Applications for metocean forecast data - maritime transport, safety and pollution

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Abstract. This lecture outlines the recent advances in the incorporation of oceanic and atmospheric forecast datasets into specialized trajectory models. These models are used for maritime safety purposes and to aid in combating oil and chemical marine pollution events. In particular, the lecture examines in detail the system assembled by the authors for improving oil spill trajectory models (OSTM) and chemical spill trajectory models (CSTM) as part of the Australian Maritime Safety Authority's (AMSA) role in Australia's national plan to combat pollution of the sea by oil and other noxious and hazardous substances. The main topics of this lecture will include:

- A summary of metocean forecast datasets currently being used operationally in the Australian region
- The incorporation of tidal current dynamics into ocean forecasting models.
- Three case studies of utilising metocean forecast datasets in maritime trajectory models, a study of the Australian Maritime Safety Authority's OSTM and CSTM systems (OILMAP, CHEMMAP and the Environmental Data Servers).
    1. The Pacific Adventurer oil and chemical Spill, offshore Brisbane (QLD)
    2. The Montara Well Head Platform Blowout, Timor Sea (WA)
    3. The towing of MSC Lugano off Esperence (WA)

1. Introduction

The operational use of metocean (meteorological and oceanic) forecast datasets is necessary for the effective response to search and rescue (SAR) incidents, mitigation of pollutant spills at sea (such as oil or chemicals), and for the response to other maritime hazards (such as towing a stranded vessel to safety). To effectively model the likely drift pattern of a person lost at sea, the movement of a marine pollutant spill, or a stranded vessel's movements, both wind and ocean current forecast datasets are required.

Among the ocean current forecast models in use operationally in the Australian and greater Asia Pacific region are the US Navy Coastal Ocean Model (NCOM) and the Australian BLUElink model. Both of these models were developed for large to mesoscale ocean circulation, and as such neither model includes the effects of tidal currents. This lack of tidal current forcing limits the effectiveness of the models in shallow near coastal waters, where tidal currents are important and can be the dominant driving force in water circulation. Asia-Pacific ASA have developed an aggregation tool which is able to incorporate the effects of both coastal tidal currents and large scale oceanic currents, producing an effective current forecast dataset for both open ocean and coastal waters alike.

There are several wind forecast models available operationally; the two used in this study were the US Global Forecast System (GFS) and the US Navy Operational Global Atmospheric Prediction System (NOGAPS).

Asia-Pacific ASA has a dedicated environmental data server (EDS) called COASTMAP EDS. This server downloads, catalogues, stores and disseminates environmental and metocean forecast and hindcast datasets for use with ASA modelling software (such as SARMAP, OILMAP and CHEMMAP). Table 1 below outlines the specifics of each of the metocean forecast models operationally available for the Australian region on the EDS.

Table 1. Operational metocean forecast models.

Model	Type	Temporal Resolution	Spatial Resolution	Spatial Extent	Update Frequency	Forecast Length
NCOM	Currents	6 hrs	1/8°	Global	daily	72 hrs
BLUElink	Currents	24 hrs	1/10° -< 2°	Effectively (90°E-180°E, 75°S -16°N)	2 x weekly	144 hrs
GFS	Winds	6 hrs	1/2°	Global	4 x daily	180 hrs
NOGAPS	Winds	6 hrs	1/2°	Global	4 x daily	144 hrs

The availability of several different forecast models provides an excellent opportunity to compare the various model outcomes of a particular drift scenario. If the outcomes are similar, then there is consensus between the datasets, and the modeller can be confident that the forecast is as accurate as possible. If there is a discrepancy between the forecasts, then there is no consensus, which suggests that the forecast may not be as reliable. In such a situation it is necessary for the modeller to further revise the input data based on field observations to ascertain which may be the most reliable forecast.

Operational consensus forecasting has been used successfully in meteorology; however its application in oceanographic forecasting has been minimal thus far. This however is changing, and the adoption of consensus forecasting in the oceanographic community is increasing. Several case studies of the operational use of consensus forecasting are outlined in the following sections. The first relates to the Pacific Adventurer oil spill which occurred off Moreton Island, Queensland; the second was the Montara oil well blow out which occurred on the North West Shelf, Western Australia, and the final was the towing of the MSC Lugano off Esperance in Western Australia (see Figure 1).

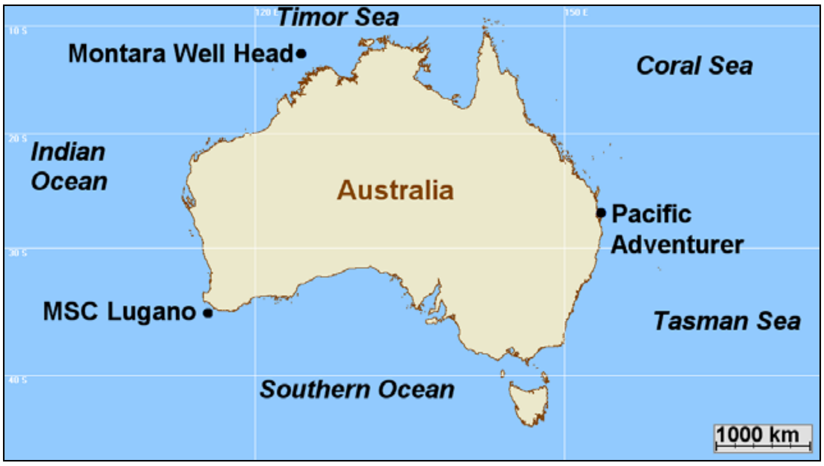

Figure 1. Map showing the location of the incidents, Pacific Adventurer oil and chemical spills, Montara well head blowout, and MSC Lugano towing.

2. Review of meteorological and ocean forecast models

2.1. BLUElink Ocean Model

The BLUElink project became operational in 2007 from the collaboration between the Australian Bureau of Meteorology (BoM), Royal Australian Navy (RAN) and the Commonwealth Scientific Industry Research Organisation (CSIRO). Operationally, it is now under the management of the Australian Bureau of Meteorology. There are several components to the BLUElink system, including operational forecasts, reanalysis and data assimilation. The operational forecasts from BLUElink used in this study were derived from the Ocean Model Analysis and Prediction System (OMAPS-fc). This system uses the Ocean Forecasting Australia Model (OFAM) which is based on the Modular Ocean Model version 4 (MOM4) [1]. The 3D model has a resolution of 1/10° (~ 10 km) in the Australian region (90°E – 180°E, 75°S – 16°N), with up to 2° resolution elsewhere around the globe, to reduce computational costs. There are 47 vertical layers, with the topmost 20 layers being 10m thick. [2] Data assimilation is controlled by the BLUElink Ocean Data Assimilation System (BODAS) which is an ensemble optimal interpolation (EnOI) scheme that assimilates Sea Surface Temperature (SST), Sea Surface Height (SSH) and temperature and salinity profiles. Atmospheric fluxes are currently provided by the BoM Global Atmospheric Prediction System (GASP) [3]. The BLUElink system provides up to 144 hour forecasts of the sea surface current velocities, at 24 hour intervals.

2.2. NCOM Ocean Model

The Navy Coastal Ocean Model (NCOM) is a 3D global ocean current forecast model which was developed by the Naval Research Laboratory (NRL) and was transitioned to be run operationally by the Naval Oceanographic Office (NAVO). The forecast model is based on the Princeton Ocean Model (POM) and has global coverage with a horizontal resolution of 1/8°. Vertical resolution is controlled by an σ-z coordinate system with 19 σ-coordinate layers in the upper 137m (topmost surface layer thickness of 1m) and 21 z-coordinate layers from 137m to 5500m. Data assimilation is controlled by the Modular Ocean Data Assimilation System (MODAS) which assimilates temperature, salinity and SSH. Atmospheric forcing is provided by the Navy Operational Global Atmospheric Prediction System (NOGAPS) atmospheric fluxes [4]. NCOM provides a 72 hour forecast of the sea surface current velocities, at 6 hour intervals.

2.3. GFS Atmospheric Model

The Global Forecasting System (GFS) is a global spectral numerical model operationally run by the US National Oceanic and Atmospheric Administration (NOAA). The T254 version (used in this study) provides global coverage with a horizontal resolution of 1/2° with 64 unequally spaced vertical layers. GFS model output consists of 10 metre U and V wind velocities with a forecast length of up to180 hours and a temporal resolution of 6 hours [5].

2.4. NOGAPS Atmospheric Model

The Navy Operational Global Atmospheric Prediction System (NOGAPS) is a spectral general circulation model (GCM) which has been under constant development at the NRL over the last 20 years. It is the principal source of atmospheric forcing for the US Navy ocean models (eg. NCOM) and short term numerical weather prediction (NWP). NOGAPS uses a one way coupling system to capture ocean – atmosphere interaction. NOGAPS has global coverage, with horizontal resolution ~ 1/2°. The forecast length of the NOGAPS product is 144 hours with temporal resolution of twelve hours (at 00 and 12 UTC) and updates at 06 and 18UTC to enable background forecasts, which are used in the analysis. Outputs from the model include momentum flux, both latent and sensible heat fluxes, precipitation, solar and long wave radiation and surface pressure, as well as 10 metre U and V wind velocities [6,7].

3. Case studies of the operational use of meteorological and ocean forecast datasets

Three case studies involving the operational use of metocean datasets were investigated. Two were in response to pollutant spills, the first was the Montara well head blowout in Western Australia, and the second was the Pacific Adventurer oil and chemical spills off Moreton Island in Queensland whilst the third case study presented herein was the towing support of the disabled MSC Lugano off Esperance in Western Australia. The two oil spill studies demonstrate how consensus modelling has been used operationally, and show when consensus was reached, and when it was not.

3.1. Case Study 1 – Pacific Adventurer

In the early hours of the morning on the 11th of March 2009 the Pacific Adventurer encountered severe weather conditions (as a result of nearby Tropical Cyclone Hamish) whilst on route from Newcastle to Indonesia. As a result of the severe weather conditions, 31 shipping containers (containing a total of approximately 600 tonnes of ammonium nitrate) were lost overboard. Several of the containers ruptured the ship’s fuel tanks, which resulted in the loss of 270 tonnes of heavy fuel oil to the marine environment [8]. At the request of the Australian maritime Safety Authority (AMSA), Asia-Pacific ASA provided modelling support to the response teams to determine the likely fates and possible shoreline strikes of the heavy fuel oil (HFO) and the dissolved concentrations of the ammonium nitrate in the water column.

3.1.1. Oil spill forecast

Panels in Figure 2 show the various model runs completed using OILMAP to determine the likely trajectory of the HFO. Environmental forecast data was sourced from the COASTMAP EDS. Specifically NCOM and BLUElink forecast ocean currents aggregated with tidal currents provided the current forcing, whilst GFS and NOGAPS wind forecast models provided wind forcing. To account for variability in the inputs (such as wind gusts) uncertainty particles are included in the model runs. These uncertainty particles are subjected to winds and water currents that have been varied by up to ±30% of their strength and ±30° in direction.

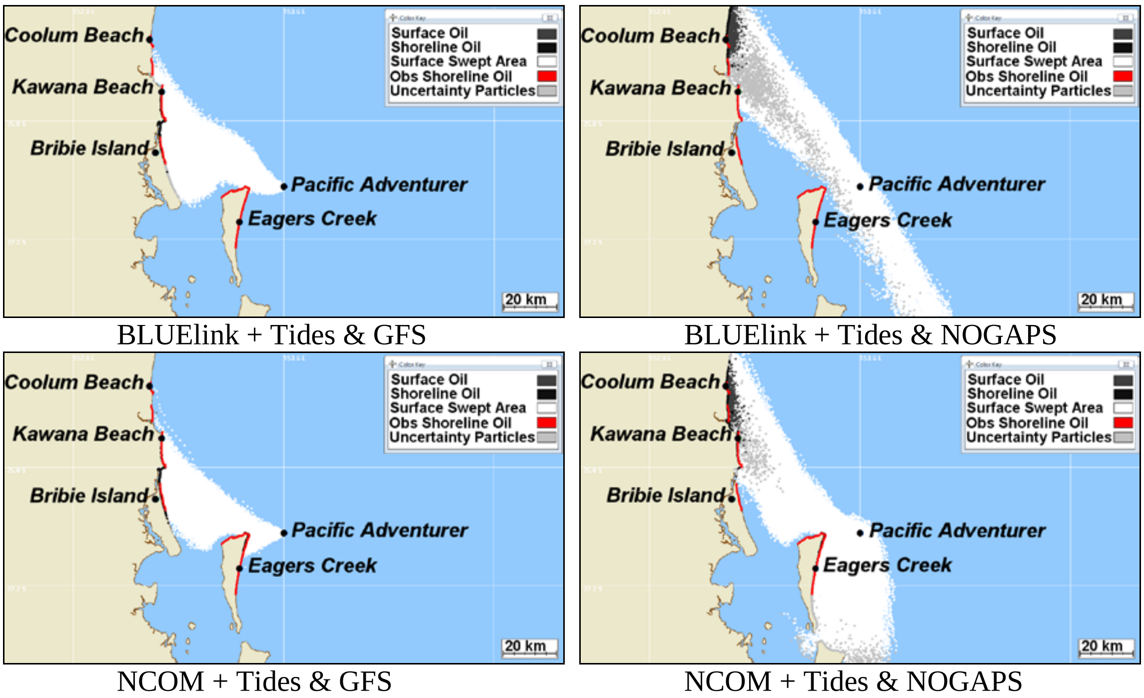

Figure 2. The four different model runs completed when forecasting the Pacific Adventurer spill. Top BLUElink plus Tides, Bottom NCOM plus Tides, Left GFS winds, Right NOGAPS winds.

The black dots represent the likely surface oil locations, the white dots represent the water surface swept by the oil, the light grey represents the uncertainty particles used by the model, and the red indicates the full extents of the shoreline oil stranding, as reported by Maritime Safety Queensland.

As shown, there is a general consensus between the model forecasts. All four model forecasts show that the shorelines on the northern end of Moreton Island and the beaches near Kawana will be impacted, with the possibility of shoreline impacts to the beaches both north and south of the Kawana Beach region. The best correlation between the model predicted shoreline impacts and observed shoreline impacts was attained by using NCOM predicted currents aggregated with tidal currents, and the GFS forecast winds (bottom left panel of Figure 2).

3.1.2. Chemical spill forecast

The simulation of a mass release of the entire contents of all overboard containers was completed using the CHEMMAP software. This was indicative of a worst case scenario where all 31 of the lost containers would rupture expelling ammonium nitrate over a period of 4 hours after hitting the seabed. NCOM plus tides and GFS winds were used as the forcing data for the CHEMMAP model run. The CHEMMAP system predicted that a release of 600 tonnes of ammonium nitrate would quickly dissolve in the water column.

The results are shown below in Figure 3, which describes the re-projected location of the reported incident and the projected path of the simulated ammonium nitrate spill over 96 hours. The key indicates the dissolved concentration of the chemical in the water column in milligrams per cubic meter, from the surface to depths divided into five layers. The concentrations of ammonium nitrate within the water column fell to 1 mg/L (1,000 mg/m^3) within 4 days following the event. Due to the near seabed release, dissolved concentrations remain near the bottom well away from the surface where they might enter Moreton Bay.

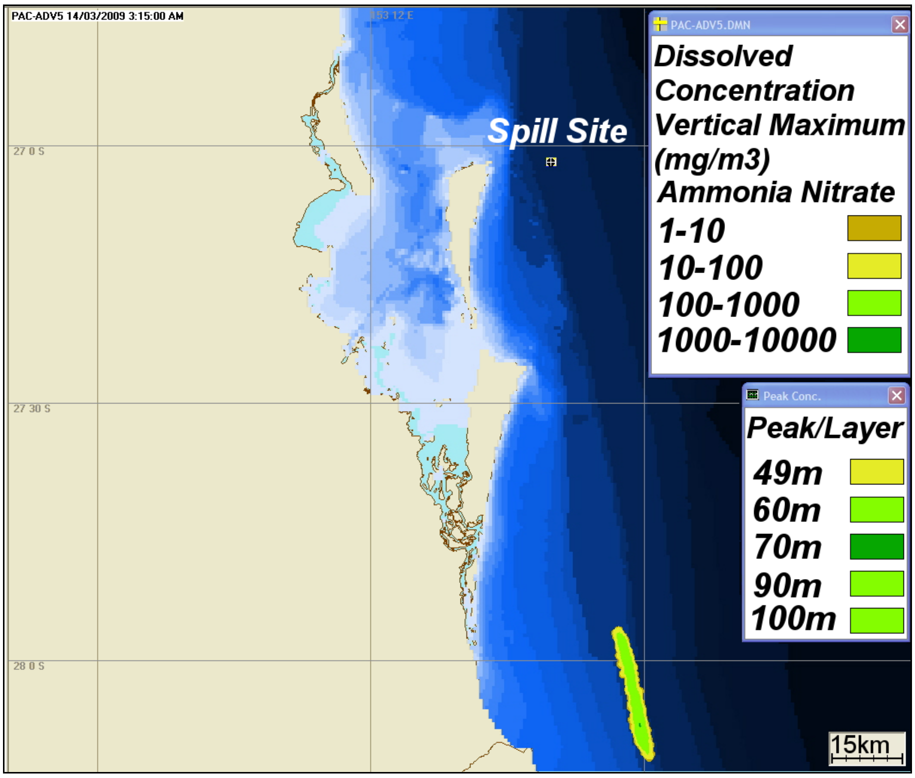

Figure 3. Pacific Adventurer chemical spill showing concentration and location of dissolved ammonium nitrate 96 hours after release

3.2. Case Study 2 – Montara Well Head Blowout

During the morning of 21st of August 2009, well control at the Montara well head was lost. The Montara well head is located approximately 680 km west of Darwin off the Kimberly coast in Western Australia. An estimate of 400 barrels per day of crude oil was being discharged into the sea. The leak continued for 74 days discharging a total of 30,000 barrels until the well was successfully "killed" on the 3rd November 2009 [9].

Asia-Pacific ASA provided modelling support throughout this incident. At the beginning there was no consensus between the forecast models, with a different direction of travel predicted for the NCOM plus tidal currents, the BLUElink plus tidal current forecast data, and the GSLA plus tidal current data.

The GSLA currents are generated from mapping Gridded Sea Level Anomalies, which provide geostrophic flow estimates. This approach gives a good representation of the general circulation of the ocean, however as the produced current field uses measurements of sea level anomalies that can be up to several days old, it essentially produces a nowcast of the sea state, rather than a forecast. This can work well for large scale circulation which takes time to set up, and has time scales of the order of weeks to months; however GSLA currents are not able to reproduce meso to small scale circulation which have time scales of hours to days [10]. GSLA currents do however provide a good reference to validate forecast model (NCOM and BLUElink) performance at recreating the oceanic circulation.

Two surface drifters were deployed to provide observed estimates of the currents. These revealed that the currents were tidally governed (as shown by the oscillations in the buoy trajectories). This indicates that for successful prediction of drift patterns of objects or oil in this region, the addition of the tidal component to the surface currents is vitally important.

As the incident continued, the forecast datasets proved to better resolve the surface currents in the region when compared to several other drifter tracks, the location of predicted surface oil and observed surface oil, and when directly comparing the NCOM and BLUElink forecast current vectors with hindcast currents. Of the 13 weeks that the oil was tracked, approximately 10 weeks returned very good current forecast data.

Each dataset (NCOM, BLUElink and GSLA) was tested against the over flight and satellite imagery to ensure the best forecasts were produced. Table 2 below shows the periods throughout the 92 days of the incident (from 21st August 2009 until 23rd November 2009) for which dataset was found to produce the most accurate forecast of oil movement.

Table 2. Metocean forecast products used during the Montara well head blowout for oil spill forecast modelling

Start	End	Days	Wind	Current
21/08/2009	30/10/2009	10	GFS	GLSA+Tides
30/08/2009	27/10/2009	57	GFS	BLUElink+Tides
27/10/2009	06/11/2009	10	GFS	NCOM+Tides
06/11/2009	11/11/2009	5	GFS	GSLA+Tides
11/11/2009	23/11/2009	12	GFS	BLUElink+Tides

Forecast bulletins were produced routinely throughout the Montara event by APASA to outline the expected operational conditions, and likely whereabouts of oil. Refer to Appendix A for the reproduction of one of these forecast bulletins (for 29th October 2009).

3.3. Case Study 3 – MSC Lugano Stranding.

The MSC Lugano is a 240m container ship which was en route from Adelaide in South Australia to Fremantle in Western Australia. On the 31st of March 2008 it was disabled by an engine room fire and as a result, was in jeopardy of grounding off Esperance, Western Australia.

Three tugs from nearby Esperance were called in to provide assistance, whilst another larger and better equipped tug was en route from Fremantle. The tugs took the MSC Lugano in tow however they were not designed or equipped for deep ocean towing and ran into difficulty off Pt D'Entrecastreux whilst on a passage northward to Fremantle. The vessels were not making any headway due to very high surface current speeds and were at risk of losing the tow [11].

The Western Australian authorities advised the vessels to proceed further offshore into deeper water in an attempt to avoid the high current speeds and coastal hazards. However consensus ocean current forecast data (NCOM and BLUElink) indicated stronger currents offshore when compared to inshore. Upon further inspection of the forecast currents it was deemed that the tow remain closer to the shore in the more favorable current conditions. The tow was successfully completed on the 13th of April 2008. Figure 4 below shows a snap shot of the surface currents in the region at the time of the towing. Note the stronger southerly currents offshore of Cape Leeuwin, compared to the currents closer inshore to Cape Leeuwin.

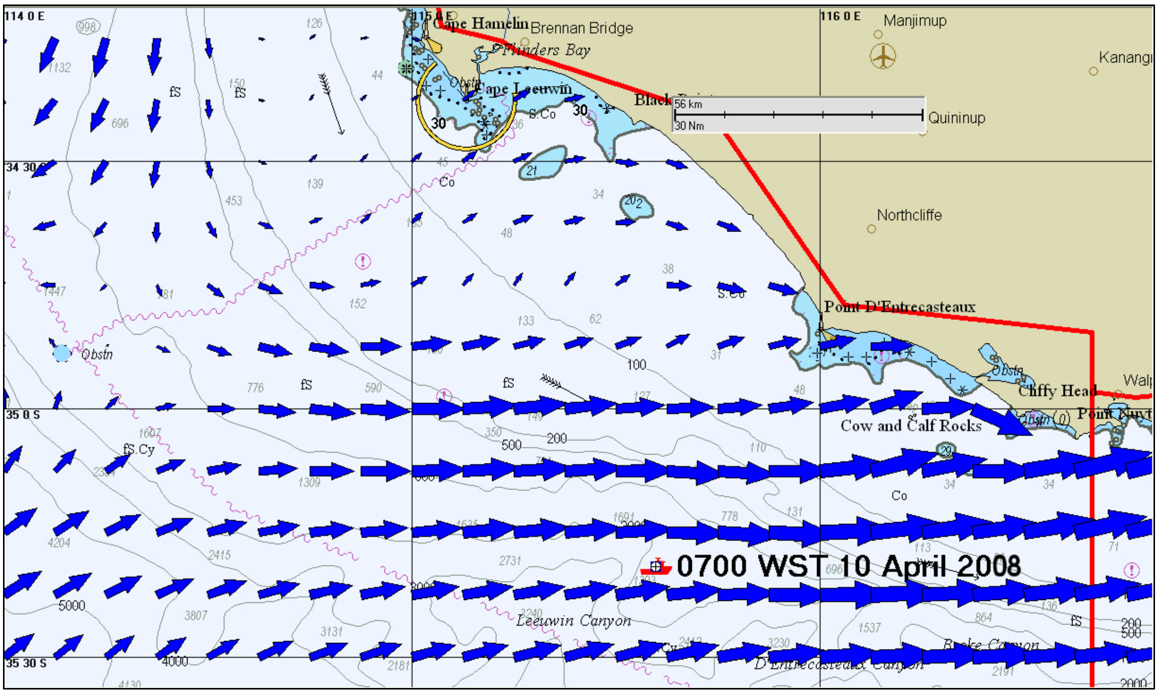

Figure 4. Snap shot of surface currents off Esperance Western Australia.

4. Conclusions

The growing view is that oceanographers should follow the best-practice methodology used by weather forecasters to take full advantage of the multiple wind and ocean forecasting datasets available. This is made particularly evident through the three case studies investigated above. Weather forecasters use all available datasets and assess each of them to develop a consensus of opinion from the various weather forecast models on what might occur. With multiple ocean forecasting datasets available now, the same approach can be applied, for example oil spill models rely on good forecasts of both currents and weather to accurately predict the oil's future drift and potential impact zones.

Both winds and currents are used as input data to ASA's OILMAP and CHEMMAP spill models and have been able to successfully predict the movement of oil or chemicals over time if the forecast winds and currents have been accurate.

The latest approach is to run the same spill scenario with different datasets. When consensus between forecast models is reached, the outcome gives a higher level of confidence in the spill predictions. If different forecast datasets result in disparate trajectories and outcomes, then there are multiple viable outcomes, and a low level of confidence in any one prediction. The spill forecasts can then be issued with a confidence indicator, based on the degree of consensus obtained from the multiple analyses performed. Field observations such as aircraft over flights, drifting buoys, or satellite-derived observations can all be used to help estimate errors in the forecast data.

One such reason for not attaining consensus between forecast models is the location or positioning of mesoscale eddies. Mesoscale eddies have spatial extents in the order of tens of kilometers, where large scale eddies tend to have a spatial extent of greater than 100km. As the two aforementioned global current forecast models (NCOM and BLUElink) have spatial resolutions of approximately 10 km, they are essentially semi–mesoscale eddy resolving models. To adequately resolve mesoscale eddies, a resolution in the order of 5-6km at a minimum is required. Problems arise with semi-mesoscale eddy resolving models when eddies are misplaced or even absent completely.

Acknowledgements

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Appendix A

SPILL FORECAST BULLETIN FOR MONTARA INCIDENT
ISSUED MIDDAY 29-OCTOBER-2009
FOR THE AUSTRALIAN MARITIME SAFETY AUTHORITY

Over flight and satellite observations collected from the 24th – 28th October 2009 have been used to update oil, oil patches and wax positions within the AMSA OILMAP Oil Spill Trajectory Model (OSTM). The recent satellite observations indicated that the slick was patches of oil/wax lying east and southeast of Montara extending to the south as patches (refer to Figure 5). The winds have remained favourable over recent days which has seen the edge of the slick move parallel to the coast north-eastward rather than towards to coast. Using these observations, the latest wind and ocean forecast data has been incorporated to provide "search areas for oil and wax" for midday (Darwin Time) on the 30th and 31st of October 2009, as shown in Figures 6 and 7 below. Please note that the brown dots in the figures below indicate "search areas for oil and sheen". The density of the brown dots in the figure below indicates the likelihood of finding oil or wax in the various locations around the Montara well site. Due to the containment and dispersant operations, far field predictions are typically for defining search areas for scattered weathered oil and wax patches which may no longer be visible on the water's surface, hence this forecast is potentially a 'worst-case' depiction of the spill at this time.

The wind conditions for Montara are expected to be north-westerly winds (4-12 kts) for 30th October 2009, weakening from the north for 31st October, 2009. At the Montara well site, tidal oscillations are expected to be weak as we move through the neap tidal phase in the Timor Sea. The slick will generally drift southward over the forecast period. Fresh oil flows at Montara are predicted to be as follows:

- *30th Oct 2009: Weak SSE flow at 9am; Weak SSW flow at 3pm (4-12 knot NW winds);*
- *31st Oct 2009: Weak SSW flow at 9am; Weak NW flow at 3pm (weak northerly winds);*

To the far north in deep waters (The Timor Trench), the Indonesian Thru Flow current continues to flow strongly WSW. This strong flow is now spinning anticlockwise current eddies along the northern shelf-break which are moving position, allowing deepwater flows to spill over the shelf and drive the slick around Montara generally southward over the forecast period.

At Ashmore, Hibernia and Cartier Reefs, the forecast indicates that previously reported small patches of weathered wax will remain in the vicinity of Ashmore and Cartier Reefs. These patches were reported with dimensions of 50m x 50m or less.

For waters between the West Atlas rig and the Kimberly coastline, the forecast indicates that the oil patches should drift slowly southward. The southeastern most position of this part of the slick (last described as very scattered small patches of wax) will remain north of Holithuria Banks. These patches may no longer be visible on the water's surface, and are not expected to reach any shorelines during the forecast period. [12]

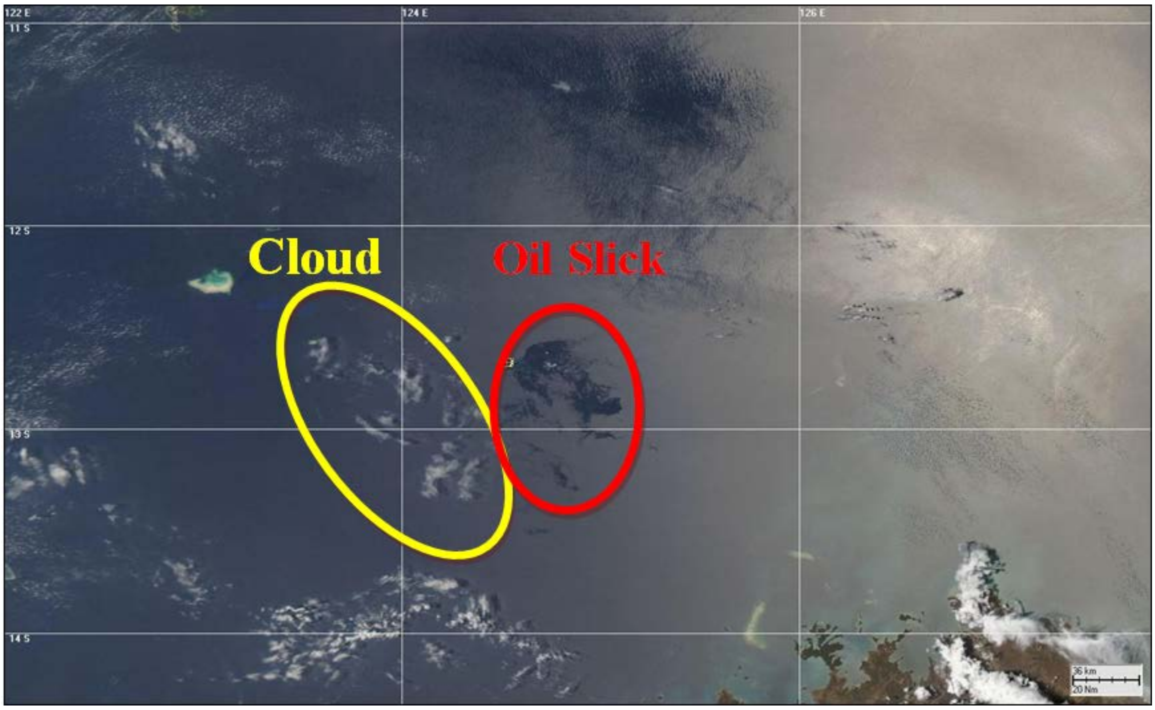

Figure 5. AQUA Satellite Observation at UTC0500 28th October 2009. The darker colour within the red circle is indicative of surface oil slick; the white colour within the yellow circle indicates cloud.

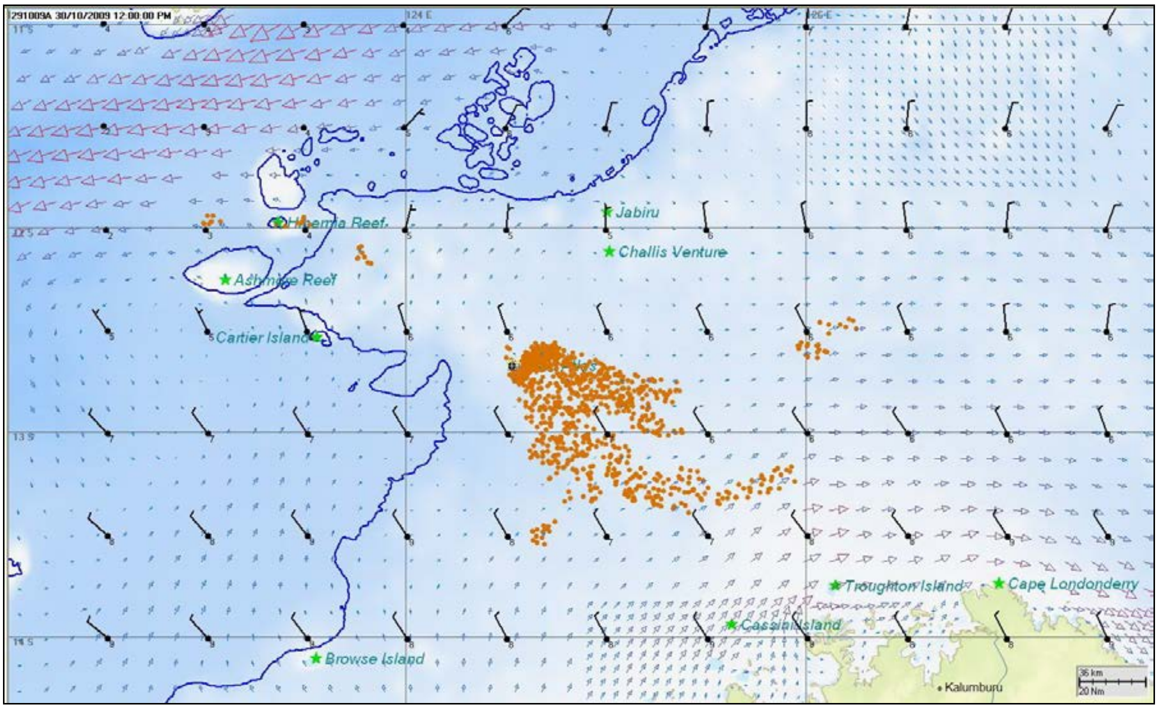

Figure 6. Forecast of surface oil (as represented by the orange spots) at 12pm on the 30th October 2009. The surface currents are shown by the coloured arrows and the wind conditions are shown by the wind barbs.

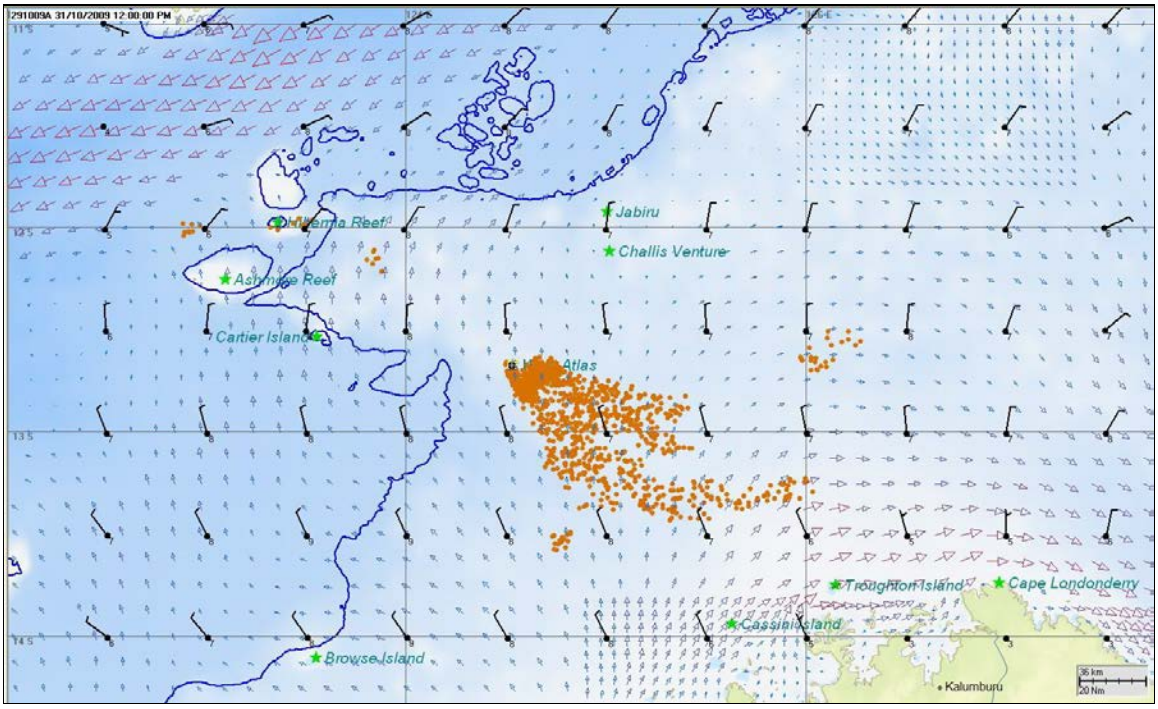

Figure 7. Forecast of surface oil (as represented by the orange spots) at 12pm on the 31st October 2009. The surface currents are shown by the coloured arrows and the wind conditions are shown by the wind barbs.