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Evaluation of met-ocean forecast data effectiveness for tracking drifters deployed during operational oil spill response in Australian waters

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ABSTRACT

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Pollution of the marine environment from hydrocarbon spills is a potential environmental issue with many incidents being reported in recent times. The need for a better understanding of the ocean circulation for spill predictions is essential so that correct response actions can be implemented to minimise environmental damage. There are currently several ocean current models available in the Australian region. This study was aimed at investigating which forecast currents work best when tracking surface drifters deployed during operational oil spill response.

The track of a drifter deployed during the Montara well release in the Timor Sea (October 2009) was modelled using six different current models including BLUElink, FOAM, GSLA, HYCOM, NCOM and NLOM. Wind forcing was also required to simulate the track of the drifter and was provided by two wind forecast models, GFS and NOGAPS. Therefore, an ensemble of 12 different model forcing combinations were possible.

The NCOM current model with NOGAPS winds produced the best result with an absolute error of 7.19 km after 120 hours (5 days); however NCOM currents with GFS winds tended to more closely predict the track throughout the entire simulation, although the error at the end of the simulation was slightly higher at 11.51 km.

ADDITIONAL INDEX WORDS: : *current forecasting, ocean drifters, oil spill*

INTRODUCTION

The Montara well release is a recent long-duration hydrocarbon spill incident which occurred between August and November 2009 in the Timor Sea, within Australian waters. The region where this spill took place has a very high ecological significance as it is in close proximity to the Kimberley coast, which is one of the most remote, rugged and untouched stretches of coastline in Australia. There was the potential for great ecological destruction had this incident not been responded to in a timely and effective manner, utilising the most up to date technology available. The use of metocean forecast data and

numerical trajectory models are required to adequately forecast the movement of a spill (King et al., 2010a).

If a sound knowledge of the slick movement can be forecast, the most effective spill response can be undertaken. This can lead to a reduction in the potential costs of the cleanup and can help to reduce the impact the spill has on the natural environment.

During the Montara incident several self locating datum marker buoy (SLDMB) drifters were deployed in close proximity to the slicks to “ground truth” the oceanic currents. This is common practice in oil spill events and search and rescue (SAR) scenarios as it gives the response team a better understanding of the nature of the surface currents and how well they are being replicated by current forecast models.

Table 1: Current and wind model parameters.

| Model Name | Model Type | Horizontal Resolution | Vertical Coordinate | Temporal Resolution | Grid Limits [Higher Resolution] |
|------------|------------|-----------------------|-----------------------------|---------------------|--|
| BLUElink | Current | 1/10° (11.1 km) | 47 z levels | 24 hr | Global [16°N - 75°S, 90°E - 180°E] |
| FOAM | Current | 1/6° (18.5 km) | 50 z levels | 24 hr | Global [0°N - 60°S, 100°E - 77°W] |
| GSLA | Current | 1/4° (27.8 km) | Surface Only | 24 hr | Australia 9.75°N - 59.75°S, 57°E - 175°W |
| HYCOM | Current | 1/12° (9.3 km) | 32 Isopycnal / σ / z | 24 hr | Global |
| NCOM | Current | 1/8° (13.9 km) | 40 σ / z level | 6 hr | Global |
| NLOM | Current | 1/32° (3.5 km) | 7 Lagrangian layers | 24 hr | Global (> than 200m deep) |
| GFS | Wind | 1/2° (55.6 km) | 64 σ levels | 6hr | Global |
| NOGAPS | Wind | 1/2° (55.6 km) | 30 σ levels | 6hr | Global |

This study investigates the use of a numerical trajectory model SARMAP which is forced by six different ocean general circulation models (OGCM) and two wind forecast models to determine which combination of current and wind models predicted the track of a drifter deployed during the Montara response. These models include; the Australian BLUElink model (Australian Bureau of Meteorology, 2007), the UK Forecasting Ocean Assimilation Model - FOAM (Storkey et al., 2010), the Australian Gridded Sea Level Anomaly - GSLA geostrophic sea surface currents, the US HYbrid Coordinate Ocean Model - HYCOM (Chassignet et al., 2009), the US Navy Coastal Ocean Model - NCOM (Barron et al., 2007), and the US Navy Layered Ocean Model - NLOM (Shriver et al., 2007).

As each of the six different current models vary significantly in terms of their horizontal and temporal resolutions, vertical coordinate systems, data assimilation methods and bathymetry; this study investigated how these differences affected the model's ability to be used for short term drift prediction.

The study also examined how consensus forecasting can be used in oceanography to predict the drift of objects at sea, and increase the confidence of those predictions, by utilising an ensemble of different model predictions. Previous works by King et al., (2010b) investigated the use of consensus forecasting by using a combination of four different model generated datasets (two current models and two wind models) to forecast the track of oil and drifters in incidents which recently occurred in Australian waters.

The work by Bernstein (2009) was similar as it studied the use of several different datasets to track drifters. It differed however as the region of focus was coastal waters off the United States of America, and as such many of the current models it utilised were different to those available in Australian waters.

Table 1 outlines the various parameters of the current and wind models which were used in this study. Contained therein are model type, horizontal and temporal resolution, vertical coordinate systems and their extent of coverage. The vertical coordinate systems vary significantly between all of the models used in this study, ranging from z-level (fixed geopotential layers), σ -coordinate (terrain following layers), isopycnal (density following layers), Lagrangian layers, and various combinations of these systems. The number of layers, the type of vertical coordinate system used and the thickness of these vertical layers all have an impact on the model's ability to replicate the surface currents. The models which have higher resolution in the vertical layers (and a higher temporal resolution) have a significantly increased response to inertial oscillation. This means that the model can produce more accurate surface currents as it is better able to respond to inertial changes, such as those imparted on the model water surface by fluctuations in the wind field.

As shown in the table the horizontal resolution also varies greatly between each of the models, ranging from as coarse as $1/4^\circ$ for GSLA right down to $1/32^\circ$ for NLOM. This has strong implications when modelling meso-scale eddies. Typically a resolution of $1/8^\circ$ or finer is required to permit eddies in the model, with finer resolution much more desirable, but of course finer resolution comes at a computational cost. Also if the model does not have the resolution to describe certain physical characteristics, parameterisations need to be employed to account for this shortfall. These parameterisations can lead to increased error in the forecast model if not defined correctly (Hernandez, 2010).

The drifter began 350 km off the West coast of Australia, just off the continental shelf, in waters approximately 600m deep (refer to Figure 1). Throughout the five day track the drifter proceeds initially in a North East direction before swinging towards the North West into deeper waters (~1000m), and finally

tracking South West for the remainder of the time into shallower waters (~300m).

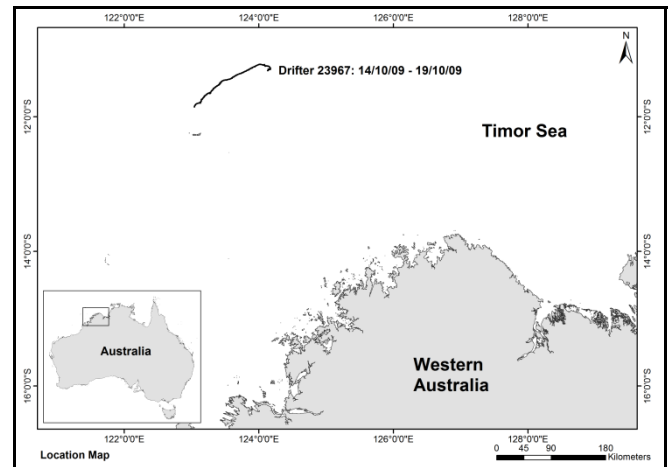


Figure 1: Location map showing the location of the drifter 23967 off the Western Australian coast.

MODELLING METHODS

Several SLDMBs were deployed by responders during the Montara well release to ground truth the prevailing ocean currents at the location. These SLDMBs were deployed with the leeway characteristics of a person in water (PIW). Applied Science Associates' (ASA) SARMAP trajectory modelling software was used to numerically model a single particle trajectory with the leeway parameters for a PIW, which included a wind factor of 1.1% and a wind divergence angle of 40° , as indicated by Allen and Plourde (1999). This Lagrangian approach was selected as drifters are Lagrangian by nature, so it was the most logical method to adopt.

A 120 hour track of drifter 23967 was chosen for this study. The track was initiated at 00:15 14/10/09 at location 11.313056 S, 124.128889 E and finished five days later at 00:15 19/10/09 some 133km to the south west of its initial position.

Six different forecast/hindcast current models were used to provide the current forcing, and two different wind forecast models were used to provide the wind forcing on the drifter. As each of the current models did not include any tidal signal, tidal currents were aggregated with the oceanic circulation models to provide a total surface current. Each of the six current models were combined with each of the wind forecast models for the 120 hour period, which resulted in an ensemble of 12 different model combinations. The locations of the drifter and the modelled drifter were output for every hour throughout the model run to analyse the absolute error. The great circle distance formula was used to calculate this difference in position, and is given in Equation 1 below. The equation for the bearing of the error from the drifter to the modelled drifter is given by equation 2.

$$\text{Distance (km)} = \text{acos}[\sin(\text{lat1}) * \sin(\text{lat2}) + \cos(\text{lat1}) * \cos(\text{lat2}) * \cos(\text{lon2} - \text{lon1})] * 6371 \quad (1)$$

$$\text{Bearing (rad)} = \text{atan2}[\cos(\text{lat1}) * \sin(\text{lat2}) - \sin(\text{lat1}) * \cos(\text{lat2}) * \cos(\text{lon2} - \text{lon1}), \sin(\text{lon2} - \text{lon1}) * \cos(\text{lat2})] \quad (2)$$

Where: $lat1$ = Actual latitude of drifter (in radians)
 $lat2$ = Modelled latitude of drifter (in radians)
 $lon1$ = Actual longitude of drifter (in radians)
 $lon2$ = Modelled longitude of drifter (in radians)

RESULTS / DISCUSSION

The results for the simulation of drifter 23967 for a period of 120 hours (5 days) from 14/10/10 until 19/10/10 are shown graphically in Figure 2 (GFS) and Figure 3 (NOGAPS). The symbols on the track lines represent the locations of the drifter (or modelled drifter) at 6 hourly intervals. As shown in these figures NCOM and HYCOM performed the best throughout the simulation, with BLUElink and NLOM performing the worst.

Tidal oscillations were more evident with the model runs which came into shallower waters (NLOM, GSLA, FOAM) compared with those which tended to stay in deeper waters (BLUElink, NCOM, HYCOM).

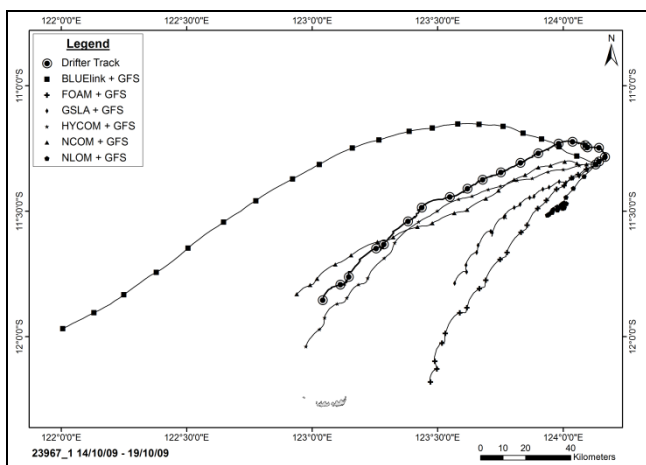


Figure 2: Drifter 23967 predicted paths over 120 hours from midnight 14/10/09 to 19/10/09 using various current forecast models and GFS winds.

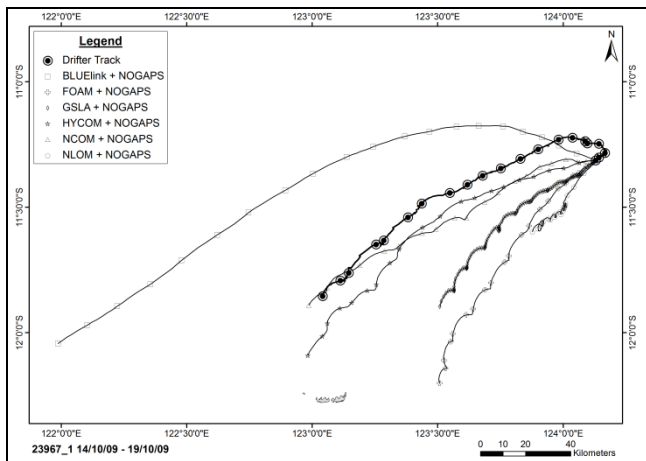


Figure 3: Drifter 23967 predicted paths over 120 hours from midnight 14/10/09 to 19/10/09 using various current forecast models and NOGAPS winds

Initially the drifter travelled north east for 12 hours before turning north west for 30 hours and then finally followed a south westerly track for the rest of the duration. None of the forecast

models were able to replicate the initial north easterly drift which may have been due to the presence of a meso-scale eddy which was either misplaced or absent in the models.

All of the models produced results which tended to follow the south west track of the drifter, however due to their inability to replicate the initial north easterly component of the drift; the final error for some models was quite high.

An analysis of the error was carried out for each simulated drifter track (using each combination of forecast currents and winds) and is summarised in the tables which follow. Table 2 shows the absolute error (in km) for all six current forcing runs when coupled with GFS winds, and Table 3 shows the absolute error (in km) for the same six current forcing however utilising NOGAPS for wind forcing. The minimum and maximum final error after the 120 hour simulation is shown in **bold** and *italics* respectively.

Table 2: Error analysis for Drifter 23967 using various forecast current forcing and GFS forecast winds.

| Time (hrs) | BLUElink (km) | FOAM (km) | GSLA (km) | HYCOM (km) | NCOM (km) | NLOM (km) |
|------------|---------------|-----------|-----------|------------|--------------|-----------|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 20.45 | 13.97 | 14.07 | 18.88 | 12.46 | 19.54 |
| 24 | 28.62 | 19.67 | 18.19 | 27.53 | 17.88 | 29.03 |
| 36 | 41.35 | 28.30 | 22.56 | 36.83 | 25.31 | 28.97 |
| 48 | 47.36 | 32.17 | 19.19 | 34.35 | 23.85 | 26.62 |
| 60 | 54.86 | 35.57 | 16.51 | 32.37 | 22.12 | 31.52 |
| 72 | 65.17 | 41.29 | 20.31 | 39.64 | 21.54 | 40.62 |
| 84 | 72.12 | 48.57 | 32.63 | 39.10 | 18.04 | 59.05 |
| 96 | 85.00 | 47.62 | 41.00 | 28.65 | 15.04 | 74.78 |
| 108 | 97.88 | 52.86 | 51.21 | 20.94 | 13.74 | 91.28 |
| 120 | <i>113.41</i> | 59.17 | 57.75 | 21.82 | 11.51 | 104.61 |

Table 3: Error analysis for Drifter 23967 using various forecast current forcing and NOGAPS forecast winds.

| Time (hrs) | BLUElink (km) | FOAM (km) | GSLA (km) | HYCOM (km) | NCOM (km) | NLOM (km) |
|------------|---------------|-----------|-----------|------------|-------------|-----------|
| 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 12 | 20.19 | 14.40 | 14.76 | 19.12 | 12.59 | 20.21 |
| 24 | 28.37 | 20.00 | 19.24 | 27.54 | 17.92 | 29.61 |
| 36 | 41.08 | 29.88 | 24.89 | 36.90 | 26.14 | 31.07 |
| 48 | 47.86 | 34.21 | 22.29 | 34.90 | 25.96 | 29.25 |
| 60 | 56.22 | 38.95 | 20.41 | 33.79 | 26.52 | 33.10 |
| 72 | 67.21 | 44.66 | 23.45 | 41.20 | 23.88 | 40.54 |
| 84 | 75.33 | 51.85 | 32.83 | 40.97 | 21.28 | 56.31 |
| 96 | 88.25 | 51.07 | 37.69 | 30.86 | 15.21 | 68.95 |
| 108 | 101.45 | 56.68 | 46.20 | 24.25 | 11.38 | 84.51 |
| 120 | <i>116.66</i> | 63.80 | 51.06 | 27.13 | 7.19 | 95.46 |

Figure 4 shows the error analysis for the six current models combined with GFS winds plotted as a time series with time (in hours) across the x axis, and error (in km) along the y axis. As shown there is a general trend for the models to increase in error as time progresses, however both NCOM and HYCOM increase in error up until around the 70 hour mark, where the modelled drifter tends to veer back towards the track of the actual drifter.

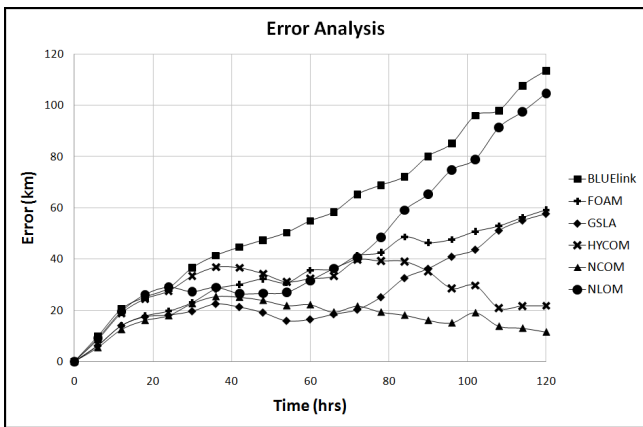


Figure 4: Error analysis for drifter 23967 over 120 hours from 14/10/09 – 19/10/09 using 6 different ocean current models and GFS winds.

Average and maximum winds for the area of interest were 6.43 knots and 11.45 knots respectively for GFS, and 9.02 knots and 14.39 knots respectively for NOGAPS. These figures indicate that on a whole, the NOGAPS winds were significantly stronger than the GFS winds. As the drifter only has a wind factor of 1.1% of the 10m wind speed, the overall effect of this stronger wind on the movement of the drifter is quite small. This effect can be seen in Figure 5 which shows a stick plot of the error of the actual drifter track and the modelled drifter track when forced with NCOM currents. The stick plot shows error as distance and direction (as opposed to the conventional speed and direction of standard stick plots) during the 5 days the drifter track was modelled. The length of the “sticks” is representative of the distance the modelled drifter was away from the actual drifter, whilst the angle at which the “sticks” point outwards is representative of the direction towards where the modelled drifter was compared to the actual drifter. The solid line indicates the simulation which utilised GFS winds, where the dashed line indicates the simulation which utilised NOGAPS winds. This figure shows the effects the two different wind models had on the drifter. It indicates that there was a much more southerly trend in the error of the NOGAPS run, compared with the GFS run.

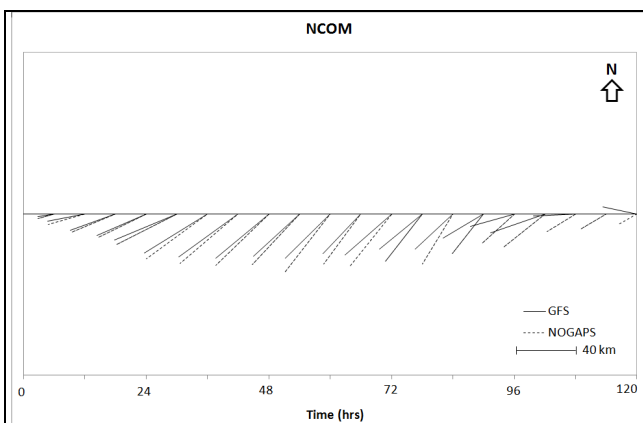


Figure 5: Stick plot showing 6 hourly distance and direction of error from actual drifter track to NCOM predicted track using GFS (solid line) and NOGAPS (dashed line) winds.

CONCLUSION

The NCOM model was the most accurate over the 5 days modelled, for both the GFS and NOGAPS wind fields. This is possibly due to NCOM’s higher temporal resolution and vertical resolution, especially in the surface layers, when compared to the other current models. NCOM employs five 1m thick layers in the surface, and has a temporal resolution of 6 hours. Both of these attributes enabled a much faster response from the atmospheric forcing to the surface layers (which is where the drifters are acting) resulting in a much more dynamic and responsive surface layer. The results reveal that with such a large range of outcomes from commonly used models the need for further testing and validation is essential and that every endeavour should be made to continue drogue deployment at spill events for model validation purposes.

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