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Pilot investigation of the origins and pathways of marine debris found in the northern Australian marine environment

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July 2008

Prepared for the Department of the Environment, Water, Heritage and the Arts

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1. EXECUTIVE SUMMARY

In addition to large quantities of general debris, thousands of derelict fishing nets are found on parts of the Gulf of Carpentaria coast bordering the Arafura Sea. Most of these derelict fishing nets have been identified as being of Asian manufacture but it is currently not possible to ascertain where they were lost or discarded from their construction or condition.

In a preliminary attempt to shed some light on the question of the origins of derelict fishing nets found along the northern Australian coastline, numerical simulations of the paths taken by floating items through Australian and Asian waters were performed and the existing archive of satellite-tracked Global Drifters (920 of which have been recorded in the region 19ºS-15ºN, 110ºE-156ºE from 1990 to the present) were examined.

The numerical simulations used a global ocean model recently completed as part of the CSIRO/Bureau of Meteorology/Royal Australian Navy Bluelink project. The model has 10km horizontal resolution and 10m vertical resolution for the entire Australasian region. It is the basis of Australia's new operational ocean forecasting capability.

In contrast with what has been assumed to be the case, the drift simulations found no evidence that nets stranding on the shores of Arnhem Land and Gulf of Carpentaria were likely to have been lost or discarded in south east Asian waters farther away than the Arafura Sea.

Instead modelling showed that marine debris passing through Torres Strait had a high probability of coming close to the Arnhem Land coastline, or entering the Gulf of Carpentaria, where it might strand in the Cape Arnhem-Groote Eylandt region in the Dry Season, or in the Weipa region during the Wet Season, which is the observed pattern of arrival of derelict fishing nets.

The archive of Global Drifter data is essentially silent on the question of western or northern origins of debris, because so few drifters make complete transits of the Indonesian Archipelago. Interception by mariners in small boats potentially explains this apparent contradiction of the known existence of the Indonesian Throughflow.

What the drifter data clearly does show, however, is that many drifters in the South Pacific Ocean have stranded on the Great Barrier Reef, raising the question of whether many derelict fishing nets have taken similar paths, in which case it is possible that some have passed through Torres Strait and stranded on the Arnhem Land coast.

There is little documented evidence of large numbers of stranded nets on the Great Barrier Reef. If it can definitely be shown that few nets strand on the Great Barrier Reef, the only remaining explanations of the Arnhem Land strandings are that either: 1) our ocean model under-estimates the eastward and southward movement of the surface layer, either during the Wet Season in general, or during the Dry Season as an unresolved coastal jet, or 2) the origin of items is relatively close to the point of stranding, ie within the Arafura Sea.

Suggestions for further work towards identifying the source of stranding nets are:

- Investigate whether nets are stranding on the outer reefs of the Great Barrier Reef,
- Deploy low-visibility, satellite-tracked drifters at 10ºS 132ºE (near Darwin) at intervals early in the Wet Season, to see how far they go and to provide validation data for the present and next-generation Bluelink velocity estimates.
- Establish a HF radar to measure currents through Torres Strait to monitor the eastern source of waters entering the Arafura Sea.
- Re-run the present net-drift simulation model once the next version of the Bluelink hydrodynamic model is complete, to see if the developments, including reduction of flow through Torres Strait by incorporating a representation of tidally-enhanced bottom friction, alters the results.

2. INTRODUCTION

2.1 Aims and objectives

The development of plastics was initially welcomed because it suddenly became possible to easily and cheaply manufacture durable items of complex shape and form. Unfortunately, a large fraction of these items end up in the world's oceans where their durability is a problem rather than a virtue. The accumulation of rubbish in the world's oceans is a growing problem that is attracting more and more attention. Many nations have programs to address both the causes, and the impacts, of this problem.

The northern coast of Australia is one region where large amounts of debris are found (Kiessling, 2003, White, 2003, White, 2004, White, 2006). Of particular concern are abandoned or lost fishing nets (Figure 1) because they entangle and kill many fish, sharks, and turtles while drifting. Many derelict fishing nets are found in the Gulf of Carpentaria (Figure 2), on the eastern side from Cape York to south of Weipa during the Wet Season, when the north west monsoon blows, and on the western side from Cape Arnhem to Groote Eylandt during the Dry Season when the south-east trade winds blow. Derelict fishing nets are a small fraction by number of debris items, but a large fraction by weight (Kiessling, 2003). A few are Australian prawn nets but most are of Taiwanese, Japanese or Indonesian manufacture. What is not known is how these nets come to be in Australian waters. To begin to explore that question, by analysing the ocean circulation of the region, is the primary goal of the present study.

Figure 1 A derelict Taiwanese gillnet in the Arafura Sea. Ripples can be seen emanating from a struggling hawksbill turtle. Reproduced from White (2006). Image © Ben Slater.

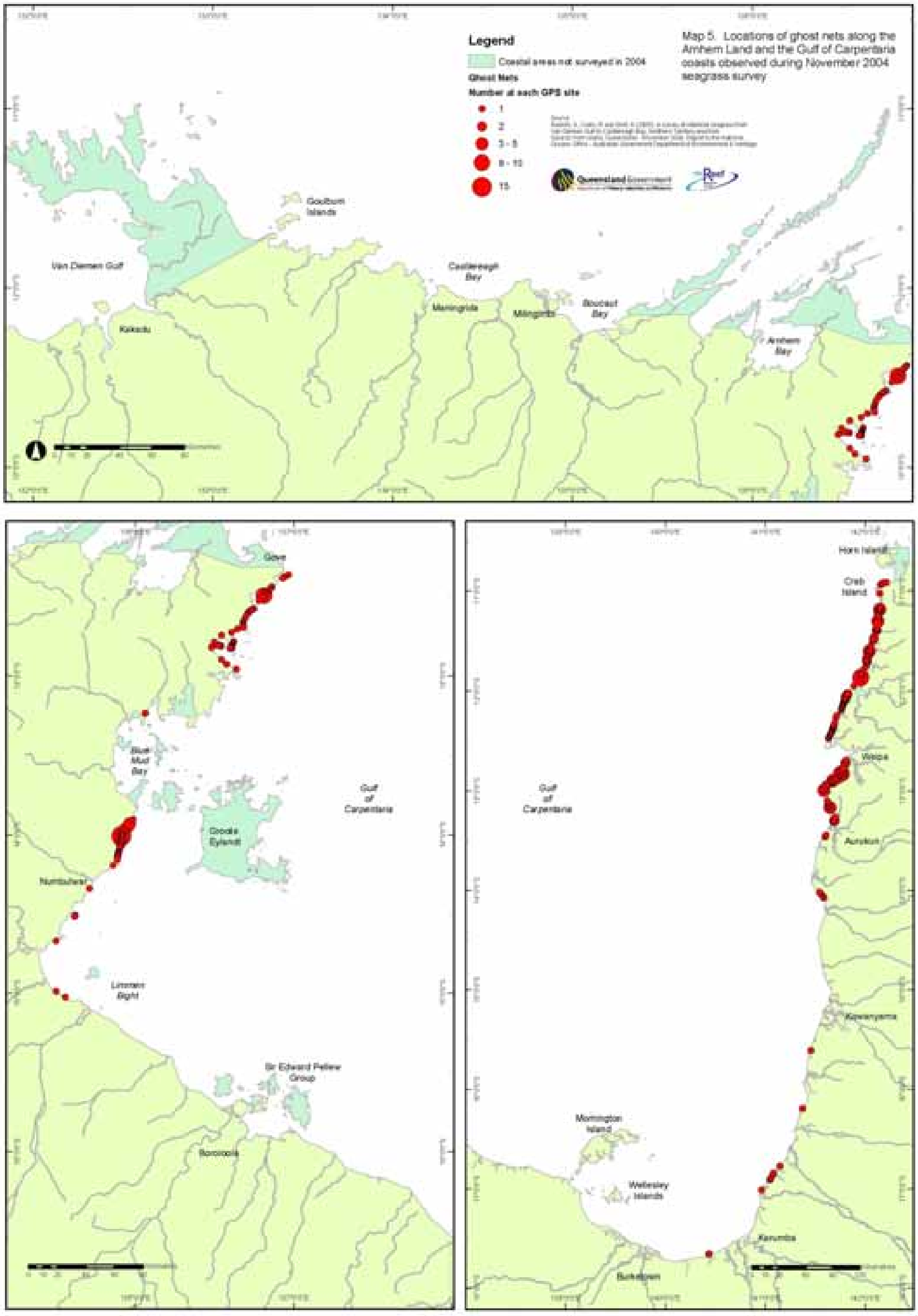

Figure 2 Derelict fishing net density in the Gulf of Carpentaria recorded by the helicopter seagrass survey of Roelofs *et al.* (2005). Reproduced with permission of A. Roelofs, Queensland Department of Primary Industries and Fisheries.

2.2 The dynamics of drift and accumulation

All forms of marine debris move in response to the combined effect of the movement of the water in which they float, and the force of the wind on the exposed portion of the item (known as windage). An item with high windage will move rapidly downwind. An item with no windage, but floating near (within 1m or so) to the surface, will also tend to move downwind, but only as fast as the near-surface layer of the ocean. Larger items, for example derelict fishing nets that hang several meters down from buoys, will move at a velocity that is the average, over the appropriate vertical range, of the velocity of the water.

The velocity of the water can be thought of the sum of many independent contributions. For example, the tide may be going one way, but the wind blowing the other. Also, the effect of the wind and heating is felt at many scales. Locally, the wind may be driving surface waters in the opposite direction to the general flow set up by the winds blowing over adjacent regions. The variation of the water velocity with depth is a complex function of the recent history of the strength and direction of the wind, solar heating, night-time cooling, rainfall and evaporation. The horizontal variability of the water velocity is also complex, not just because the topography over which the water flows is irregular, but because fluid flow is often inherently unstable. The rotation of the Earth is another very significant contributor to the complexity of geophysical fluid dynamics.

Apart from the fact that a drifting item moves at some vertically-averaged velocity, and subject also to windage, there are several other reasons that drifting items do not move in the same way as the water in which they float.

One is that having buoyancy, a drifting item is always at the surface, which is not true for any particular parcel of water. This becomes especially important when there is convergence of the surface velocity field, which can occur in the open ocean as well as at the coast. Convergence is generally accompanied by subduction. Indeed, if subduction does not occur then the surface of the water must rise, as occurs due to tides and waves. On longer time-scales, however, most of the convergence is balanced by subduction. Buoyant items accumulate wherever there is subduction because they cannot sink like the water that carried them to that point or line. Hence, when the wind blows onshore, the shoreward motion of the water carries items, even those without windage, towards the coast where they accumulate rather than sinking and flowing offshore as the water does.

In the open ocean, subduction can occur even in the absence of wind forcing. For example, when two water masses of different temperature and salinity meet, the denser one tends to sink under the lighter one. Other circumstances can also lead to what mariners call ‘tide lines’ – long, dense accumulations of buoyant matter.

A second reason that drifting items do not move just like water is that they are subject to snagging on the bottom. Items will accumulate where there is a high probability of snagging on the bottom. This, too, is complex because the probability of un-snagging, itself a function of many factors, is equally important. In a channel, for example, items might accumulate in one place as the current flows one way, but be released if the current turns around. Variations of sea level, due to tide, wind and waves, will also play a role in the snagging and un-snagging of items.

A domestic example serves to illustrate how spatial variations of the probability un-snagging can lead to accumulation of items. Dust in the air in a house is constantly falling slowly to the floor, at a fairly uniform rate. Our walking around and moving objects, re-suspends this dust back into the air, but not at a uniform rate. Regions where the air remains still (like under the bed) become regions of net settlement simply because once settled, the dust is unlikely to be re-suspended. Compared with other areas of Australia's marine environment, the Arafura Sea and the Gulf of Carpentaria are not regions of strong currents. This is especially true in the shallows of the Gulf, which is why Wolanski and Ridd (1990) suggested that the Gulf of Carpentaria is ringed by a 'coastal boundary layer' that traps items, both living and non-living. The gentle bathymetry and large tidal range in parts of the Gulf may also be factors that contribute to the concentration and stranding of marine debris, including derelict fishing nets along areas of the Gulf coastline.

In summary, a likely result of the fact that current speeds are low in the Gulf of Carpentaria is that a derelict fishing net entering the Gulf has a low probability of leaving, leading to accumulation.

2.3 Scope of study

The drift characteristics of items of debris depend crucially on their size and windage, both of which vary widely. The scope of this study is restricted to marine debris that has minimal windage. This is to allow a focus on derelict fishing nets which are believed to be amongst the most harmful types of debris to marine wildlife and the most hazardous to mariners (Figure 1). Derelict fishing nets are found in a range of sizes, and since the direction and speed of the water varies considerably with depth below the surface, different size nets can have considerably different drift characteristics. Results and discussion are presented for two size classes, which are referred to as 'deep submerged' and 'shallow submerged', representing nets which occupy the upper 10m, and 1m, respectively, of the ocean.

Many derelict fishing nets are found along the northern Australian coastline, particularly in the Gulf of Carpentaria (Figure 2). A number of community surveys have found that derelict nets tend to wash ashore on the eastern side of the Gulf of Carpentaria during the Wet Season, when the north-west monsoon blows, and on the western side during the Dry Season when the south-east trade winds blow. Clearly, items in the Gulf of Carpentaria are coming ashore on whichever is the downwind coast at the time. The focus of the present study is to identify pathways of derelict nets that are found in the northern Australian marine environment, and to determine the geographic origins of those nets.

The scope of the present study is limited principally to the horizontal movement of items due to movement of the water. Aggregation at points of convergence is considered incidentally, while the processes associated with snagging and un-snagging of items are explicitly excluded.

Returning to the analogy of house dust, the focus is on the question of how dust is getting into the room, and where it came from, rather than on what is causing local accumulations, or how much of what enters the room is settling on the floor.

The range of possible source regions of derelict fishing nets found in the northern Australian marine environment is extensive. White (2003) suggested that many nets originate from Indonesia, Korea, Japanese, Chinese or Taiwanese fisheries operating in waters north of Australia, and hypothesized that the combined influence of the north-west monsoon and the generally southwestward flow of water through the Indonesian archipelago brings these items into the Gulf of Carpentaria. To test this hypothesis, the geographic scope of the present study was designed to be large enough to allow the possibility of finding pathways to the Gulf of Carpentaria from as far away as south-east Asia.

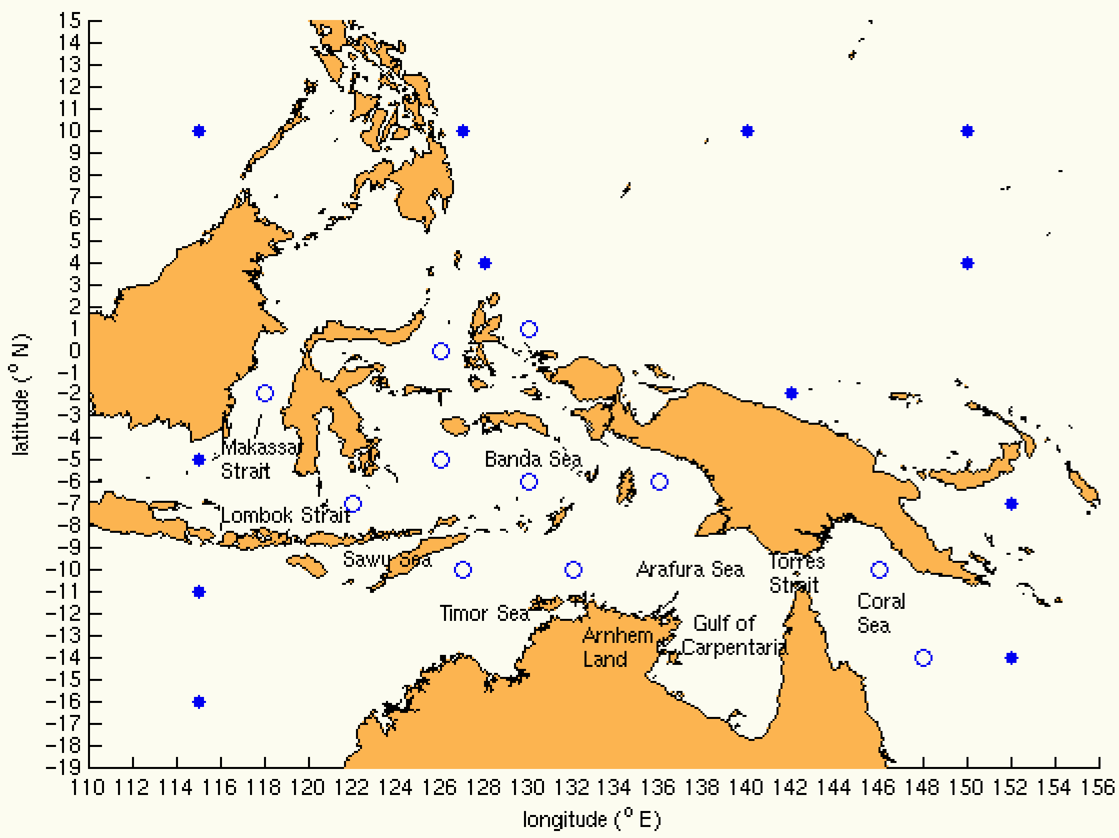

Figure 3 Map of study region showing geographic names and the ‘Far Field’ (solid circles) and Near Field (open circles) subsets of points where virtual drifters were released in the model.

Two general approaches are taken. One is to analyse the global database of trajectories of satellite-tracked drifters. These drifters do not drift exactly like derelict fishing nets, but there is no other observational technique that is nearly as directly relevant. The second approach is computer simulation. The existing archive of output from a recently completed high-resolution (10km horizontally, 10m vertically and 1 day temporally) global ocean re-analysis is exploited by using it as input to a particle-tracking model that computes the trajectories of both ‘deep submerged virtual drifters’ and ‘shallow submerged virtual drifters’ (as they are referred to hereafter) released at a number of ‘Far Field’ and ‘Near Field’ points (Figure 3).

3. METHODS

3.1 Global Drifters

For many years large numbers of satellite-tracked drifting buoys have been deployed in the world's oceans by various meteorological and oceanographic agencies in order to obtain measurements of:

- sea surface temperature for calibration of satellites,
- sea surface current velocity to improve our understanding of global circulation, and
- atmospheric pressure for ingesting into numerical weather forecasting models.

The drifters (Figure 4, Figure 5) comprise a 30-40cm diameter surface buoy holding the sensor and communication electronics and a 12m long wire connected to a 6m-long sea-anchor that is designed to ensure the drifter is water-following rather than wind-following. The drag profile of the drifter is therefore quite a similar to that of a derelict fishing net, so its drift characteristics are likely to be essentially the same.

CSIRO Marine and Atmospheric Research maintain a constantly-updated archive of these drifter data. Since January 1990, 920 drifters have entered the region 19ºS-15ºN, 110ºE-156ºE.

Figure 4 Global drifter with deployed sea-anchor visible . (Reproduced from http://www.aoml.noaa.gov/phod/dac/gdp_drifter.html)

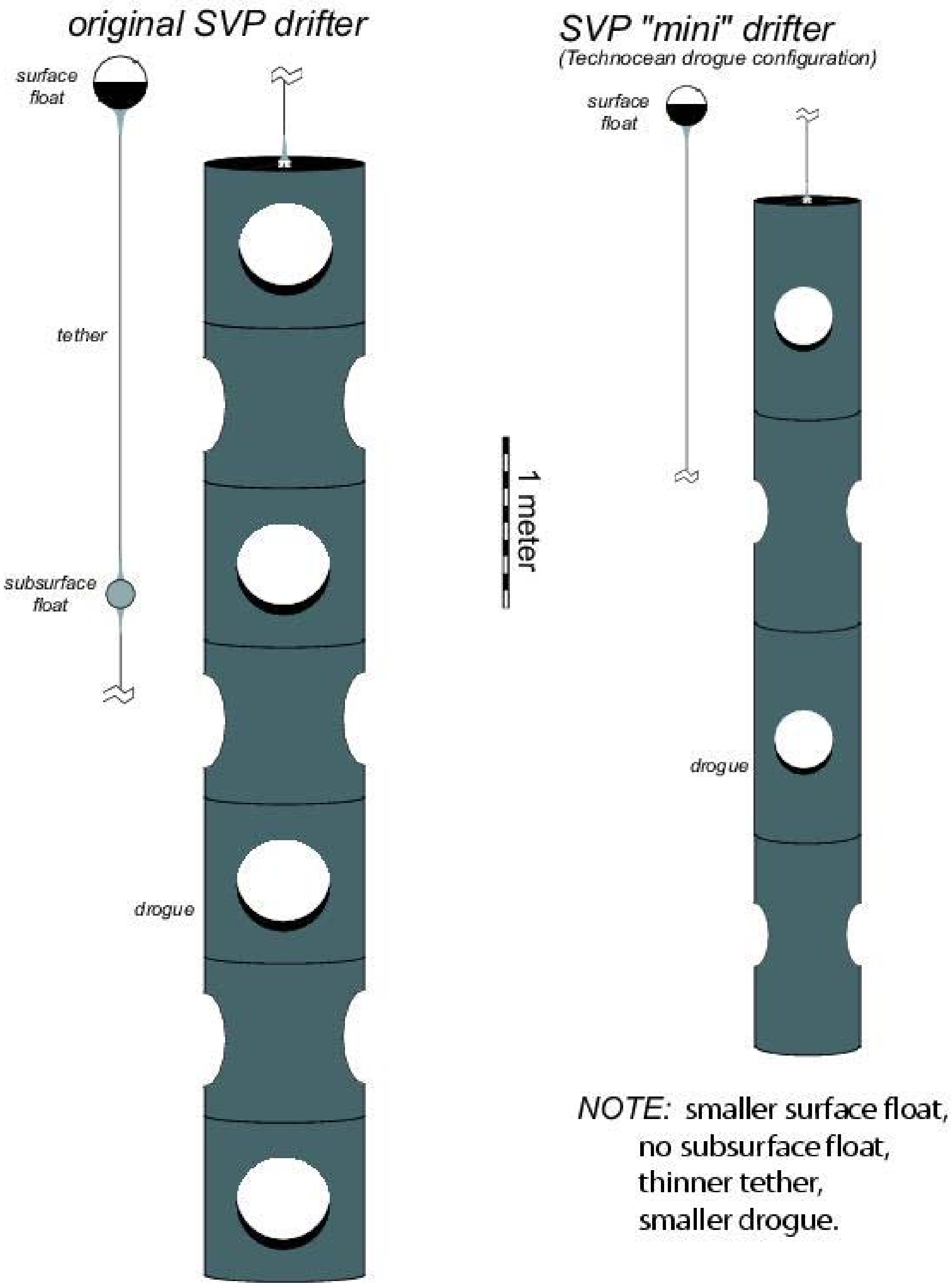

Figure 5 Schematics of the older Surface Velocity Program drifters, and newer Global Drifters (reproduced from http://www.aoml.noaa.gov/phod/dac/schematic.jpg)

3.2 Bluelink Model

Bluelink is the name of a recently completed project to develop a high-resolution operational ocean forecasting system for Australia. The project was a partnership between the CSIRO, the Royal Australian Navy and the Bureau of Meteorology, who have been running the system routinely since August 2007.

Prior to the commissioning of the operational forecasting system, the model was run for many years in ‘hindcast’ or ‘reanalysis’ mode, both as a test of the system, and to provide a detailed, multi-variable dataset of potentially enormous value to many fields of marine science and engineering. Running the Bluelink ReANalysis (BRAN) data-assimilating global hydrodynamic model took many months of super-computer time to complete a simulation of the 1992-2006 period. Having a horizontal resolution of 10km in the Australasian region and a vertical resolution of 10m in the top 200m of the ocean, the resulting archive of daily-averaged, three-dimensional (depth, latitude, longitude) fields of velocity, temperature and salinity is 6 TBytes. Assessing its accuracy is a major undertaking that is still ongoing, as part of a continuous process of model improvement. For a description of the model and some Australasia-wide assessment of its accuracy see Oke *et al*. (2008) and Schiller *et al*. (2008). The model bathymetry in the present study region is shown in Figure 6.

Godfrey *et al*. (2007) focussed on the region just north-west of Australia and compared the seasonal cycle of the non-data-assimilating run of the model with the seasonal cycle of:

- sea level measured by satellite,
- current velocities at a small number of mooring locations in the Timor Sea, and
- Expendable BathyThermograph temperature sections across the northeast Indian Ocean.

Godfrey *et al*. (2007) found surprisingly good agreement on sea levels and current velocities, but identified significant discrepancies in the deeper water temperature measurements.

The seasonal cycle of the surface velocity of the BRAN2.1 model is closely tied to the seasonal cycle of the winds. In February (Figure 7), in the middle of the Wet Season when the wind is from the north west, the surface flow is eastward in the Arafura Sea and a clockwise, western-intensified rotation exists in the Gulf of Carpentaria. By May (Figure 8), the influence of the southeast trade wind that blows during the Dry Season is already established, and the surface flow is to the west or west-south-west throughout the Arafura Sea and Gulf of Carpentaria. The westward surface flow reaches a peak in August (Figure 9) and is still strong in November (Figure 10), when there is also some anticlockwise surface flow in the Gulf of Carpentaria.

The full set of monthly-averaged surface velocity fields, and sub-surface strata as well, can be seen at http://www.marine.csiro.au/~griffin/debris/BRAN2.1/y95-04/index.html, or on the CD copy of this report, which includes the contents of that website.

For more information on the hindcast model runs see http://www.marine.csiro.au/ofam1/.

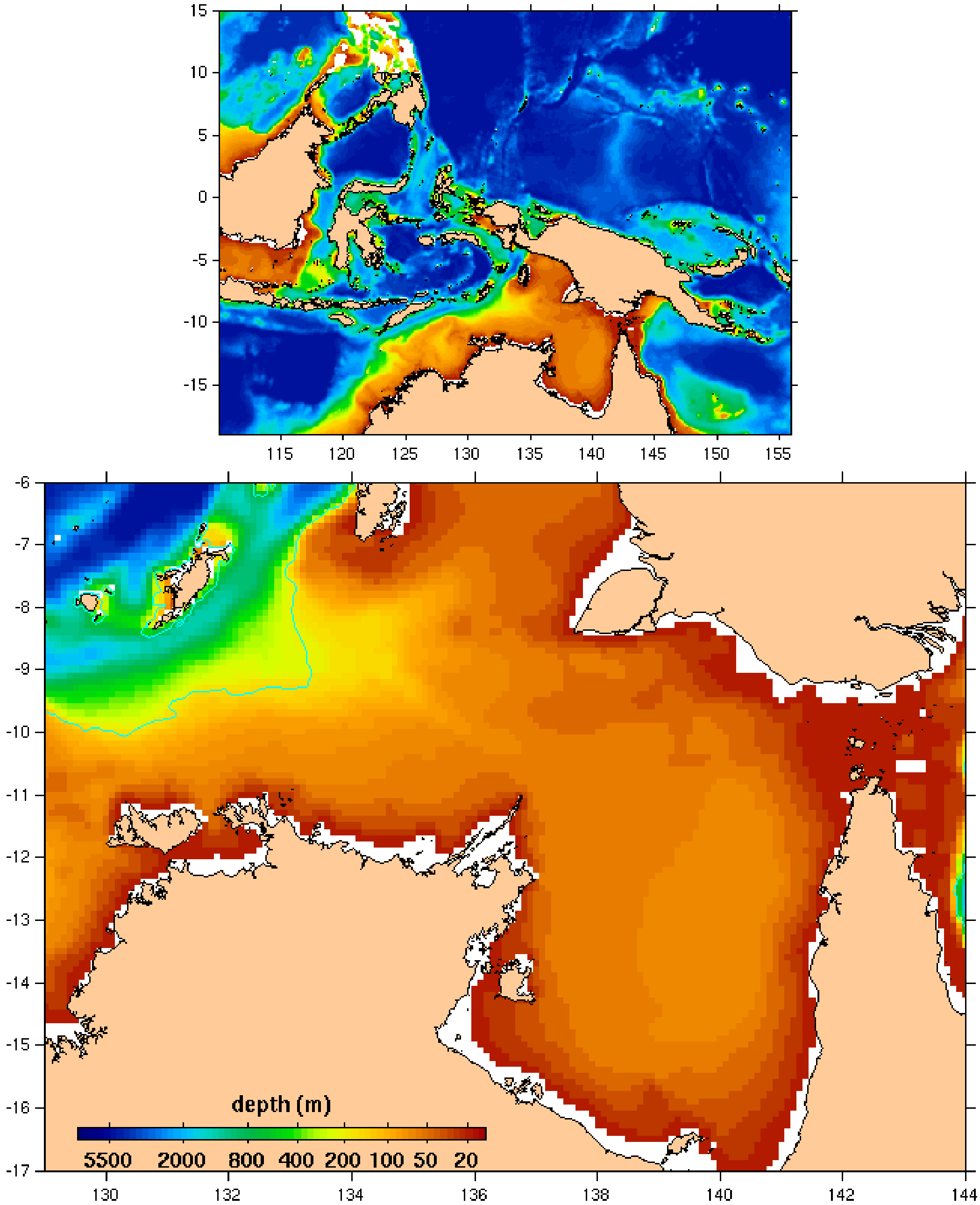

Figure 6 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the representation of bottom topography used in the Bluelink model. The depth key pertains to both panels. The position of the 200m isobath (according to the General Bathymetric Chart of the Oceans - http://www.gebco.net/) is shown in cyan in the lower panel.

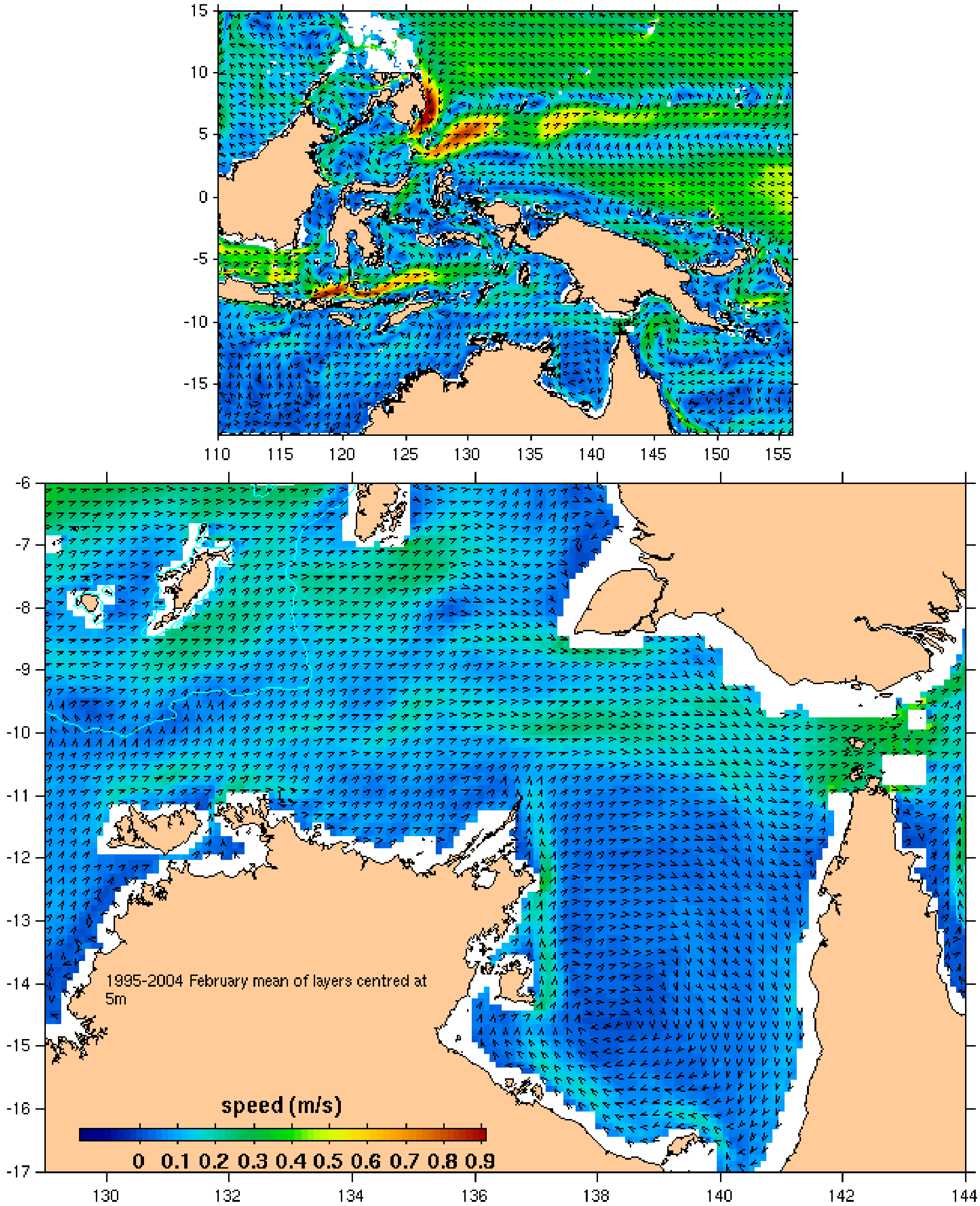

Figure 7 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the February (1995-2004) mean of surface layer (0-10m) velocity in BRAN2.1 as speed (see key) and direction (arrow heads).

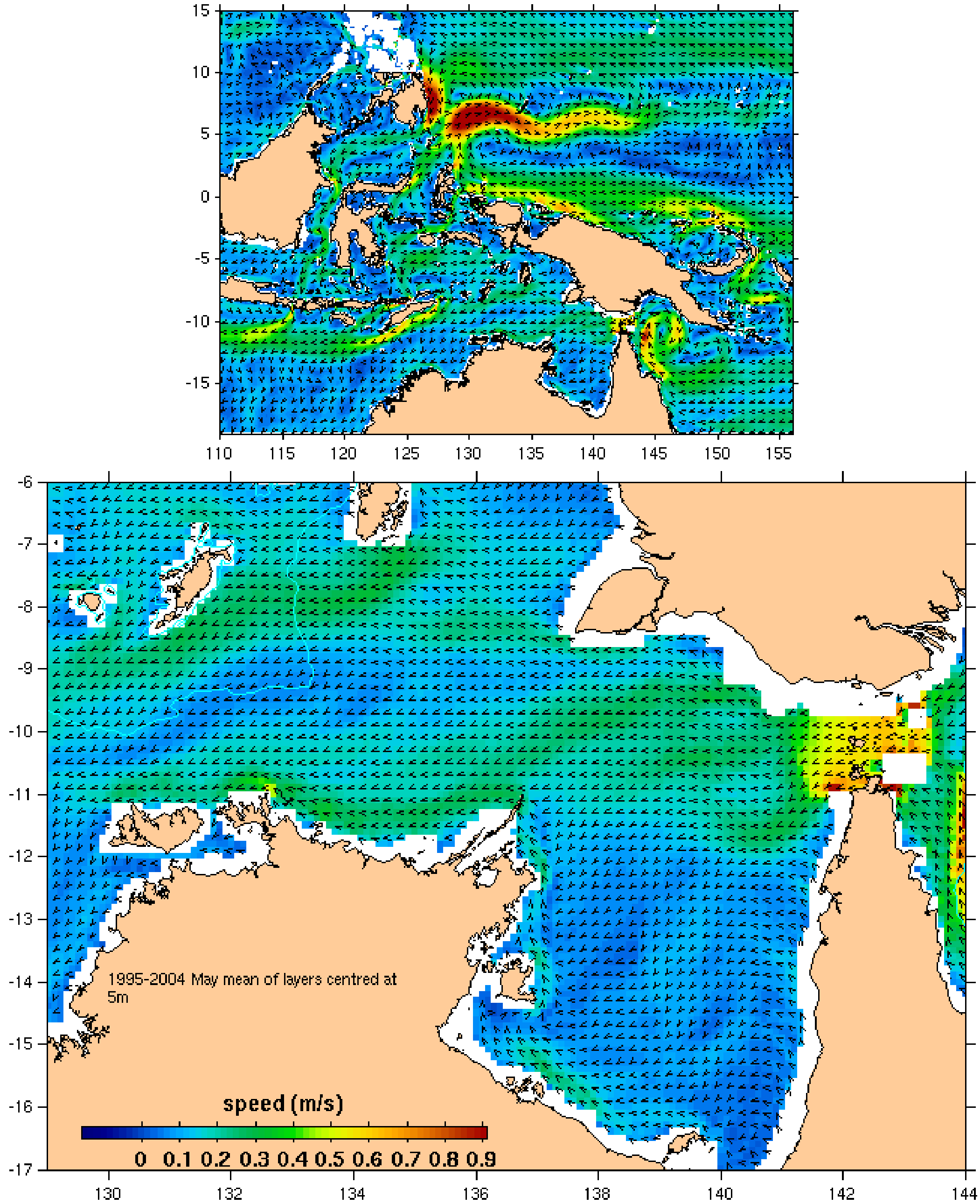

Figure 8 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the May (1995-2004) mean of surface layer (0-10m) velocity in BRAN2.1 as speed (see key) and direction (arrow heads).

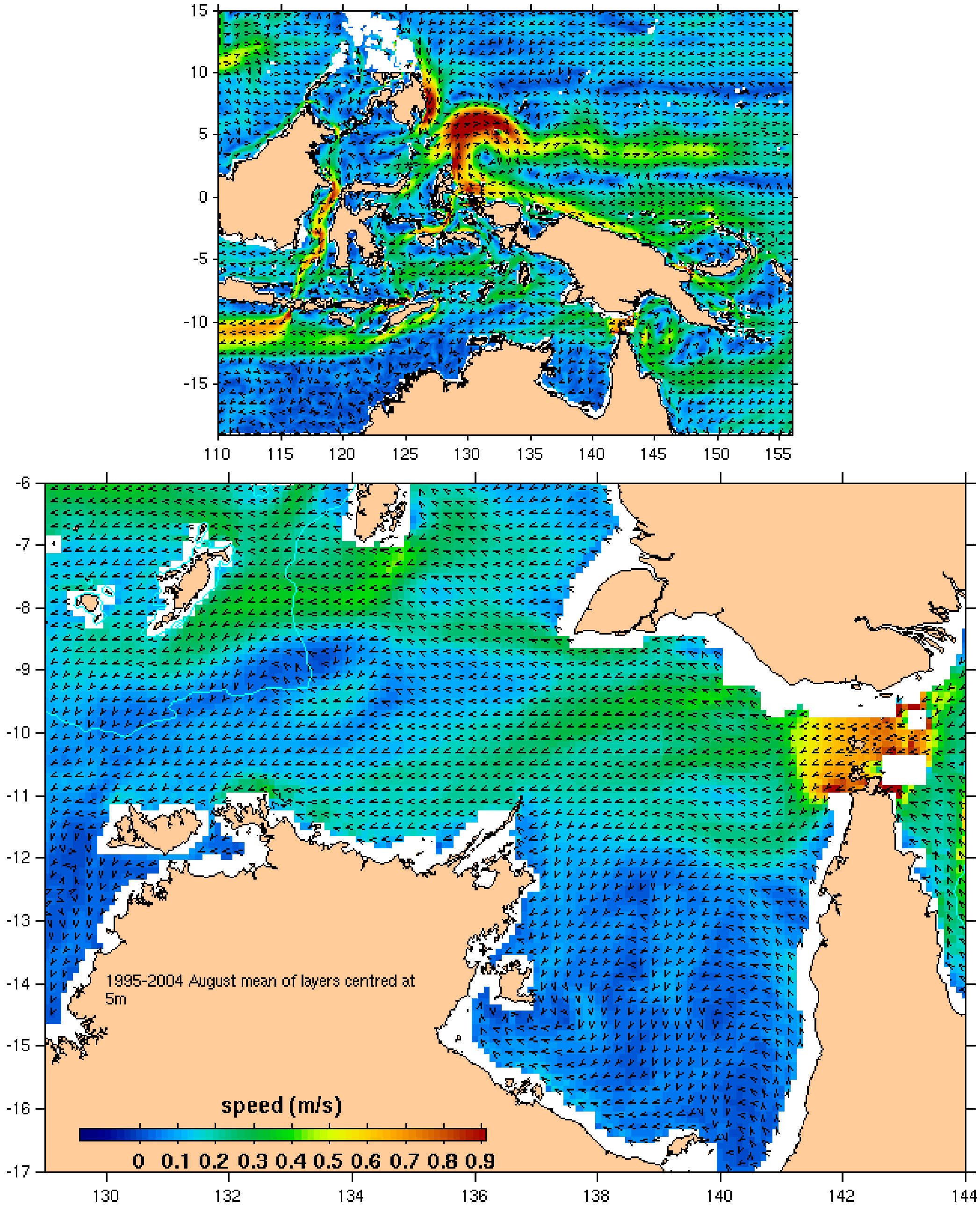

Figure 9 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the August (1995-2004) mean of surface layer (0-10m) velocity in BRAN2.1 as speed (see key) and direction (arrow heads).

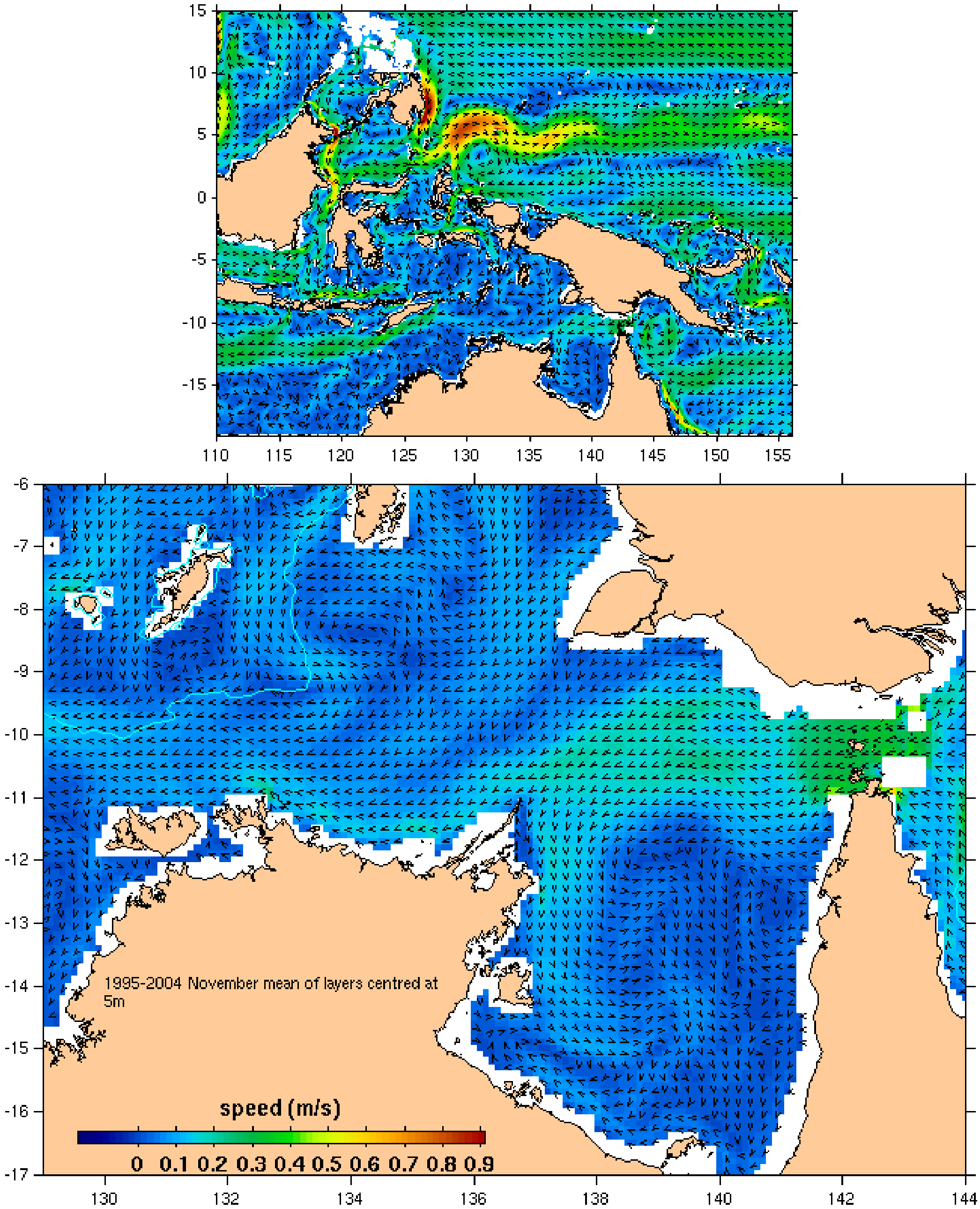

Figure 10 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the November (1995-2004) mean of surface layer (0-10m) velocity in BRAN2.1 as speed (see key) and direction (arrow heads).

For this study, the full archive of daily-averaged near-surface (0-10m average) velocity fields was used to track 'virtual drifters' by stepping their positions forward a few hours at a time using an accurate 4th-order Runge-Kutte integration. For runs of this 'offline particle tracking model' intending to simulate the motion of items closer to the surface (within 0-1m), an estimate of the near-surface wind-drift was added equal to 3% of the surface wind velocity. The same approach has recently been used by Bruce et al. (2007) for a study of the dispersal of the larvae of Southern Rock Lobster, which are close to the surface during the night.

For the simulations described here, the model was seeded with particles from a relatively small number of locations, 12 in the 'far field' and 11 in the 'near field' (Figure 3), every second day for a year at a time. These particles were then tracked for a second year during which no more were released from the starting points. The particle tracking model was run several times for all years between 1992 and 2006, using both the BRAN2.1 data set and the SPINUP4/5 data set which resulted from a long run of the model with the same atmospheric forcing, but no assimilation of ocean observations. Results from the two sets of model runs are essentially the same, so this report presents results of only the former.

3.3 Limitations of the Bluelink Model

The atmospheric and total heat and freshwater forcing applied to the model was 6-hourly fields from the European Centre for Medium-range Weather Forecasting. The ERA40 40-year Reanalysis (Uppala *et al* 2005, http://www.ecmwf.int/research/era/) was used for 1992-2002, while the operational product was used for 2003-2006. Each is believed to be the best available source of this information for the respective periods. ERA40 resolves the seasonal and intra-seasonal variability but with a relatively coarse 2.5º grid, it cannot adequately resolve some of the small-scale, energetic features, especially tropical cyclones. The operational product has finer (0.5º) resolution but less data are available for assimilation in real-time, compared with a re-analysis. There is therefore a risk that we are missing the potentially important impact of wind-forcing by poorly resolved meteorological features like cyclones.

For reasons of computational affordability, the multi-year runs of the model did not include the tide-generating forces. Schiller (2004) showed (using the precursor model to the present one) that this has some negative impacts on model accuracy in deep water because of the role that tides play in enhancing mixing. In shallow regions, tides can generate topographically-rectified flows, and can also have the effect of *reducing* the strength of wind-driven currents, by generating turbulence in the water column. This has the same effect as roughening the sea floor, because friction scales approximately with the square of the instantaneous velocity. We have demonstrated this effect experimentally with our model by running it for a trial period with the tide-producing forces included. This was an expensive experiment so the integration period could only be 6-months long (April-September). The effect can be seen by comparing Figure 11, showing a speed of 0.9m/s in Torres Strait, with Figure 12, where it is only 0.4m/s, even though the sea level difference along the Strait (not shown) is essentially the same. Unfortunately, we cannot compare the two models for the Wet Season, because the model has not been run with tides for that time of year. The next version of the Bluelink model, due to be run in late 2008 as part of the Bluelink II project, will include a spatially-dependent bottom friction enhancement term to reduce the size of this error, without incurring the cost of explicitly including tides.

The second major weakness of the Bluelink model, from the point of view of being applicable to a study of marine debris, is that the 10m vertical resolution of the model is too coarse to simulate the shear that is known to exist in the surface layers of the ocean. The addition to the model's surface layer average of an additional 'wind drift' velocity is designed to represent this shear but it is only a first approximation. It is inevitable that different results would occur if the model could be run with greater vertical resolution. Subject to available computing power, the Bluelink team hopes to improve the vertical resolution for the next run of the model in late 2008. An alternative strategy is to run a regional, high-resolution model nested within the global model. This was done recently for the Torres Strait region by Saint-Cast and Condie (2006), but to do this for the much larger region of interest here was beyond the scope of the present study.

As mentioned above, the Bluelink model is on a 10km by 10km horizontal grid, and a 10m vertical grid. For numerical reasons, no part of the model can be less than two grid cells wide, or two grid cells deep. This means some narrow passages have been closed, and some widened. Some shallow areas have been filled in, some have been made deeper. For this reason, this model would not be appropriate for simulating the stranding process, even with tides included.

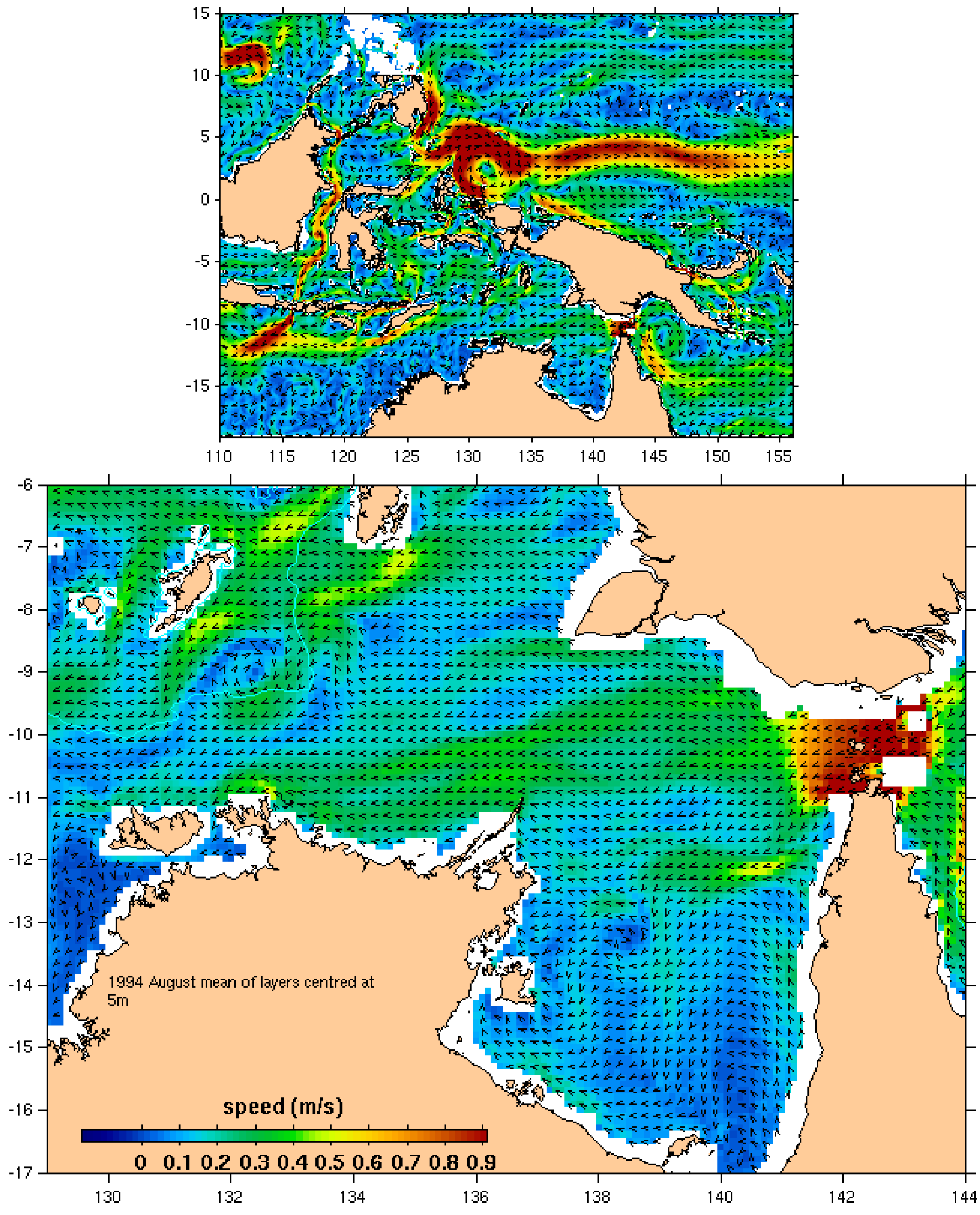

Figure 11 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the August 1994 mean of surface layer (0-10m) velocity in BRAN2.1 as speed (see key) and direction (arrow heads).

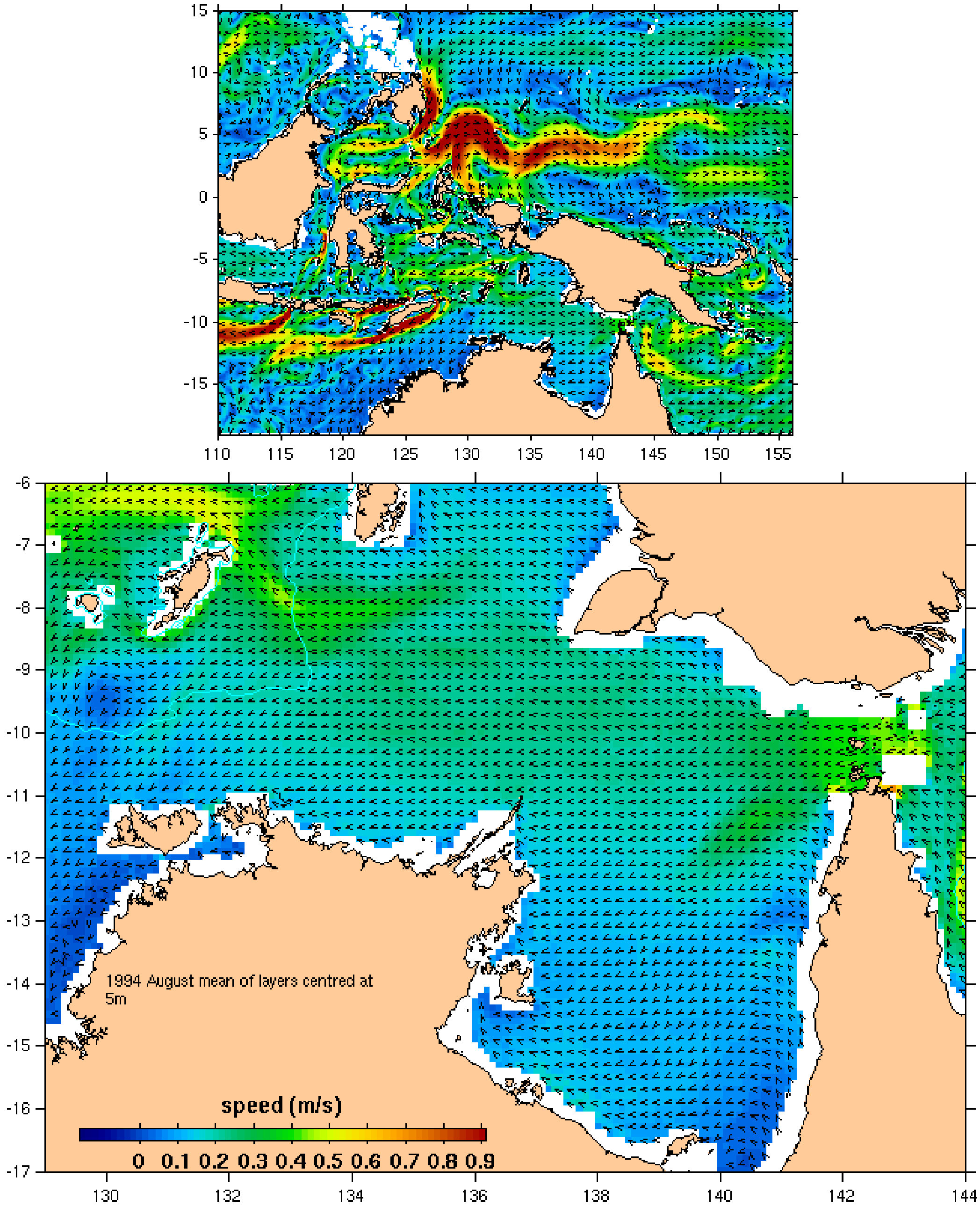

Figure 12 Map of the whole study region (upper panel) and northern Australia (lower panel), showing the August 1994 mean of surface layer (0-10m) velocity (speed as per the key and direction as arrow heads) in the test version of the Bluelink model that included tidal forcing.

4. RESULTS

4.1 Global Drifters

Of the 920 drifters that have entered the study region, only 5 entered the Arafura Sea, as detailed below:

Three drifters traversed the Arafura Sea immediately north of the Gulf of Carpentaria, all in a westward direction, having passed through Torres Strait in June 1998 or July 2007 during the Dry Season (Figure 13). Two of these immediately stranded on the Papua New Guinea coast. The third, drifter 9525564, went through Torres Strait on 9 June 1998 and stranded on Palau Jamdena (7ºS 132ºE), 1202km to the west-north-west 72 days later, crossing the Arafura Sea at an average speed of 0.2m/s (in good agreement with Figure 12).

Two drifters entered the Arafura Sea from the west, but their tracks end at 135ºE, in the northern Arafura Sea. Both did this in February 1994 (Figure 14) during the Wet Season. They came from the northern Indian Ocean, one via Lombok Strait and one via the Sawu Sea (north of Timor).

Five drifters were tracked in the Gulf of Carpentaria near where they were deployed. They did not drift into the Gulf of Carpentaria.

Drifter track segments for the individual calendar months are at http://www.marine.csiro.au/~griffin/debris/drifters/monthly/index.html .

In apparent contrast with the fact (Figure 2) that many derelict fishing nets are found in the Gulf of Carpentaria, these drifter tracks suggest that there is very little surface-layer inflow to the region. But this is probably an under-estimate, for two reasons. One is that these drifters have a conspicuous surface buoy that may attract the attention of mariners in the region. Screening of the data specifically tests for the sudden change of the drifter's velocity to the much higher speed of a vessel. A second is that they have a 20m-long sea-anchor that may snag on reefs and other underwater features, thereby reducing their chance of traversing the archipelagos and reef systems bordering the Gulf of Carpentaria. Tracks terminating at the coast in Figure 13 and Figure 14 document these strandings. These two reasons, together, possibly explain the fact that no drifters have yet made a complete transit of Makassar Strait, even though this is known to carry much of the transport of the Indonesian Throughflow (Schiller *et al*. 2006).

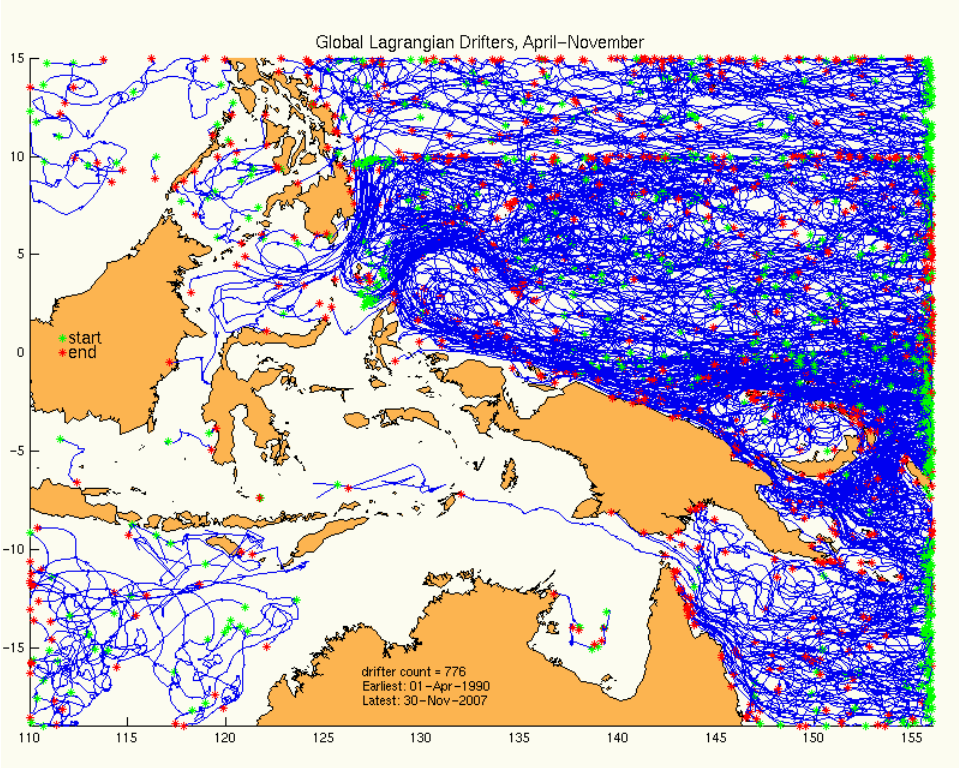

Figure 13 Tracks of Global Drifters during the Dry Season (April-November), for 1990-2007. Start and end points of track segments are shown in green and red, respectively. Note that three drifters are shown to have moved from the Coral Sea through the Torres Strait.

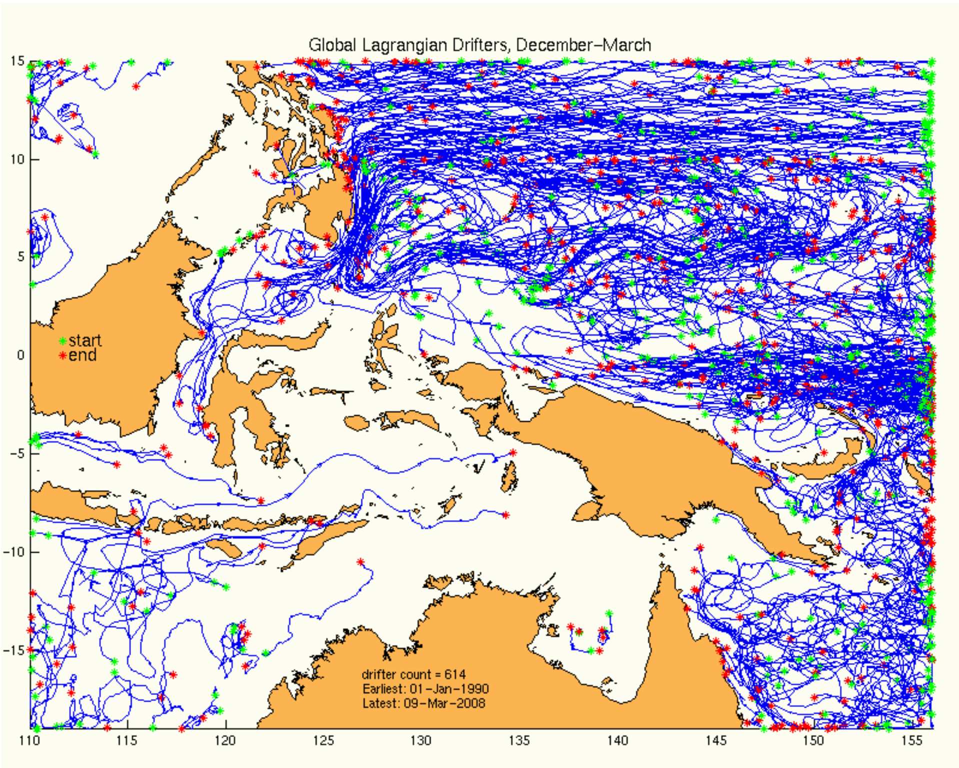

Figure 14 Tracks of Global Drifters during the Wet Season (December-March). Start and end points of track segments are shown in green and red, respectively. Note that two drifters are shown to have entered the Arafura Sea from the northern Indian Ocean.

4.2 Bluelink model

The best way to visualize the results of the modeling is to view animations of the daily movement of 'virtual drifters', but the results can also be summarized on a single page by showing the positions of the virtual drifters at stages through the year. The results are shown as sets of tracks, one page per release point, per year of release. For clarity, tracks of deeply submerged virtual drifters (representing nets hanging down to 10m) seeded far from Australia are shown separately from those seeded nearer to Australia (Figure 3). Tracks of shallow submerged virtual drifters (representing items floating entirely in the top 1m of the water) are only shown for those released nearer to Australia.

Far field release points, deep submerged (0-10m):

- 2002 release: Figure 15,
- other years: http://www.marine.csiro.au/~griffin/debris/e007/hatregsuml/
- tracks: http://www.marine.csiro.au/~griffin/debris/e007/tracks/
- animation: http://www.marine.csiro.au/~griffin/debris/e007/2004e007.AVI

Near field release points, deep submerged (0-10m):

- 2002 release: Figure 16,
- other years: http://www.marine.csiro.au/~griffin/debris/e006/hatregsuml/
- tracks: http://www.marine.csiro.au/~griffin/debris/e006/tracks/
- animation: http://www.marine.csiro.au/~griffin/debris/e006/2004e006.AVI

Near field release points, shallow submerged (0-1m):

- 2002 release: Figure 17
- other years: http://www.marine.csiro.au/~griffin/debris/e013/hatregsuml/
- tracks: http://www.marine.csiro.au/~griffin/debris/e013/tracks/
- animation: http://www.marine.csiro.au/~griffin/debris/e013/2004e013.AVI
- 2000 release: http://www.marine.csiro.au/~griffin/debris/e013/2002e013.AVI

Trajectories of virtual drifters are remarkably similar to the trajectories of real drifters in many regards. The southward Mindanao current feeding into Makassar Strait and clockwise Halmahera Eddy are clear (http://www.marine.csiro.au/~griffin/debris/e007/monthly/), as are many other well-known features of the regional oceanography.

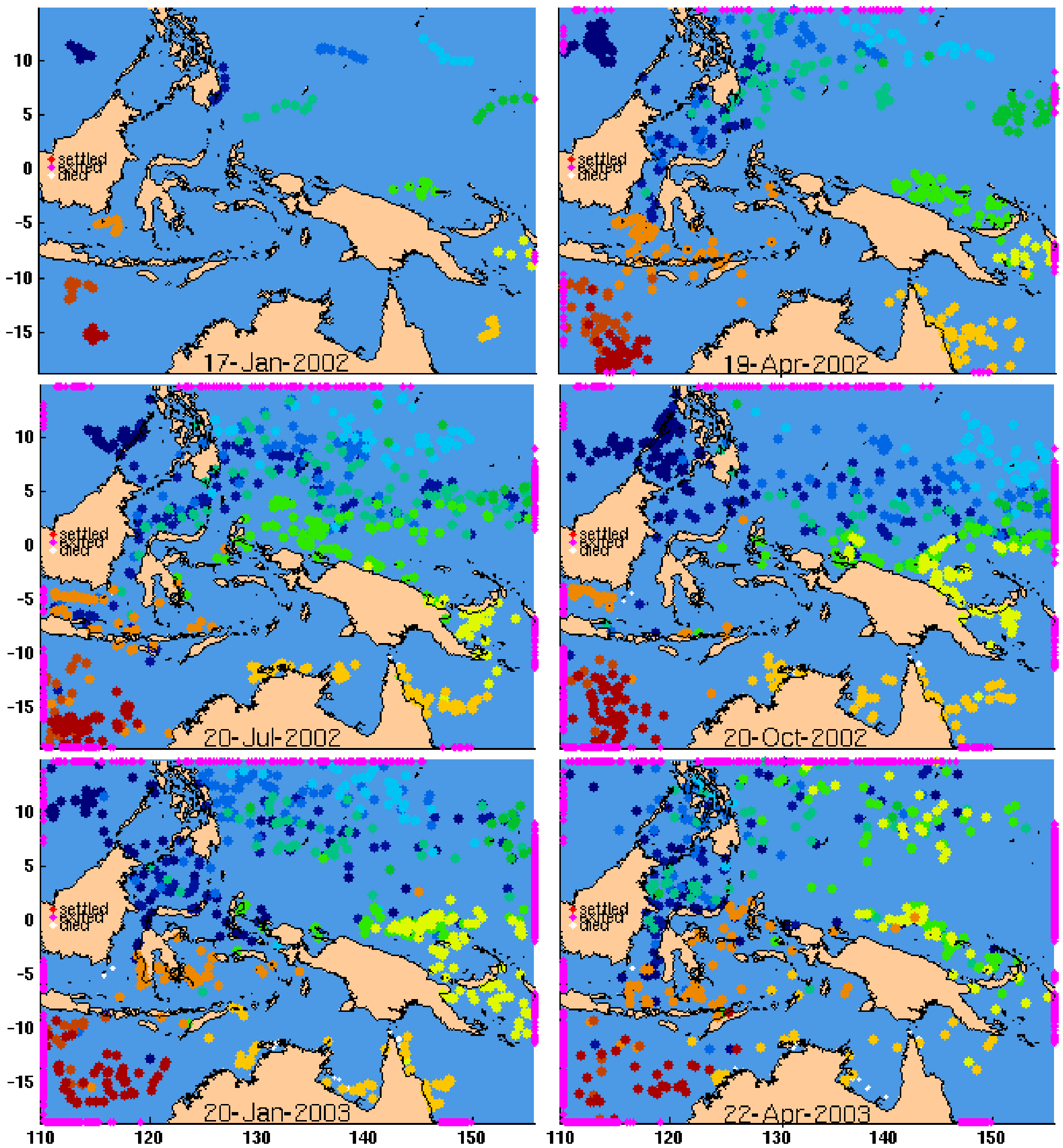

Figure 15 Positions at 3-month intervals of deep-submerged virtual drifters (each coloured to indicate its release point) released in the far field during 2002. Magenta symbols around the borders denote points where virtual drifters left the model domain.

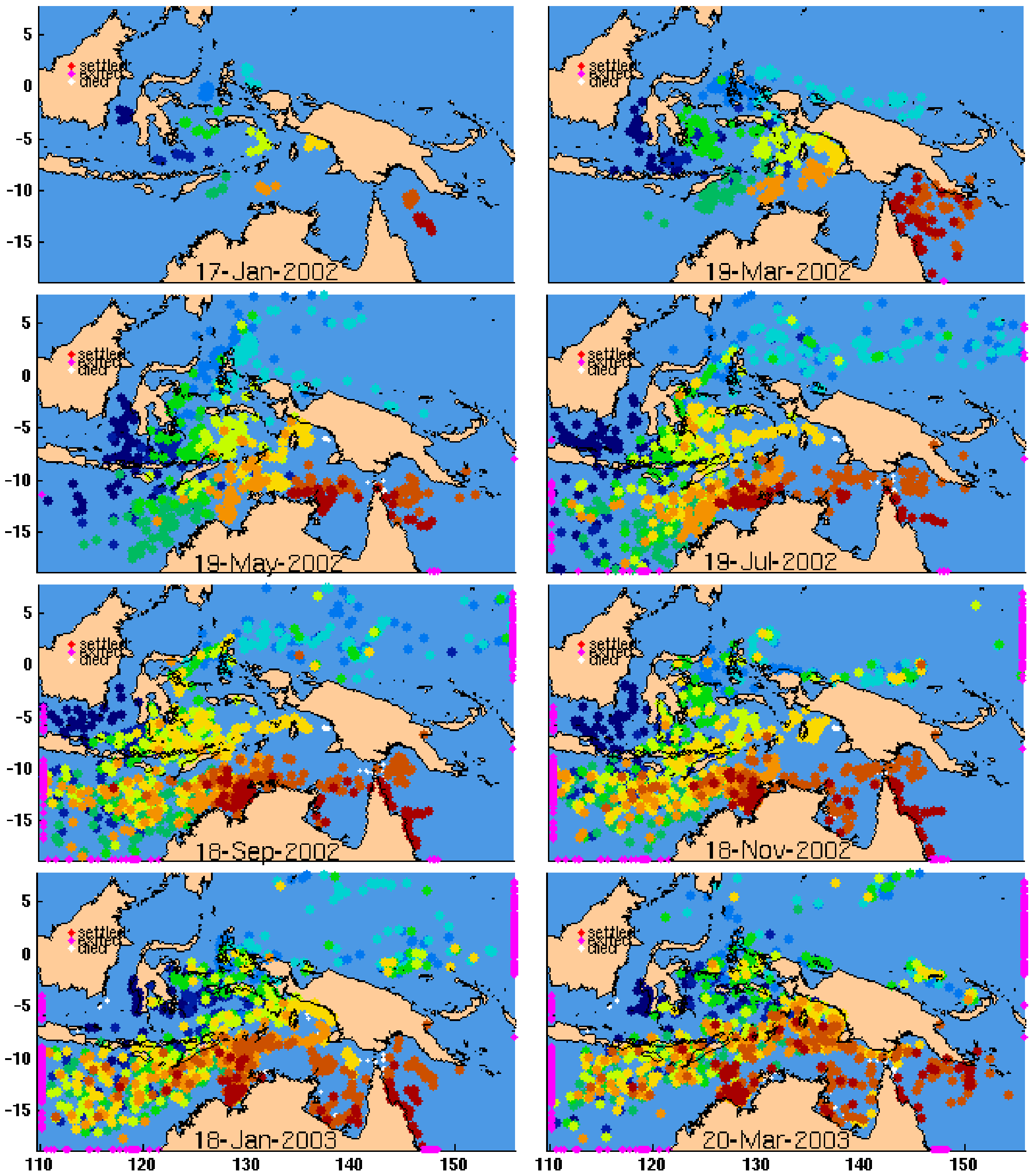

Figure 16 Positions at 2-month intervals of deep-submerged virtual drifters released in the near field during 2002.

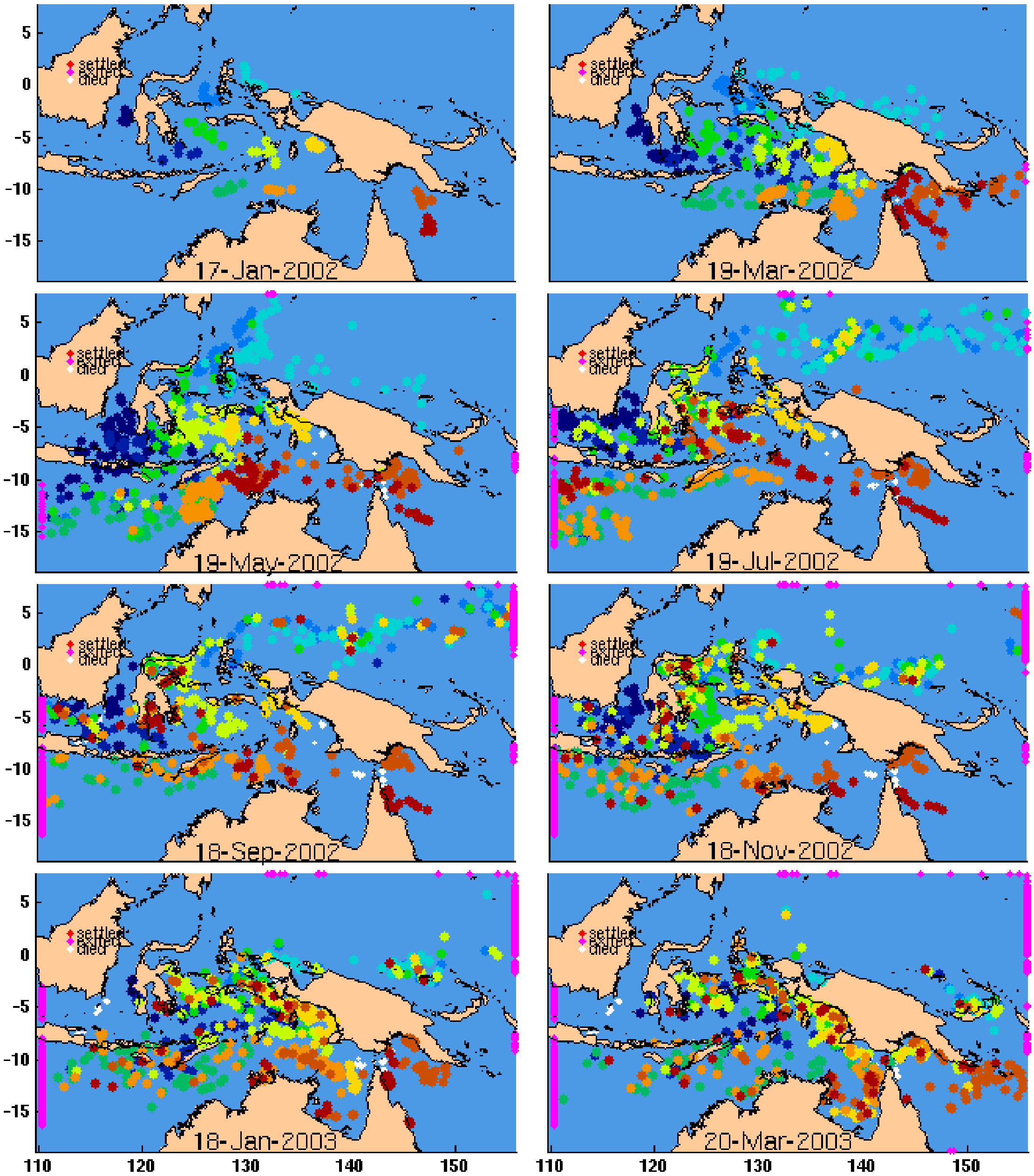

Figure 17 Positions at 2-month intervals of shallow-submerged virtual drifters released in the near field during 2002.

4.2.1 Deep-submerged virtual drifters of far field origin

In April – October (mainly April – June), several virtual drifters go westward through Torres Strait to the Arnhem Land and Groote Eylandt coasts (Figure 18).

In November-March (
Figure 19), a few of these move to the eastern side of the Gulf of Carpentaria, and there is north-eastward movement of a few virtual drifters in the Arafura Sea towards West Papua (Indonesia). What is conspicuously absent, however, is any large number of virtual drifters coming close to Arnhem Land or entering the Gulf of Carpentaria from the west.

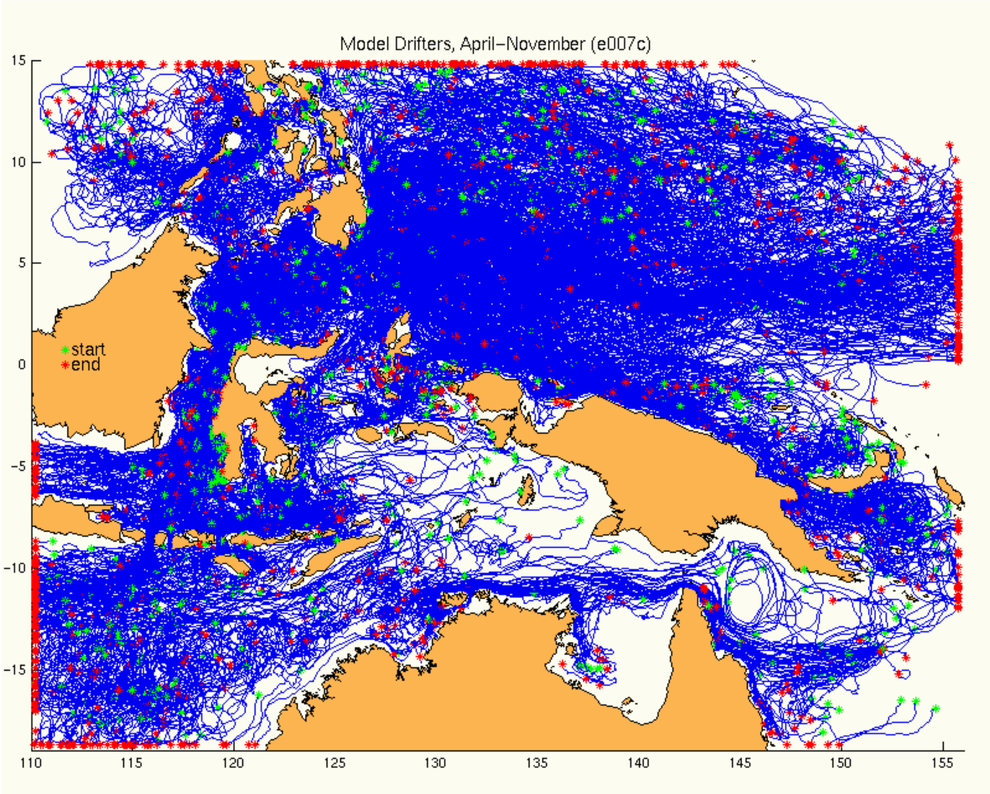

Figure 18 Tracks during the 1999-2003 Dry Seasons of deep-submerged virtual drifters seeded in the far field. Start and end points of track segments are shown in green and red, respectively.

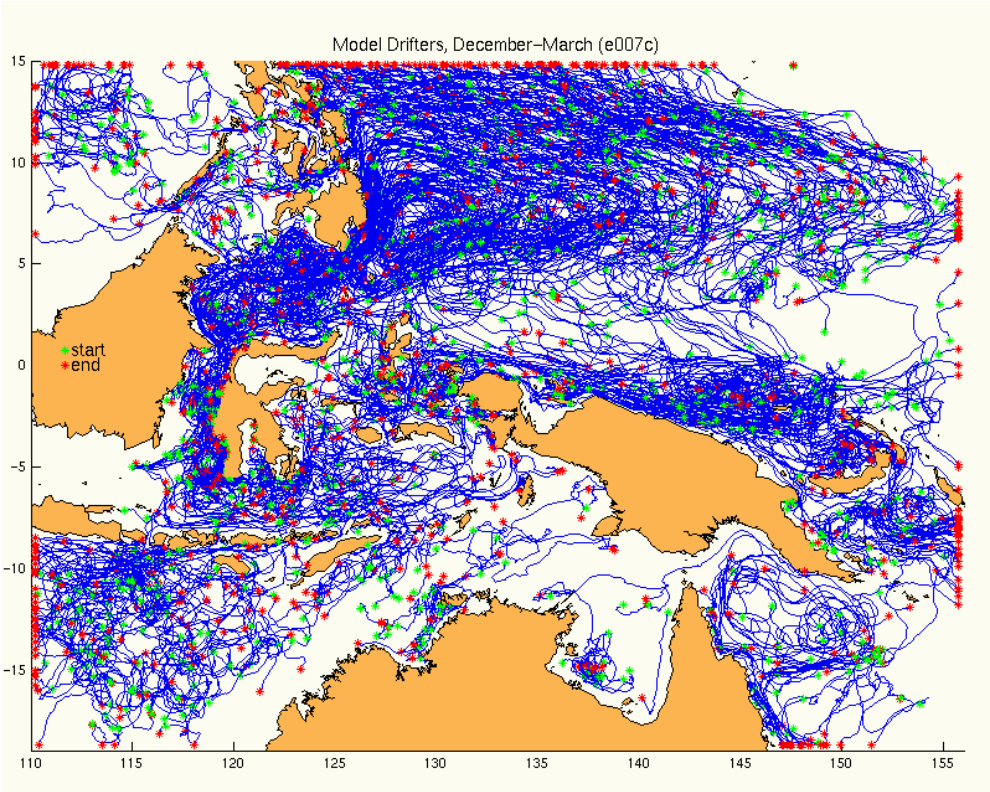

Figure 19 Tracks during the 1999-2003 Wet Seasons of deep-submerged virtual drifters seeded in the far field. Start and end points of track segments are shown in green and red, respectively.

4.2.2 Deep-submerged virtual drifters of near field origin

Even when the model is seeded with drifters in the Indonesian Archipelago, very few of these enter the Gulf of Carpentaria. Of the four example years, it is only in some years, and only from the release points in the Arafura Sea that numbers, and then only a small fraction of the total, of virtual drifters seeded west of Cape Arnhem come close to the north Australian coastline (Figure 20). Virtual drifters released farther afield do not come close to the northern Australian coastline. Even in 1999, the year during which Saint-Cast and Condie (2006) estimated that the eastward transport through Torres Strait during the Wet Season was greatest, no virtual drifters released in the Eastern Banda Sea (Figure 21) entered the Arafura Sea.

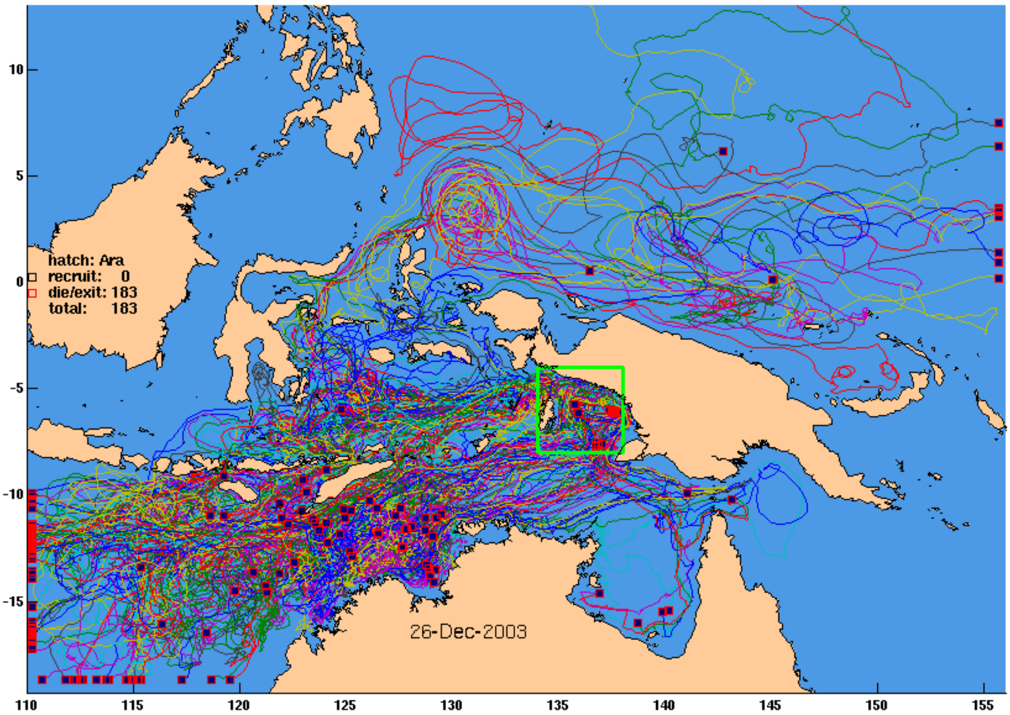

Figure 20 Tracks of deep-submerged virtual drifters released in 2002 in the northeast Arafura Sea (in the area highlighted by the square).

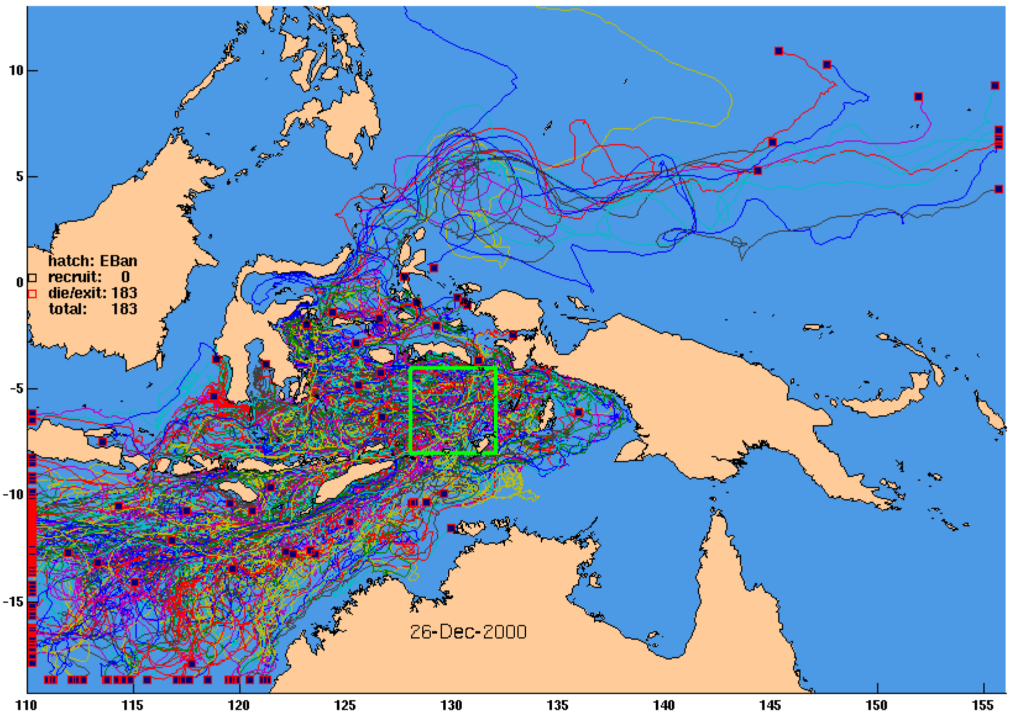

Figure 21 Tracks of deep-submerged virtual drifters released in 1999 in the eastern Banda Sea (in the area highlighted by the square).

4.2.3 Shallow-submerged virtual drifters of near field origin

To cover the possibility that using the 0-10m average velocity is not appropriate for many of the derelict fishing nets (because their centre-of-drag is closer to the surface), the model was also run for 5 release-years with an additional surface wind-drift velocity (as described in Section 3). Since this additional velocity is simply 3% of the wind velocity, this approach can also be thought of modelling the drift of a deeply-submerged item that is also subject to windage on a surface element.

Comparing Figure 22 with Figure 21 shows that the eastward movement during the Wet Season was only slightly increased for the virtual drifters released in 1999 in the eastern Banda Sea. In other years, however, the eastward displacement of some virtual drifters (only a small fraction of the total released) was considerably more but there was insufficient southward motion to take the items close to Australia.

It was only for the 2003 release-year that any (only 4 of the 183 released in the eastern Banda Sea) found their way into the Gulf of Carpentaria (Figure 23). A few from the north-west Arafura Sea release point also arrived in the Gulf of Carpentaria, as did quite large numbers from the release point near Darwin, but no virtual drifters arrived in the Gulf of Carpentaria from the release points farther afield to the west or north.

As with the other model runs, for every release year, a large fraction of the virtual drifters released in the Coral Sea either entered the Gulf of Carpentaria or passed westward close by the Arnhem Land coast (Figure 24). If we could realistically simulate the stranding process, many of these would doubtlessly end their paths in the regions where derelict fishing nets are actually found.

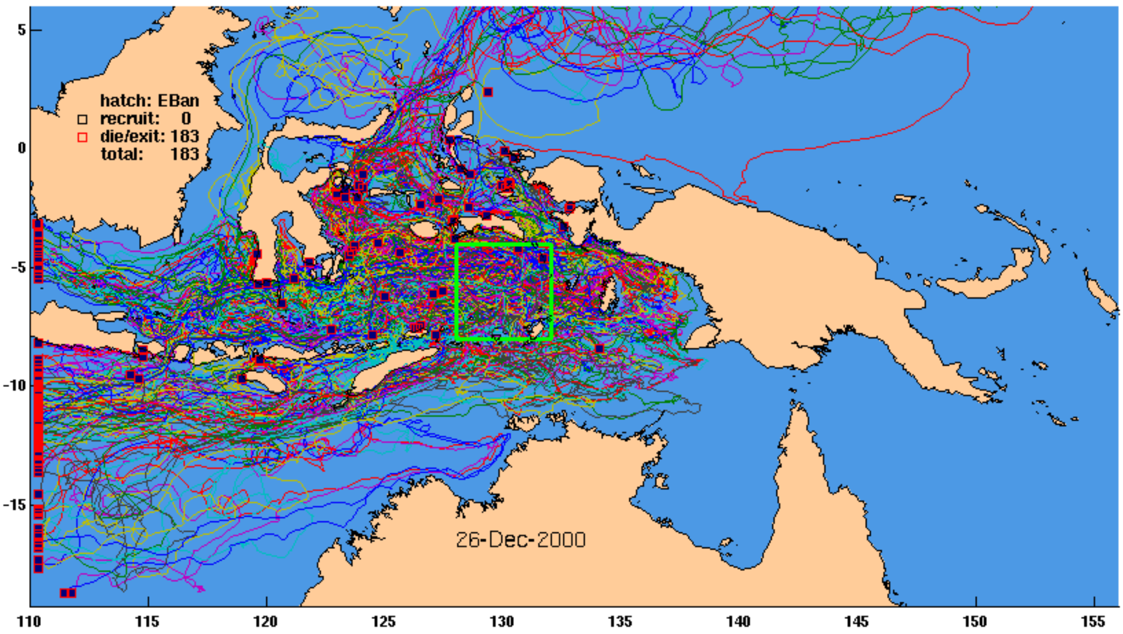

Figure 22 Tracks of shallow-submerged virtual drifters released in 1999 in the eastern Banda Sea (in the area highlighted by the square).

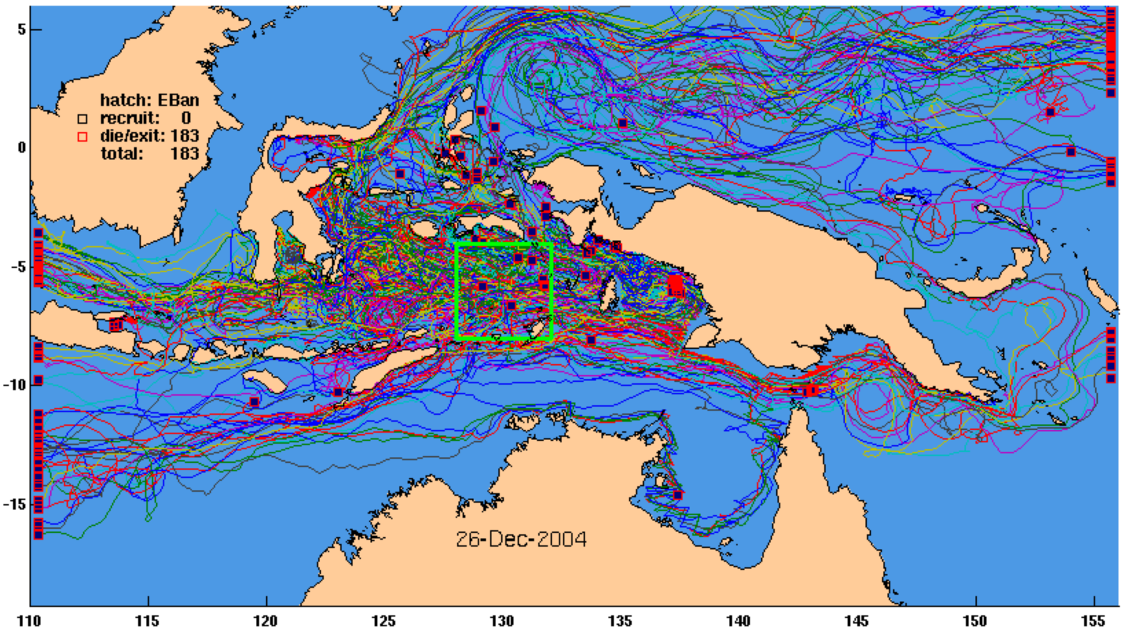

Figure 23 Tracks of shallow-submerged virtual drifters released in 2003 in the eastern Banda Sea (in the area highlighted by the square).

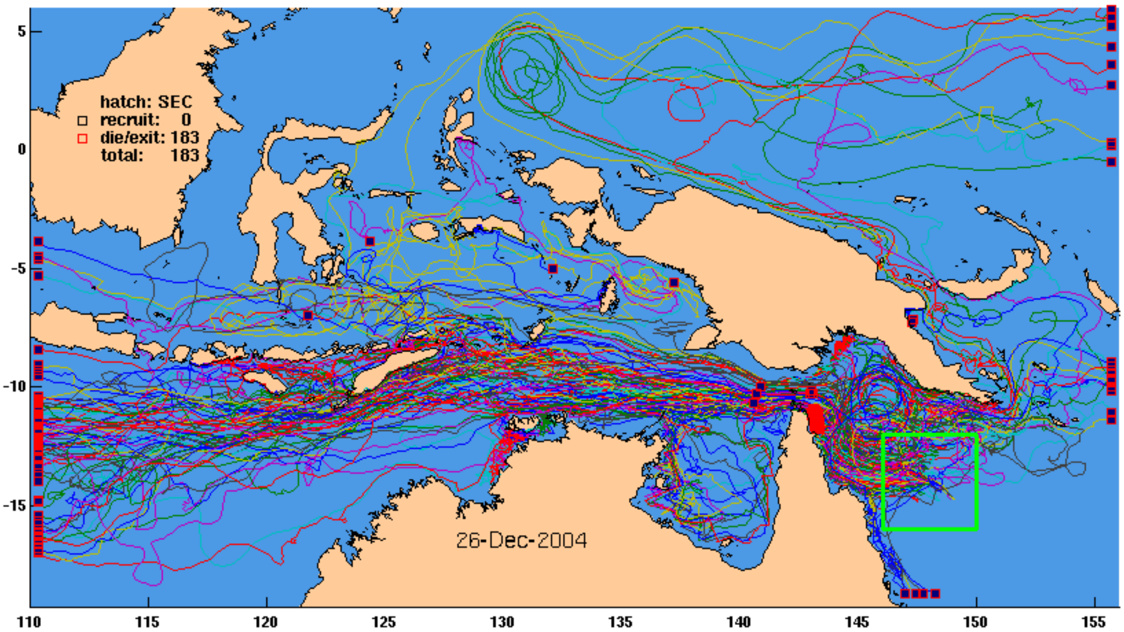

Figure 24 Tracks of shallow-submerged virtual drifters released in 2003 in the Coral Sea (in the area highlighted by the square).

5. DISCUSSION

The focus of the present study is to identify pathways of derelict nets that are found in the northern Australian marine environment, and to determine the geographic origins of those nets. Specifically, the study was designed to test the hypothesis that the combination of the Indonesian Through-flow and north-west monsoon winds could transport debris items, particularly derelict fishing nets, to the Gulf of Carpentaria from a wide range of locations in south-east Asian seas.

The study does not support the hypothesis. Instead, the modelling component of the study found that the ‘virtual drifters’ released in the south east Asian region mostly disperse into either the North Pacific Ocean or the Indian Ocean. Only a very small minority, and only from the closest regions (eastern Banda Sea and north west Arafura Sea) arrived in the Gulf of Carpentaria or along the coast of Arnhem Land. But this is not to say that no virtual drifters arrived in the Gulf of Carpentaria or along the coast of Arnhem Land. Many did, but these came from an unexpected quarter; the Coral Sea, after passing through Torres Strait.

The study also analysed the existing archive of trajectories of real, satellite-tracked drifters, or Global Drifters as they are formally known. A total of 920 of these were found to have transited the study region, but only 5 transited the Arafura Sea or Gulf of Carpentaria (not counting ones deployed in the Gulf of Carpentaria). Two approached from the west, none from the north-west, and three from the east. However, the absence of drifters completing a passage through the Indonesian Archipelago does not prove that there are no pathways of derelict fishing nets through this region. This is because it is unknown whether global drifters are salvaged by mariners in the region or are removed from circulation for any other reason.

Hence, there is no evidence from either the existing archive of global drifters, or from our model simulation to support the hypothesis that large items of marine debris that are not heavily influenced by wind reach Australia’s northern shores from points of origin west of Darwin (ie, the Indian Ocean) or north-west of the Arafura Sea (through Indonesia). This does not mean that the hypothesis is proven to be false, just that it is not proven to be true.

The model suggests that items drifting from the South Pacific and Coral Sea are likely to reach northern Australian coasts after passing through Torres Strait. There is also evidence, from the tracks of three real drifters, that drifting items do pass through the Strait. Thus the study shows that a major pathway of debris found in northern Australian waters may be the Torres Strait and the South Pacific an important source of derelict fishing nets.

To determine whether this hypothesis is plausible it is important to consider that the Dry Season is longer than the Wet Season (ie the southeast trade winds blow stronger and for longer than the northwest monsoon winds), and therefore a source of debris should be areas that are upwind of stranding areas for most of the year. The question then comes down to whether items can traverse the relatively narrow and shallow Torres Strait, and if there are any items drifting in the Coral Sea.

Since Captain Cook’s voyages, the lee-shore nature of the northern Queensland coast has been well known and is clearly demonstrated by the number of global drifters that strand on the Great Barrier Reef (Figure 25). The paths of the drifters reveal that the Pacific Ocean south of the Equator is the probable source of items washing up on the Great Barrier Reef, and/or passing through Torres Strait.

Which brings us to the principal question raised by this pilot study: Do many derelict fishing nets strand on the Great Barrier Reef? Surveys by diving and aerial reconnaissance have found very few (Dobbs, 2008), but the possibility cannot yet be ruled out.

If no, or few, nets strand on the Great Barrier Reef then it can safely be assumed that even fewer will pass through Torres Strait. Conversely, if many nets do strand on the Great Barrier Reef, then this study suggests that the South Pacific could be a major source region of the derelict nets found on the northern Australian coast.

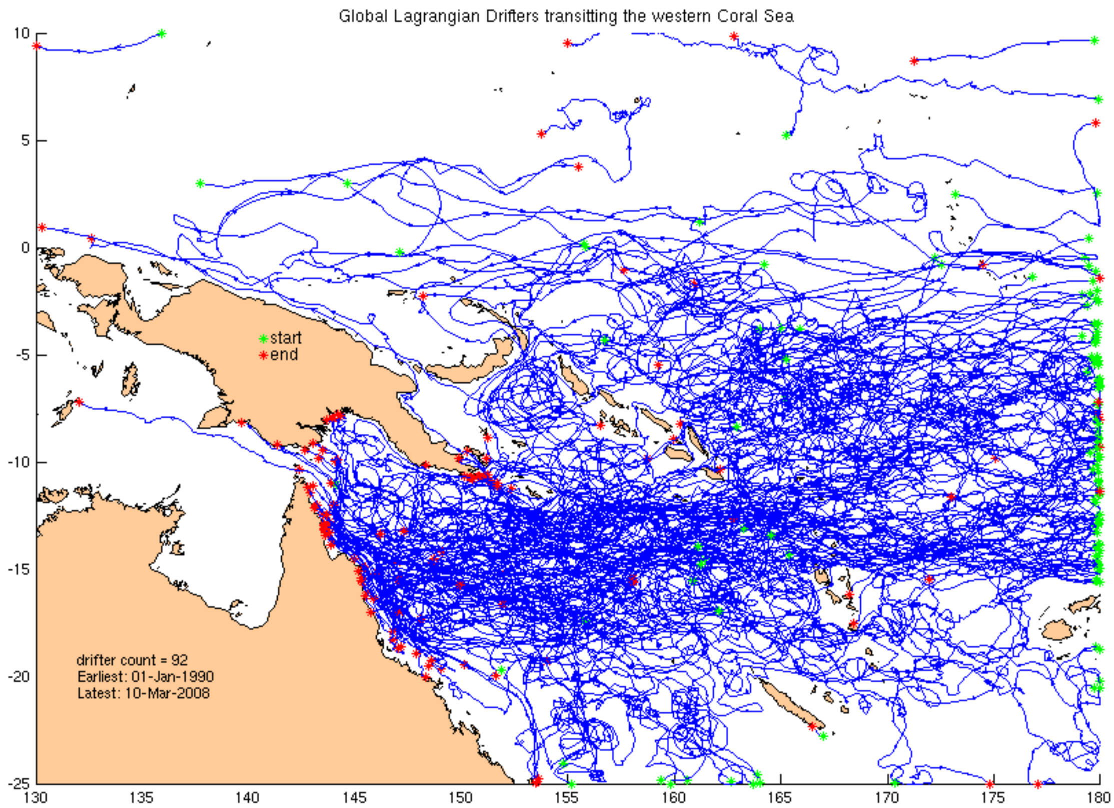

Figure 25 Tracks of Global Drifters that pass through or enter the western Coral Sea. Start and end points of track segments are shown in green and red, respectively.

6. SUGGESTIONS FOR FURTHER WORK

It was known from the beginning of the present study that ocean modelling would be heavily relied on since there are too few ocean observations relevant to the study region to be of use, either directly for the purposes of the study, or indirectly for model validation. For example, known *in-situ* measurements of ocean currents in the Arafura Sea and Gulf of Carpentaria include Church and Forbes (1983) and Wolanski and Ridd (1990). Accordingly, a comprehensive observation program in the present study region would provide important information to validate the ocean model used in present study.

The present study has concluded with one tentatively hypothesized origin of the derelict fishing nets, namely the South Pacific. This is somewhat surprising, but not unreasonable. Fortunately, the hypothesis is relatively easy to test because it also predicts that large numbers of nets should strand on the Great Barrier Reef, which, if true, would be a matter of some concern. At the time of writing, it is understood that very few nets have ever been found on the Great Barrier Reef (Dobbs, 2008). But due to the low number of observers, and the inherent nature of the outer northern Great Barrier Reef compared to the northern Australian shores west of Cape York, the possibility of nets stranding on the deep outer reefs cannot yet be ruled out.

Regardless of whether the South Pacific Ocean proves to be a significant source of nets stranding on northern Australian shores, the present study is not able to rule out the possibility that various regions west or north-west of Darwin are sources of nets, even though no evidence for this was found in the available drifter data, or the model simulations. This uncertainty results from the fact that only three satellite-tracked drifters have ever (according to the global drifter data base) transited the Arafura Sea. If more drifters had been tracked to the Arafura Sea there would be:

- examples of tracks that debris may take, and
- greater confidence in the model-derived estimates of surface velocity.

Accordingly, a recommendation is to deploy some drifters in the Arafura Sea, for example, at 10ºS 132ºE (Figure 26). These should be deployed at intervals during the beginning of the Wet Season, to see how far east (and/or north) they go, compared to model estimates for the prevailing conditions. There is less need to deploy drifters during the Dry Season because it is highly likely that they will go west and thus yield little new information of particular relevance to the present question. The drifters should be designed to be as invisible as possible, to counter the most likely explanation for the failure of standard drifters to transit the heavily-populated waters of the Indonesian archipelago, and equipped with a sea-anchor designed to mimic the vertical distribution of hydrodynamic drag typical of the types of nets of greatest concern.

These drifters cost about $5,000 each, so it is clearly not possible to release enough to derive robust statistics on the pathways of nets. Releasing 10 or 20 would, however, reveal any gross errors in the present model that may exist, and serve to help validate improvements to future models.

If the finding of the drifter study is that the model is essentially correct during the Wet Season, the possibility should be investigated that items are drawn into the Arafura Sea during the Dry Season in an upwind return flow that does not exist in the present model because the current model assumes too much water flowing through Torres Strait from the Coral Sea.

Other observational techniques that should also be considered for application across Australia's northern seas are those that are soon to be used in other regions of Australia, for the first time, as part of the Integrated Marine Observing System (FFI http://www.imos.org.au/). The observational method of most relevance to the drift of debris is probably HF radar (FFI http://imos.org.au/acorn.html). A HF radar in Torres Strait would be of great value to shipping by providing real-time maps of surface current velocity, as well as providing valuable data for scientific use. HF radars are normally deployed in pairs to resolve both vector components of the flow but in Torres Strait a single unit in the centre of the strait would suffice to measure the dominant east-west component of flow. These cost about $500,000.

The present study focussed on the question of how debris finds its way to certain places, but not on the processes which result in debris stopping rather than moving on. Exploring these processes could also be worth doing if a complete picture of debris accumulation is sought.

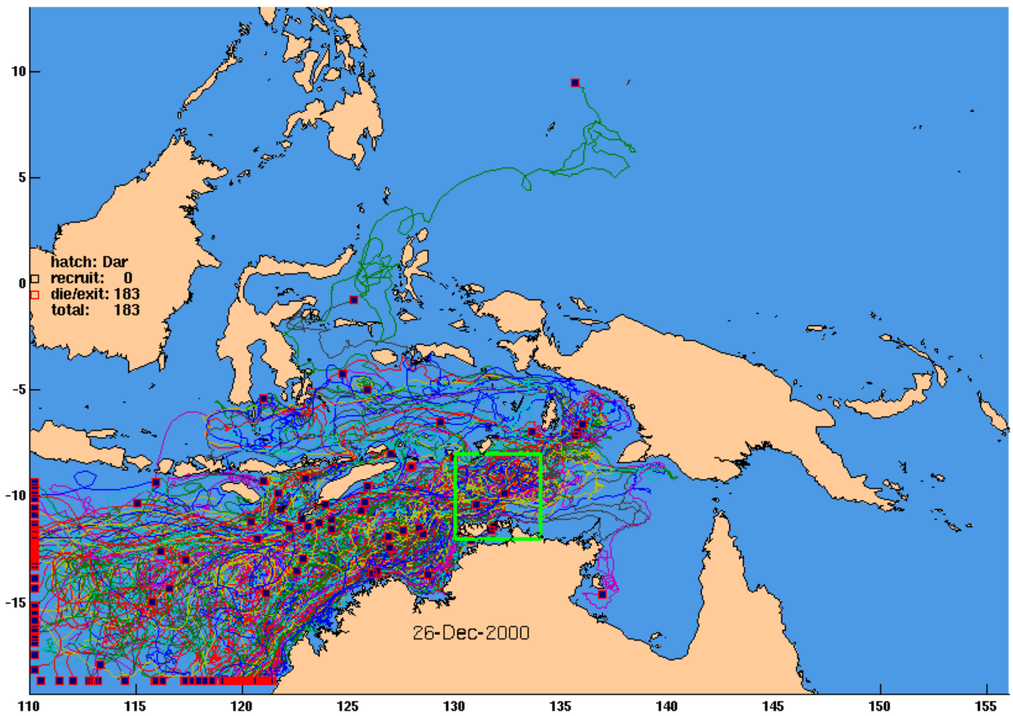

Figure 26 Tracks of deep-submerged virtual drifters released throughout 1999 at 10ºS 132ºE (in the area highlighted by the square).

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