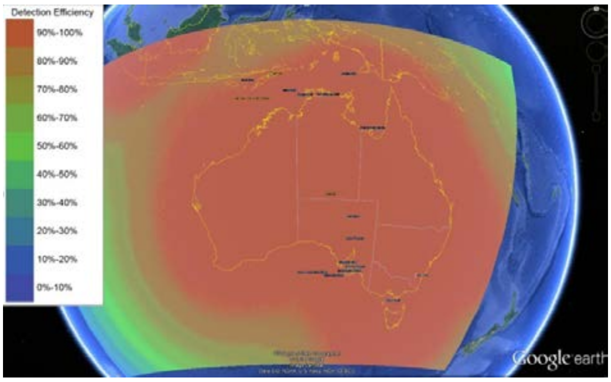

Figure 8 Australian Detection Efficiency (DE) map using 25kA as minimum strike intensity. GPATS offers DE in excess of 90% over all of continental Australia.

4.2 StrikeCast lightning forecasts & alerting

StrikeCast utilises the GPATS sensor network to facilitate a shift from reactive (realtime) into planning (forecast) mode. This is particularly prudent for storms with rapid development or movement. StrikeCast utilises updates every 10 minutes with accurate 1 hour forecasts of lightning risk (Figure 9), which are displayed using a map interface. This tool allows users to be better informed and accountable when storms are in the vicinity of their assets, and can be incorporated into Trigger Action Response Plans by adding alert radii. Users have reported increased work efficiency through reduced downtime and reduced false alarms.

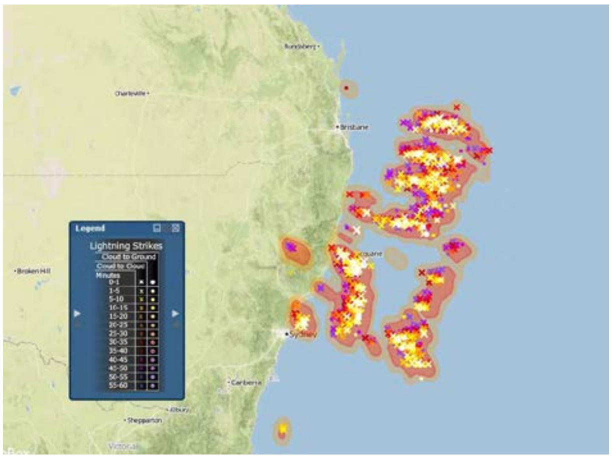

Figure 9 Latest lightning strikes and one hour forecast from the StrikeCast interface. Recent strikes are colour-coded by age (purple = oldest, white = most recent). Latest one hour forecast shows areas where lightning is near-certain (red) and likely (orange).

5. Summary

MetOcean Solutions Ltd and MetraWeather have collaborated with the New South Wales Port Authority to design a bespoke marine and atmospheric weather forecasting platform. Emphasis was put on integrating the NSWPA's wide range of instruments for real-time weather monitoring and model adjustment. Combined with the safety and operation optimizing tools available in MetOceanView, a comprehensive weather forecasting solution was created that allows the marine operations management to make informed decisions around weather reliant activities.

6. References

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[2] Holthuijsen, L. (2007). Waves in Oceanic and Coastal Waters. Cambridge University Press. ISBN 0521860288, 9780521860284.

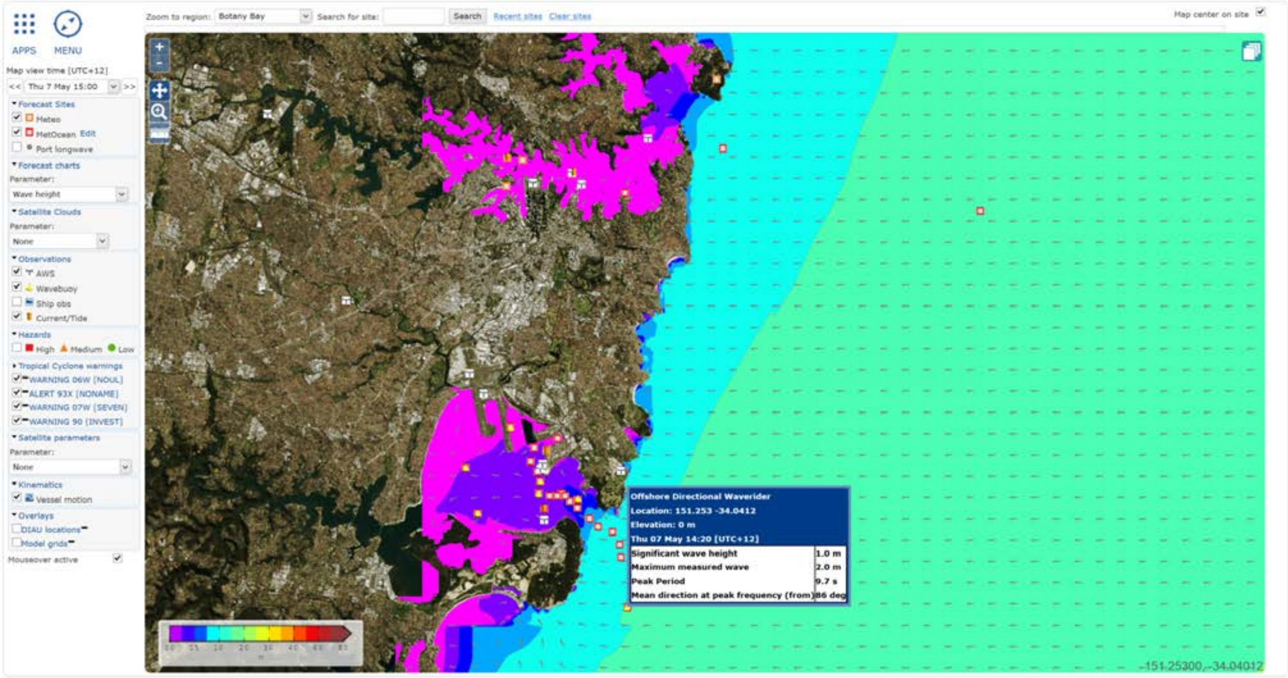

Figure 10 MetOceanView forecast page. This view shows the multiple site-specific forecast locations, real-time observation instruments and forecast map (significant wave height in this example). This interface is used by the Marine Operations Management to monitor marine forecasts for the Port of Sydney and Botany Bay.