APPENDIX B

Oil Spill Modelling Study

SUSTAINABILITY
FUTURE GROWTH

ENI-JPDA-06-105 PTY LTD

KITAN OIL SPILL RISK ASSESSMENT MODELLING

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EXECUTIVE SUMMARY

ENI-JPDA-06-105 PTY LTD (Eni) is planning to develop the Kitan oilfield, which is located in the region of the Sahul Banks in the Timor Sea. This report presents the findings of an oil spill modelling study to predict the trajectory and fate of both Kitan crude oil or diesel in the event of a spill occurring from the proposed Kitan Oilfield Development.

Six representative spill events for production were analysed:

- Scenario 1: a 7,000m^3 spill of crude oil over 24 hours, considered the largest instantaneous volume that would be spilt in the event of a rupture of a full cargo tank;
- Scenario 2: a 1,800m^3/day spill of crude oil over 56 days, representing a well blowout;
- Scenario 3: a 100m^3 spill of crude oil over 6 hours, representing the upper end of an accidental spill such as a transfer hose rupture or process leak;
- Scenario 4: an instantaneous 10m^3 spill of crude oil, representing the lower end of a significant accidental spill;
- Scenario 5: an 80m^3 spill of diesel over 6 hours, representing a loss from a ruptured fuel tank; and
- Scenario 6: a 2.5m^3 spill of diesel spill over 1 hours, representing a refuelling incident.

The assessment used an oil spill weathering model and coupled hydrodynamic and oil spill trajectory models for the Timor Sea. The models were run both deterministically and stochastically. In deterministic mode a single oil spill event is run and model. In stochastic mode multiple oil spill trajectory simulations were undertaken using historic wind data for summer and winter seasons.

The study found that the oil dispersion probability envelopes reflected the prevailing seasonal wind patterns. During summer, winds are predominantly from the west and the probability envelopes extended to the east whereas for winter, the reverse was true.

Environmentally sensitive areas in the region consist of shoals, small seamounts and reefs. The closest of these, Big Bank Shoals, is located 3km to the southwest of Kitan. The probability of oil spreading to the Big Bank Shoals was over 70% for the larger crude oil scenarios (7000m^3 over 24hrs and 1800m^3/day over 56 days) and for both diesel spill scenarios, and was 30% for the smaller crude spills. The minimum time to reach Big Bank Shoals was less than three hours during which time the spill volume would reduce by at least 60% due to evaporation.

Deterministic modelling indicated that spilled oil would remain at the sea surface. Thus, although oil may become entrained into the water column overlying the nearby Big Bank Shoals (particularly in winter), impacts on the benthic communities would not be expected to occur due to the water depth (≥20m water depth LAT), distance from the Kitan oilfield, and the degree of weathering and dilution that would occur prior to any potential contact.

Neither Kitan crude oil or diesel were predicted to make contact with land under any of the spill volume and season scenarios. Any spill occurring at the Kitan oilfield would be most likely to biodegrade at sea and should therefore be monitored and allowed to degrade naturally without the use of dispersants.

1. INTRODUCTION

1.1 BACKGROUND

ENI-JPDA-06-105 PTY LTD (Eni) is planning to develop the Kitan oilfield in the Timor Sea (Figure 1.1). This report presents the findings of stochastic and deterministic modelling study to predict the trajectory and fate of both Kitan crude oil or diesel in the event of a spill occurring during the construction or operation of the Kitan Oilfield Development. The results from this work will form part of ENI's Environment Management Plan (EMP) and assist the development of an effective Oil Spill Contingency Plan (OSCP) for the project.

The Kitan oilfield is situated in Joint Production Development Area (JPDA) in the Timor Sea, approximately 170km south of the coast of Timor-Leste and 360km north of the coast of Australia. It is located on an area of the Australian continental shelf known as the Sahul Banks, in water depths of approximately 300m. Shallow shoals and small sea mounts occur along the edge of the shelf (Figure 1.2), including:

- Big Bank, 3km to the southwest;
- Karmt, 50km to the southwest;
- Echo, 90km to the northeast; and
- Pea Shoals, 200km to the southwest.

Most of these shoals and reefs support assemblages of scleractinian coral as well as coralline algae. The nearest emergent reefs, Ashmore, Cartier and Hibernia, are located on the southwest end of Sahul Shelf. The nearest, Hibernia reef, is more than 300 km to the southwest of the Kitan oilfield.

1.2 OBJECTIVE

The objective of the study is to determine the likely fate of an oil spill occurring during the development and operation of the Kitan oilfield.

1.3 SCOPE

The scope of this study included:

- a review of Kitan oilfield oil properties;
- an assessment of oil weathering of Kitan oilfield crude and Australian diesel; and
- oil spill trajectory modelling, taking into account Kitan oil properties, weathering behaviour, and seasonal tide and wind conditions.

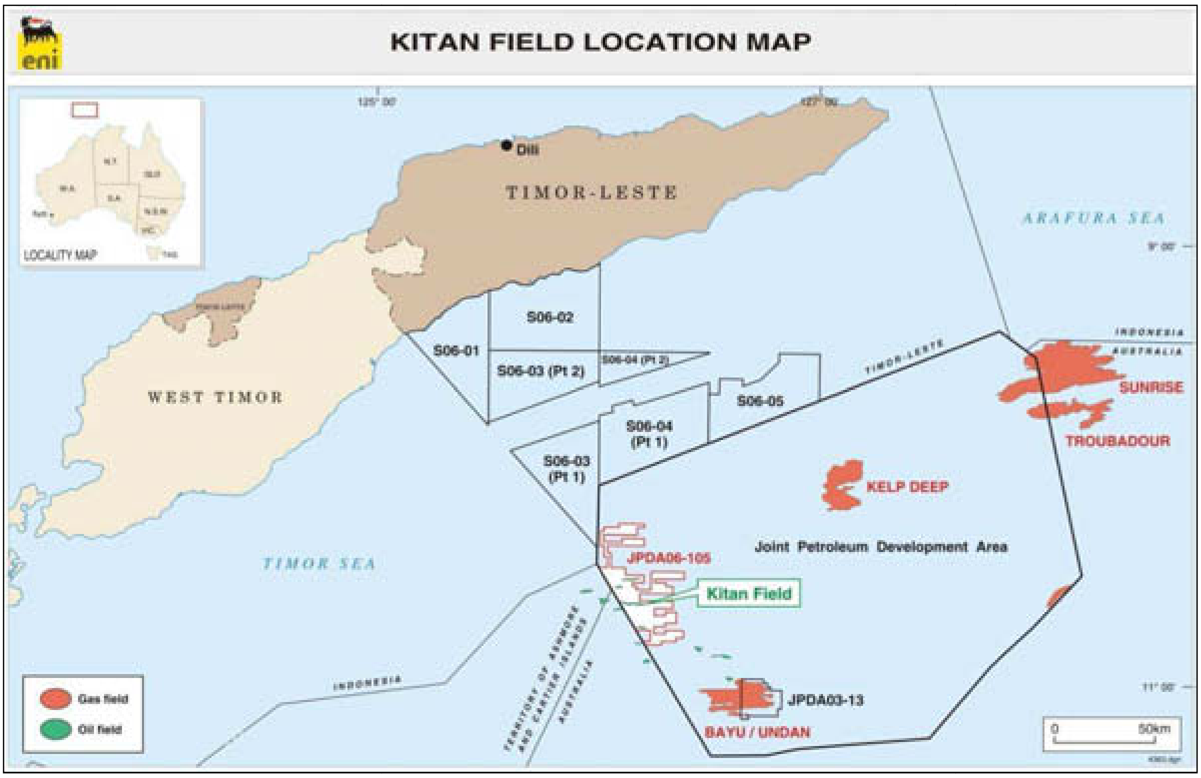


Figure 1.1 Location of the Kitan oilfield

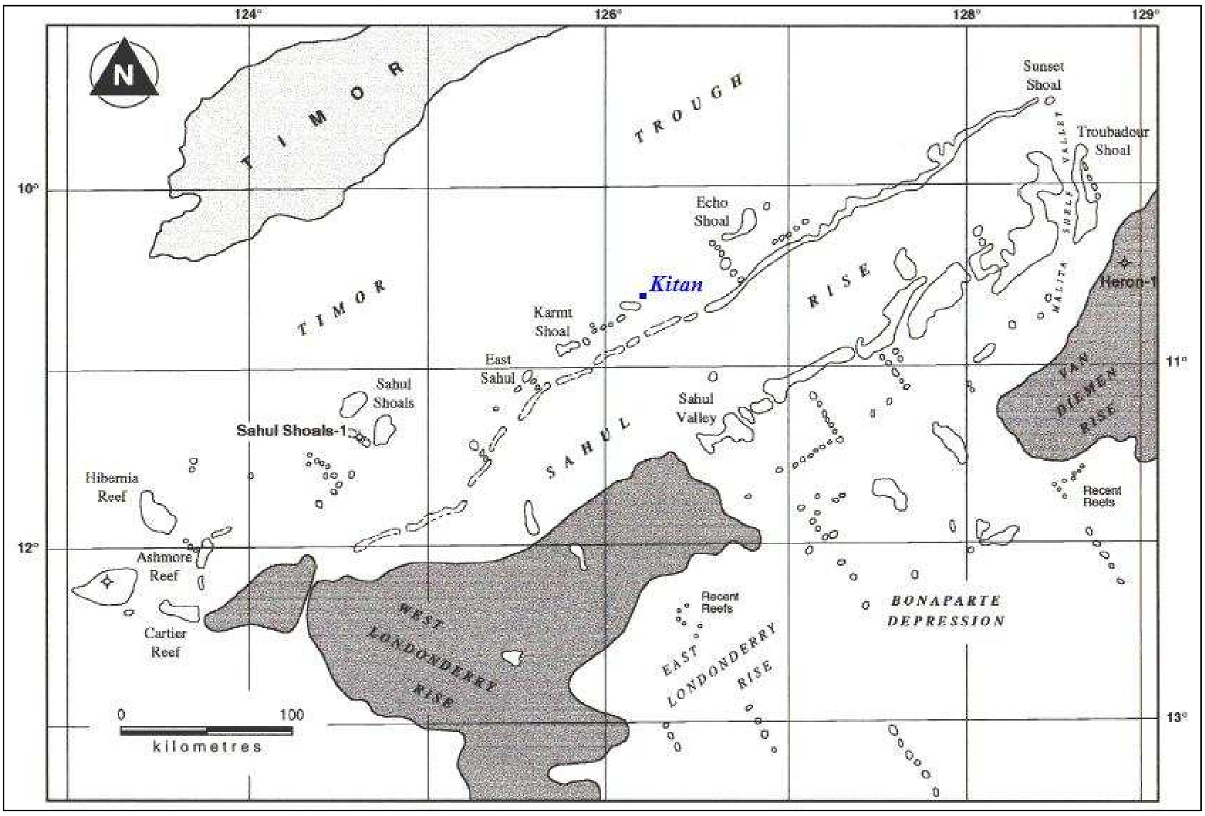


Figure 1.2 Location of the Kitan oilfield in relation to regional seamounts and shoals

2. DESCRIPTION OF RECEIVING ENVIRONMENT

2.1 CLIMATE

The Timor Sea has two distinct seasons: "winter" from April to September and "summer" from October to March. The short period between the two seasons is termed the transition season. During this period, either winter or summer regimes could dominate.

2.1.1 Winter

The "winter" dry season (April to September) is characterised by steady easterly (northeast to southeast) winds of 5 to 13m/s driven by the South East Trade Winds over Australia.

2.1.2 Summer

The "summer" season (October to March) is the period of the predominant North West Monsoon. It is characterised by mostly westerly (west-southwest) winds of 5m/s for periods of 5 to 10 days with surges in the airflow of 10 to 18 m/s for the period of 1 to 3 days. Tropical cyclones can develop between November and April resulting in short lived, severe storm events often with strong but variable winds.

2.2 WINDS

Joint frequency distributions were calculated from 10 complete years (July 1997 – Jun 2007) of verified NCEP ambient modelled data for the Kitan location. Wind roses for the winter, summer and transitional seasons are presented in Figure 2.1. These display the expected seasonal variation in prevailing wind direction, with westerlies (southwest-northwest) persisting from October to March, and a fairly rapid shift to easterlies (northeast – southeast) in late March or early April that then persist until late October or early November before the return to the westerlies.

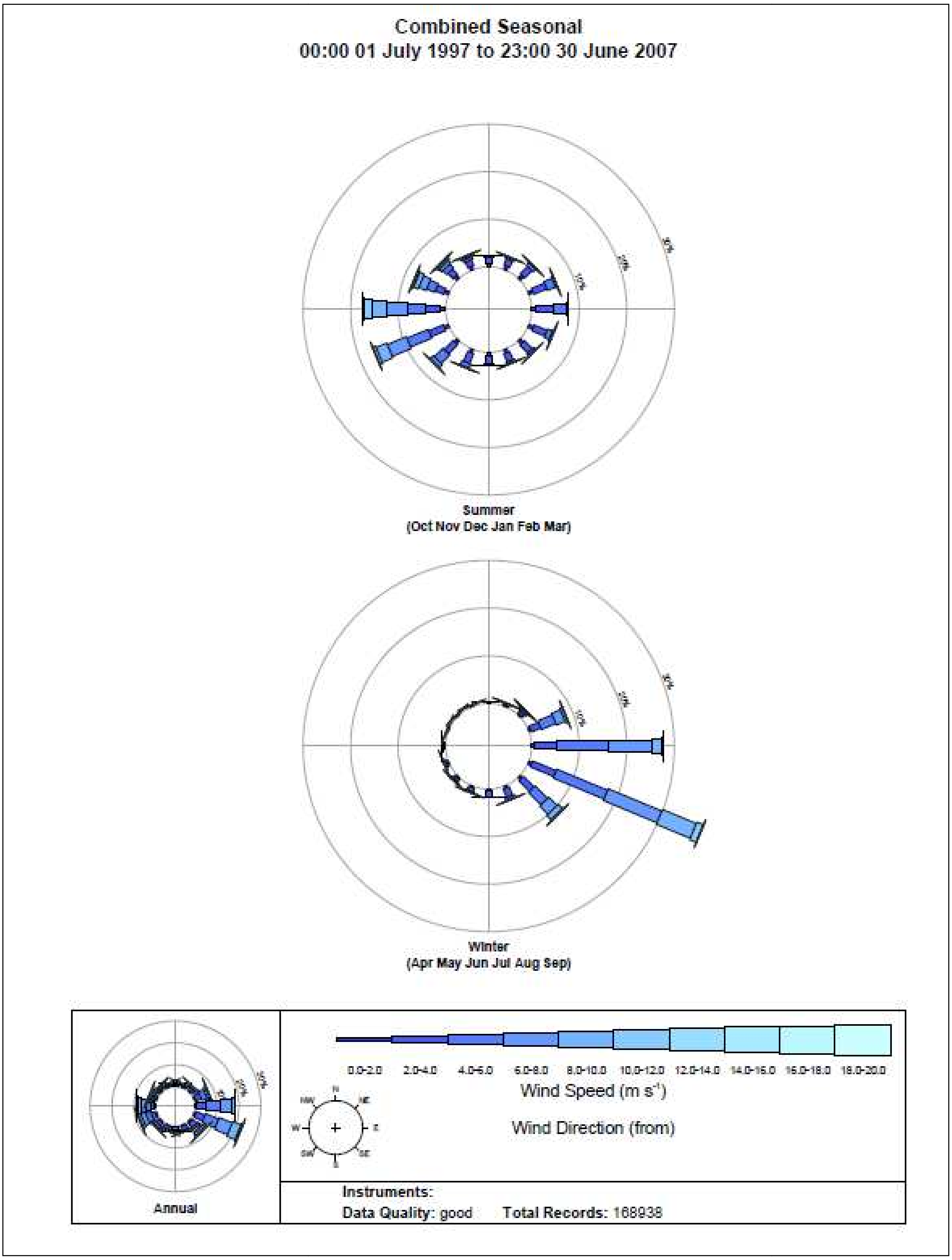


Figure 2.1 **Seasonal wind roses for the Timor Sea (Saipem Energy Services 2009)**

2.3 TIDAL RANGES

The tides in the region of the Kitan oilfield are semidiurnal (two highs and lows each day) with a slight diurnal inequality (difference in heights between successive highs and low). There is a well defined spring-neap lunar cycle, with spring tides occurring 2 days after the new and full moon. Table 2.1 provides the standard tidal levels for the Kitan oilfield. Highest Astronomical Tide (HAT) is 3.46m and the mean ranges for spring and neap tides are 2.07m and 0.29m, respectively.

Table 2.1 Standard tide levels for Kitan (Saipem Energy Services 2009)

Northern Endeavour	Level (m)
Highest Astronomic Tide (HAT)	3.46
Mean High Water Springs (MHWS)	3.12
Mean High Water Neaps (MHWN)	1.97
Mean Sea Level (MSL)	1.82
Mean Low Water Neaps (MLWN)	1.68
Mean Low Water Springs (MLWS)	0.39

2.4 CURRENTS

The main forces contributing to surface water motions at the Kitan oilfield are:

- general oceanic circulation
- astronomical tides; and
- wind stress.

The Pacific – Indian Throughflow flows south through the Indonesian Archipelago and into the Eastern Indian Ocean bathing the Browse Basin in warm, relatively low salinity seawater. At the Kitan oilfield, this may add a small westerly component to the current regime. Current speeds vary depending on the season. The lowest current speeds would occur in April at the end of the northwest monsoon when winds blow towards the Pacific whilst the highest speeds would occur in September, associated with the southeast monsoon (Wijffels *et. al*. 1996).

Near-surface tidal currents in the region are anti-clockwise rotational, and flood towards the south-southeast and ebb towards the north-northwest. Current speeds range from about $0.2ms^{-1}$ on neap tides to $0.4ms^{-1}$ on spring tides.

Surface currents are expected to reflect seasonal wind regimes. The'typical 'rule of thumb' for wind driven surface currents is that they are approximately 2% – 4% of the wind speed 10m above the sea surface. Local wind-driven surface currents may attain maximum speeds of $0.7ms^{-1}$ during extreme monsoonal or Trade Wind surges. More typically however, wind-driven surface current speeds would be in the range of $0.2ms^{-1}$ to $0.4ms^{-1}$.

2.5 WAVES

Waves at the Kitan oilfield will comprise contributions from:

- Southern Ocean swells;
- summer monsoonal swells;
- winter easterly swells; and
- locally generated seas.

The most persistent swell arrives from the south and southwest with typical heights of 1m in summer and 2m in winter. Since longer period swell suffers less dissipation, periods of long-travelled swell commonly reach 18 seconds and occasionally exceed 20 seconds.

Shorter period swell (6 to 10 seconds) may result from summer westerlies over the western portions of the Timor Sea, winter easterlies over the Arafura Sea and the eastern portions of the Timor Sea and from tropical cyclones.

Local wind-generated sea is highly variable but typically ranges in period from 2 to 6 seconds with heights of up to 6m during strong persistent forcing at some locations (Swan *et. al.* 1994).

2.6 WATER TEMPERATURES

Surface sea temperatures in the vicinity of the Kitan oilfield are expected to range from about 30°C in summer to 28°C in winter.

3. METHODS

3.1 GENERAL

The trajectory and fate of Kitan crude oil and diesel were modelled using an oil spill trajectory model comprising three modules:

- a hydrodynamic module that provides the necessary velocity fields to advect the oil;
- an oil spill weathering module that predicts the behaviour of the oil in the receiving environment; and
- an oil spill trajectory module that simulates the fate of the oil.

These modules are described in more detail in the following subsections.

3.2 HYDRODYNAMIC MODEL

3.2.1 Tidal hydrodynamics

The hydrodynamics applied in the present study were computed using a combination of HYbrid Coordinate Ocean Model (HYCOM) and the finite elements model QUODDY. HYCOM is a data-compiled hybrid generalised coordinate ocean model, sponsored by the National Ocean Partnership Program as part of the U. S. Global Ocean Data Assimilation Experiment. Computations are carried out on a cylindrical map projection grid between 78°S and 47°N (1/12° equatorial resolution), where the horizontal dimensions of the global grid are 4500 x 3298 grid points resulting in ~7 km spacing on average. Daily hindcast values are available from 3 November 2003 to the present day.

QUODDY solves the time dependent, free surface circulation problems in three dimensions (Ip and Lynch 1995). The algorithms that comprise QUODDY utilise the finite element method in space and the model can be applied to computational domains encompassing the Deep Ocean, continental shelves, coastal seas and estuarine systems.

Model grid and bathymetry are shown in Figure 3.1 and Figure 3.2, respectively. The bathymetry was interpolated from the Australian Geological Survey Office database. The model was forced from the open boundary by tidal elevations calculated from the M2, S2, N2, O1 and K1 tidal constituents. Amplitudes and phases for these were taken from the FES-95.2 global ocean model (Le Provost *et al.* 1998).

The model has undergone extensive validation and found to compare favourably against measured currents and tidal elevations in the Timor Sea.

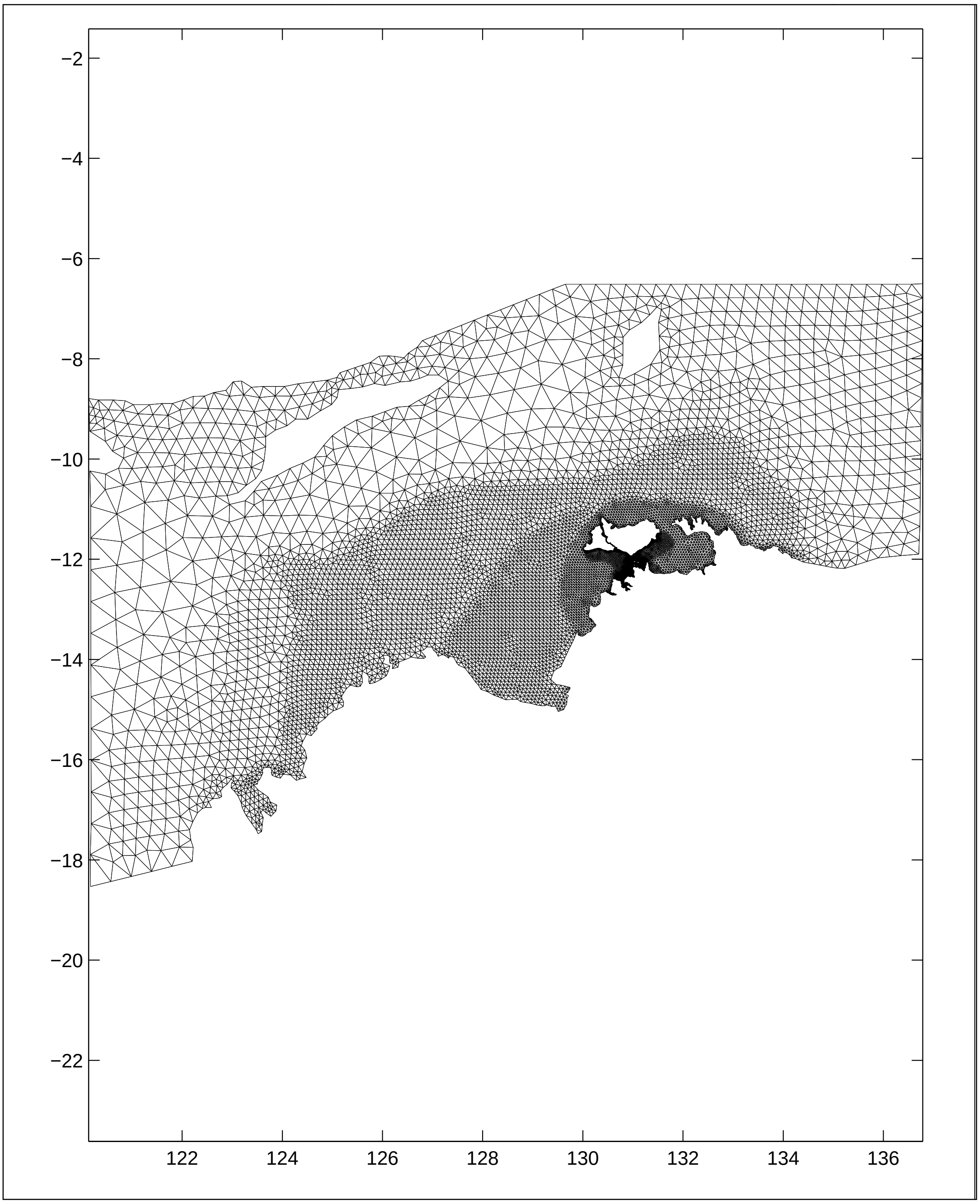


Figure 3.1 Timor Sea model grid.

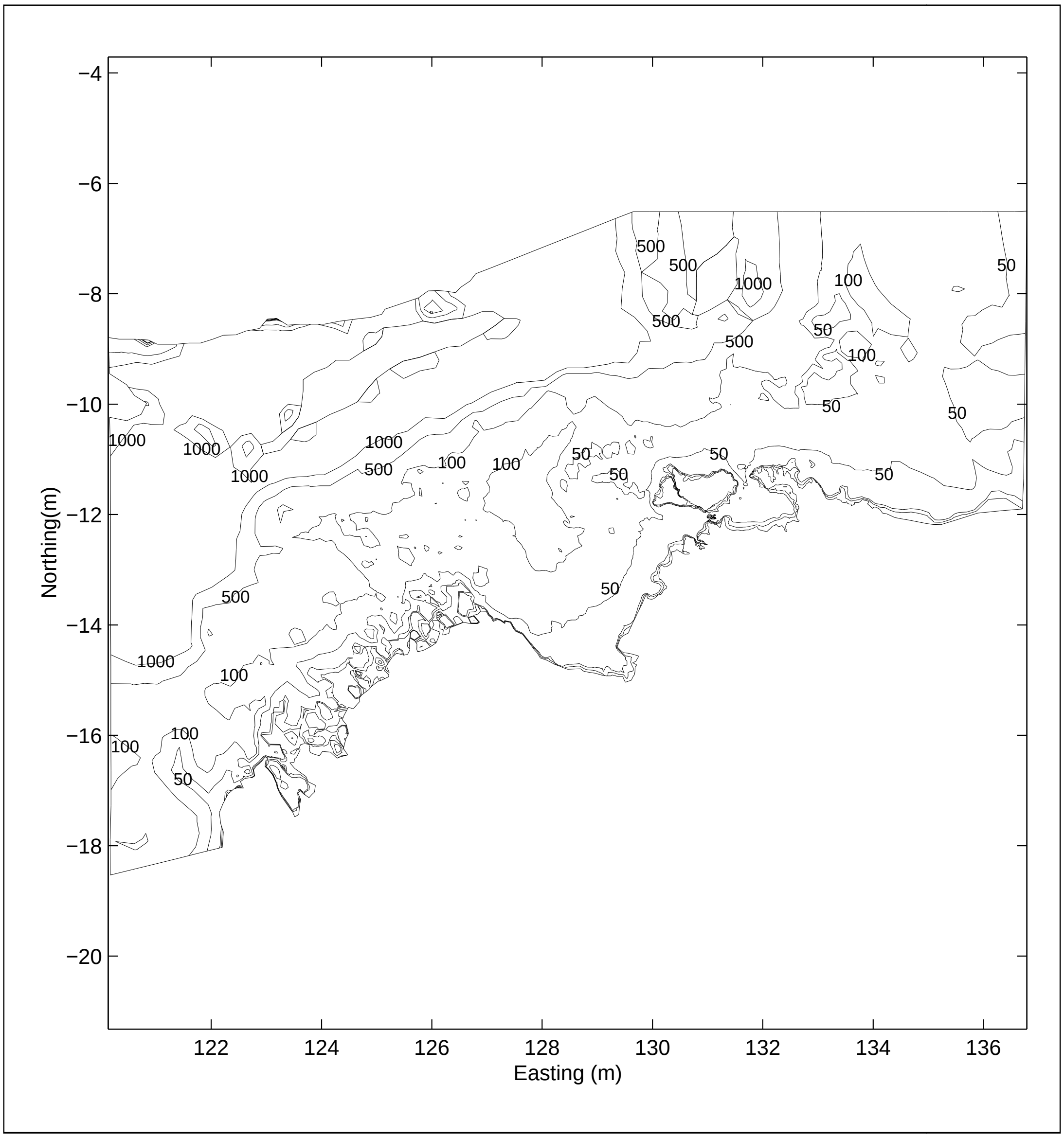


Figure 3.2 Model Bathymetry.

3.2.2 Wind Data

Verified NCEP modelled wind data for the Kitan location were applied in the model. Seasonal wind roses are shown in Figure 2.1. Two distinct seasons are evident: summer and winter.

3.3 OIL SPILL WEATHERING MODULE

The National Oceanic and Atmospheric Administration's (NOAA's) Automated Data Inquiry for Oil Spills (ADIOS2) model was used to simulate detailed evaporation, dispersion and emulsification of the spill. Input data for ADIOS2 includes:

- oil properties (API, viscosity, distillation curves);
- spill details (volume and duration of the spill); and
- environmental data (wind and sea surface temperature).

3.3.1 Kitan Oil

The properties of Kitan crude oil were characterised by Intertek (2008) and are summarised in Table 3.1. It is a light crude with an API of 57° and a specific gravity of 0.751. The distillation cuts indicate that about 80% of the oil is volatile or semi-volatile (percentage boiling off at less than 265°C) suggesting that it will evaporate readily.

Asphaltene and wax concentration are low (<0.05%mass and <5%mass, respectively). Studies with a sample of Kitan oil showed that no persistent viscous/solid emulsion layers were observed in the water cuts ranging from 5 to 70 volume percent at 7.6°C (EAL, 2009). The oil is therefore not expected to form a stable emulsion at the temperatures found in the Timor Sea.

Table 3.1 Expected Kitan oil properties (from Intertek, 2008)

Parameter	Value
API	56.8
Specific Gravity	0.751
Kinematic Viscosity (cSt)	1.04@20°C
Asphaltene	<0.05%mass
Wax	<5%mass
Distillation Cuts Temp (°C)	**Mass %**
30	8
60	12
90	29
120	47
150	57
180	68
210	74
230	78
270	86
300	90

3.3.2 Diesel

Diesel is a light petroleum distillate. Different diesels have varying properties, but have a density in the range 0.84 to 0.88 g cm^{-3} (30 – 32 °API), with pour points of between -17°C and -30°C. As such they are classed as Group II oils i.e. light persistent oils. Diesels are expected to undergo a rapid spreading with moderate evaporative loss in tropical waters and, consequently, slicks are likely to break up. Diesel oils tend not to form emulsions at the temperatures likely to be found in the Timor Sea and so these will not inhibit spreading of the slick or evaporation rates.

For the purpose of modelling, the API was set at of 32° and viscosity at 4cSt (Table 3.2). Distillation cuts were obtained from the ADIOS2 database. These indicate that just over 30% of the oil is volatile or semi-volatile (proportion boiling off at less than 265°C).

Table 3.2 Properties of diesel fuel oil used in the model

Parameter	Heavy Oil
API (°)	32
Viscosity @15°C (cSt)	4
Pour Point (°C)	-14
Distillation Cuts	
Temp (°C)	**Vol %**
160	3
180	6
200	11
250	31
300	63
350	89
400	99

3.4 OIL SPILL TRAJECTORY MODULE

The oil spill module is based on the classic random walk particle tracking method (Sherwin 1992) and assumes that the oil can be idealised as a large number of particles that move independently under the action of tide and wind. The oil spill trajectory model is integrally linked with the finite element model and uses a highly accurate fourth order Runge-Kutta method to track particles (Blanton 1995).

Physical mechanisms included in the model are summarised in Figure 3.3 and include:

- advection by ambient currents (tide, residual, wind and wave);
- dispersion due to turbulence; and
- buoyancy.

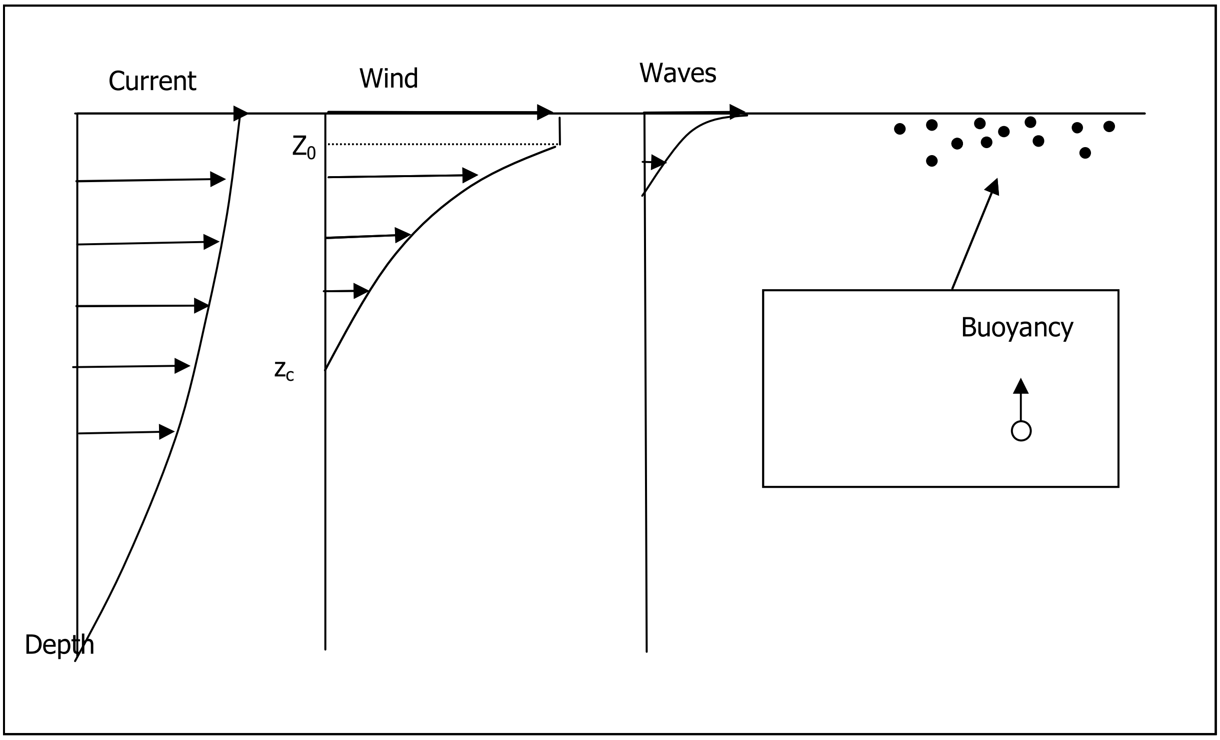


Figure 3.3 Mechanisms included in the three dimensional model

Advection is calculated by stepping through the variations in the current field in time. The effects of wind induced surface shear are modelled by the inclusion of a logarithmic velocity profile. It is assumed that the surface layer, of thickness z_0, moves at a velocity U_s (typically 3% of the wind speed) and that the wind induced velocity decays with depth according to:

$$U_z = U_s(1 - \frac{\log(z/z_0)}{\log(z_c/z_0)}$$

Where z_c is the depth at which the velocity is zero. It is assumed that z_c scales on the wavelength (L) of the surface waves, $z_c = \mu L$. μ is a free parameter in the model and has been set to 4. z_0 is also a free parameter in the model and has been set to 1 cm.

Waves are accounted for by including the Stokes drift to linear waves:

$$U_z = \frac{\omega k a^2 \cosh(2k(H-z))}{2\sinh^2(kH)}$$

Where *a* is the wave amplitude, *H* is the water depth, $w = 2\pi/T$ and $k = 2\pi/L$ for waves of period *T* and wavelength *L*. Wave height and period are calculated from equations provided in the U.S. Army Corps of Engineers Shore Protection Manual (1984). Local depth and fetch are determined in the model from the grid data. At an open grid boundary, a fetch of 100 km (i.e. virtually non-limiting) is assumed.

Dispersion is included by subjecting each particle to a random displacement at each time step. The dispersive displacement (random step) of each particle at each time step (dt) is scaled by the square root of the increment in the variance of the effluent plume which is given by the product:

(increment in variance) = 2Kdt

where K is the horizontal (K_{xy}) or vertical (K_z) diffusion coefficient. The actual step length taken by each particle is also determined by a random number selected from a normal distribution with zero mean and unit variance which is scaled by the product (2Kdt). Steps in the x, y and z co-ordinate directions are made independently. Steps in the vertical plane allow for reflection of the particle from the seabed and surface. The current velocity applied to each particle is corrected according to its level in the water column using a power law relationship.

The horizontal dispersion coefficient is approximated from data on dye diffusion studies reported by Okubo (1971, 1974) as reviewed by Bowden (1983):

$$K_x = 0.0027\ t^{1.34}$$

As the variance of a cloud increases, the cloud is dispersed by turbulence associated with increasingly larger spatial scales, such that the apparent dispersion coefficient increases with time. A maximum of 100 m^2/day is applied here, in accordance with Kullenberg (1982).

The vertical turbulent diffusion coefficient above the pycnocline is related to the wave conditions following Ichiye (1967):

$$K_z = 0.028\frac{H^2}{T}\exp(-2kz)$$

Below the pycnocline depth, K_z is assumed to be a constant equal to 10^{-4} m^2/s (Kullenberg, 1982).

Vertical advection is included as a rise velocity due to buoyancy effects. This is a function of the diameter and density of the droplets. For small particles d < d_c, where

$$d_c = \frac{9.52\nu^{2/3}}{g^{1/3}(1 - \rho_0/\rho_w)}$$

ν is viscosity of sea water, ρ_o is the density of the droplet for diameter d and ρ_w is the density of sea water, then the rise velocity, U_B, is given by a Stokes Law:

$$U_B = \frac{gd^2(1 - \rho_o/\rho_w)}{18\nu}$$

Water properties and atmospheric conditions were input to the model to predict the behaviour and fate of the oil. Industry standard algorithms were used to predict spreading (Fay 1969) and evaporation (Fingas 1999) of hydrocarbons.

The model can be run in deterministic or stochastic mode. In deterministic mode, a single oil spill scenario was run. In stochastic mode, 200 simulations were undertaken with the spill time selected randomly from the prevailing wind and tide conditions. This approach provides a more informative estimate of the risk of hydrocarbon exposure as it provides statistical weighting to the potential outcomes of a spill based on the frequency of occurrence of different ambient environmental conditions. The model output was presented as contour plots showing:

- the probability of surface exposure to oil; and
- the minimum time until contact.

In stochastic mode, processes that were modelled included spreading, evaporation and advection of the oil. Once a simulated particle reached a shoreline it was regarded as stranded. The location, drift time and remaining oil mass were registered and the particle was no longer tracked (i.e. no out-washing of oil from the shore was allowed for in the model).

3.5 OIL SPILL SCENARIOS

Six representative and credible spill events were analysed:

- Scenario 1: a 7,000m^3 spill of crude oil over 24 hours, considered the largest instantaneous volume that would be spilt in the event of a rupture of a full cargo tank;
- Scenario 2: a 1,800m3/day spill of crude oil over 56 days, representing a well blowout;
- Scenario 3: a 100m^3 spill of crude oil over 6 hours, representing the upper end of an accidental spill such as a transfer hose rupture or process leak;
- Scenario 4: an instantaneous 10m^3 spill of crude oil, representing the lower end of a significant accidental spill;
- Scenario 5: an 80m^3 spill of diesel over 6 hours, representing a loss from a ruptured fuel tank; and
- Scenario 6: a 2.5m^3 spill of diesel spill over 1 hours, representing a refuelling incident.

These scenarios are summarised in Table 3.3.

Table 3.3 Summary of oil spill scenarios

Scenario	Probability[1]	Description	Oil type	Spill Volume (m^3)	Spill Duration
1	One in 1,000,000 years	Rupture of a crude storage tank on the FPSO	Crude oil	7000	24hrs
2	2.5 x 10^{-4} per drilled well (OGP, 2010)	Well Blowout	Crude oil	1800m^3/day	56 days
3	One in 100 – 1,000 years	Upper end of an accidental spill such as a transfer hose rupture or process leak	Crude oil	100	6hrs
4	One in 2 – 3 years	Lower end of a significant accidental spill	Crude oil	10	Instantaneous
5	One in 100 – 1,000 years	Loss of fuel from a storage tank on a refuelling vessel	Diesel	80	6hrs
6	One in 2 – 3 years	Refuelling accident	Diesel	2.5	1hr

[1] From Woodside, 2002, unless otherwise specified.

4. RESULTS

4.1 EVENT 1: LOSS OF 7000M^3 OF CRUDE OVER 24 HOURS

4.1.1 Predicted Weathering Behaviour

Figure 4.1 and Figure 4.2 show the results from the ADIOS2 modelling for light and strong winds, respectively. Under light winds (4ms^{-1}), approximately 60% of the oil is predicted to evaporate within 24 hours, 1% is predicted to become entrained into the water column leaving 39% on the sea surface (Figure 4.1). After five days, these numbers increase to 80%, 3% and 17%, respectively.

Under strong winds (10ms^{-1}), approximately 65% of the original spill volume is predicted to evaporate within 24 hours, 5% is predicted to become entrained into the water column leaving just 30% on the sea surface (Figure 4.2). After five days, these numbers increase to 80%, 12% and 8%, respectively.

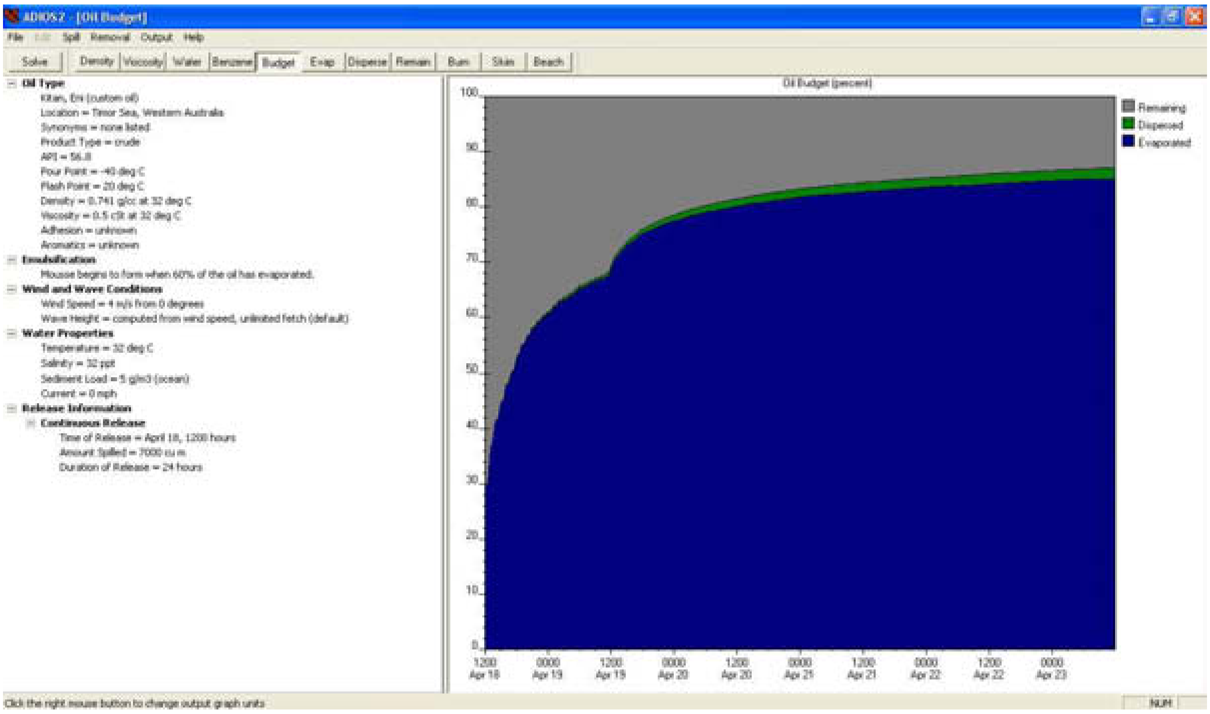


Figure 4.1 Predicted weathering of Kitan oil for a continuous release of 7000m^3 spill over 24 hours for a 4ms^{-1} wind

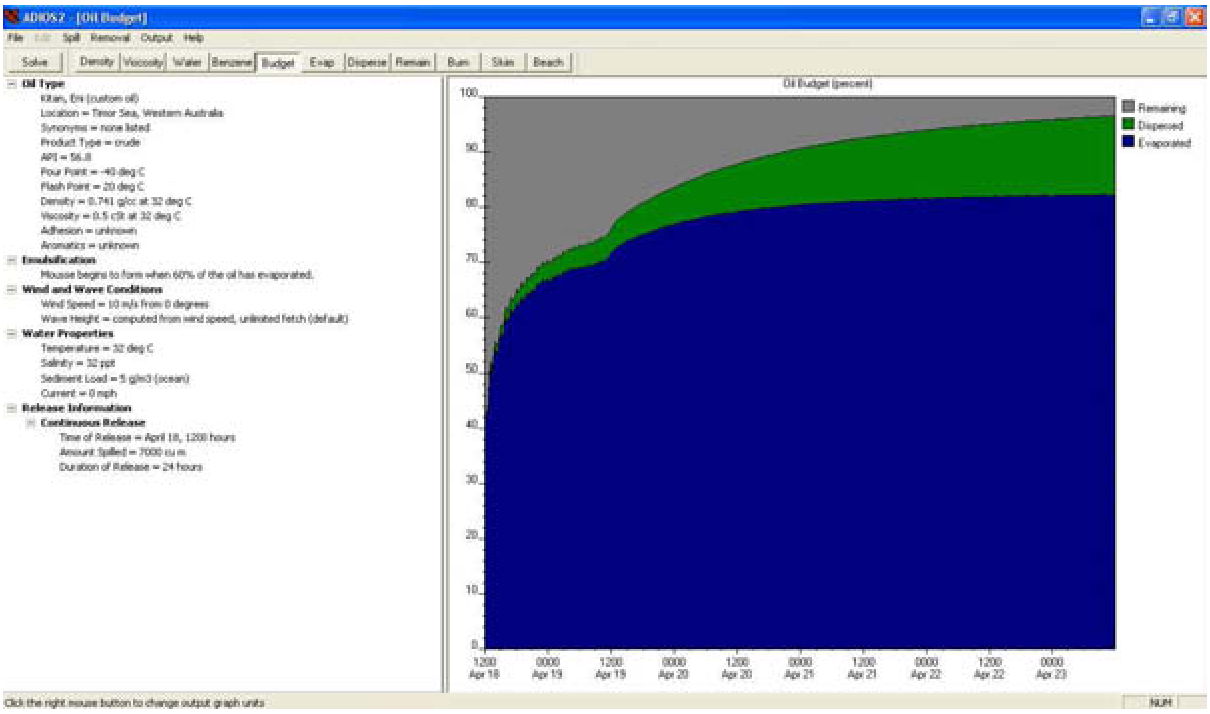
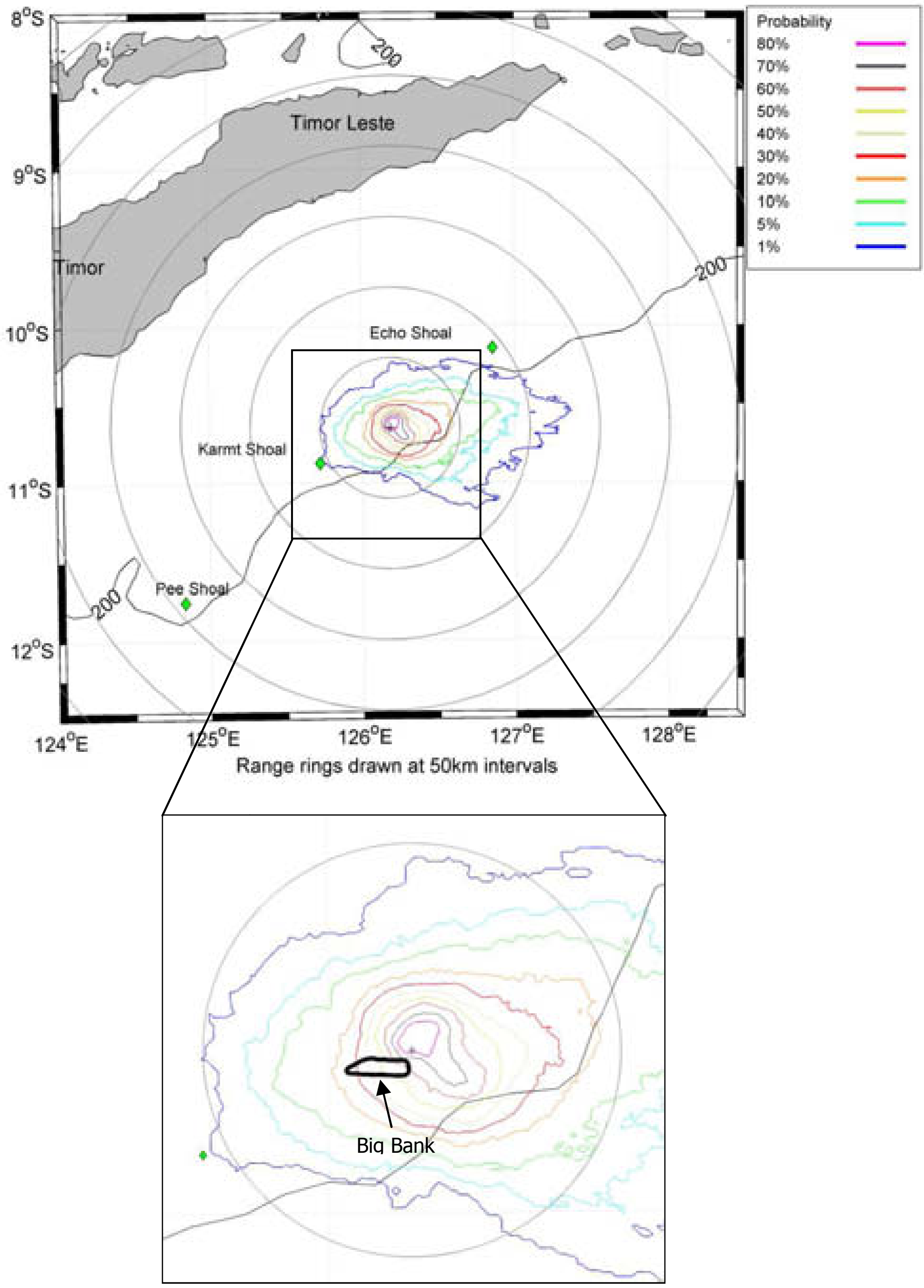


Figure 4.2 **Predicted weathering of Kitan oil for a continuous release of 7000m^3 spill over 24 hours for a 10ms^{-1} wind**

4.1.2 Stochastic Modelling

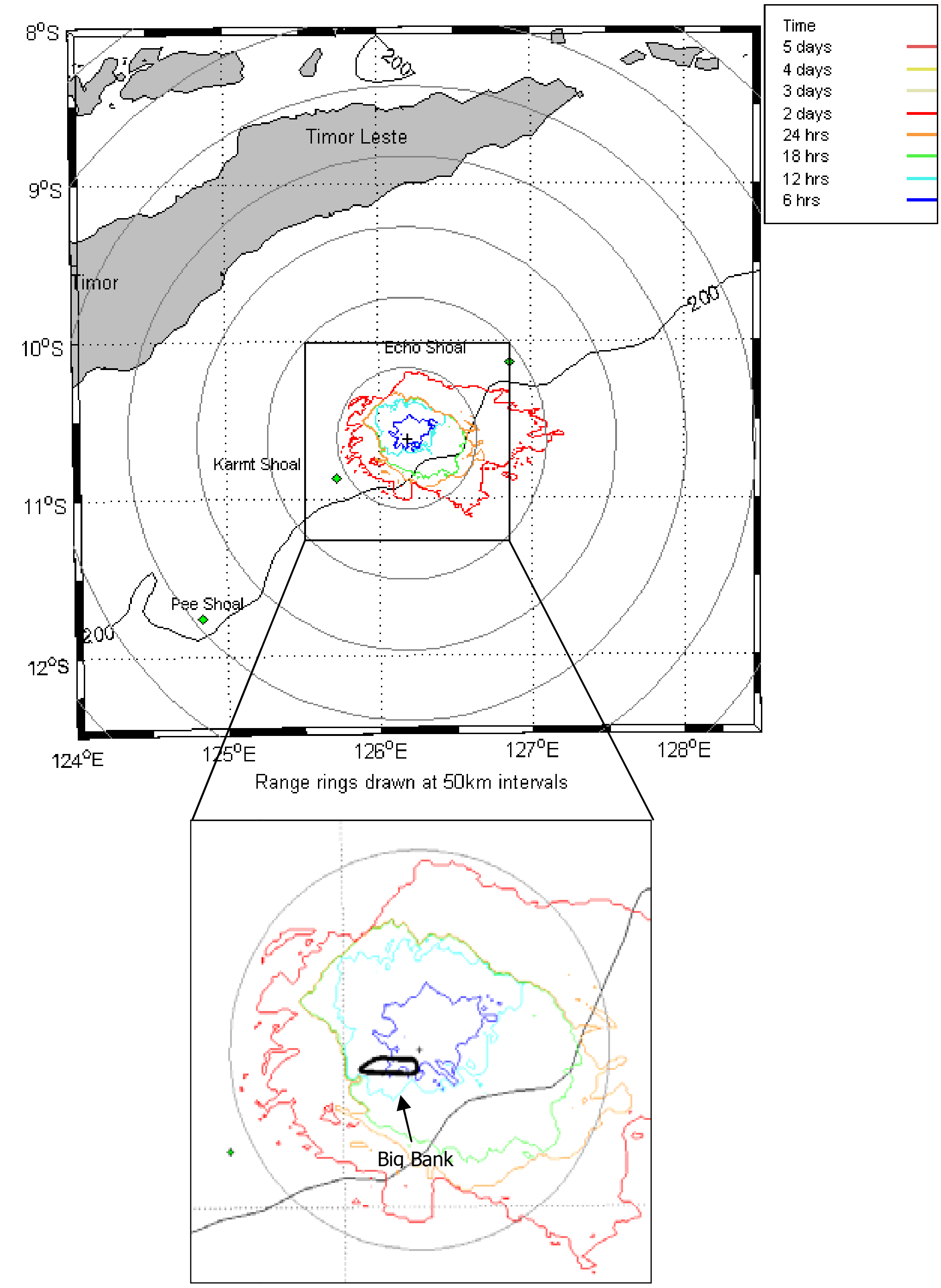
Under summer conditions, the outer (1%) probability envelope extended 125km to the east and 50km to the west, reflecting the predominant wind direction during this season (Figure 4.3). Under this scenario, there was a 70% probability that oil would reach the Big Bank Shoals and 1% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.4) by which time the spill would have evaporated by about 50% of its original volume. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 100km to the west and <50km to the east, reflecting the predominant wind direction during this season (Figure 4.5). Under this scenario, there was a >80% probability that oil would reach the Big Bank Shoals and 1 to 5% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.6) by which time the spill would have evaporated by 50% of its original volume. The spill was not predicted to make contact with land.



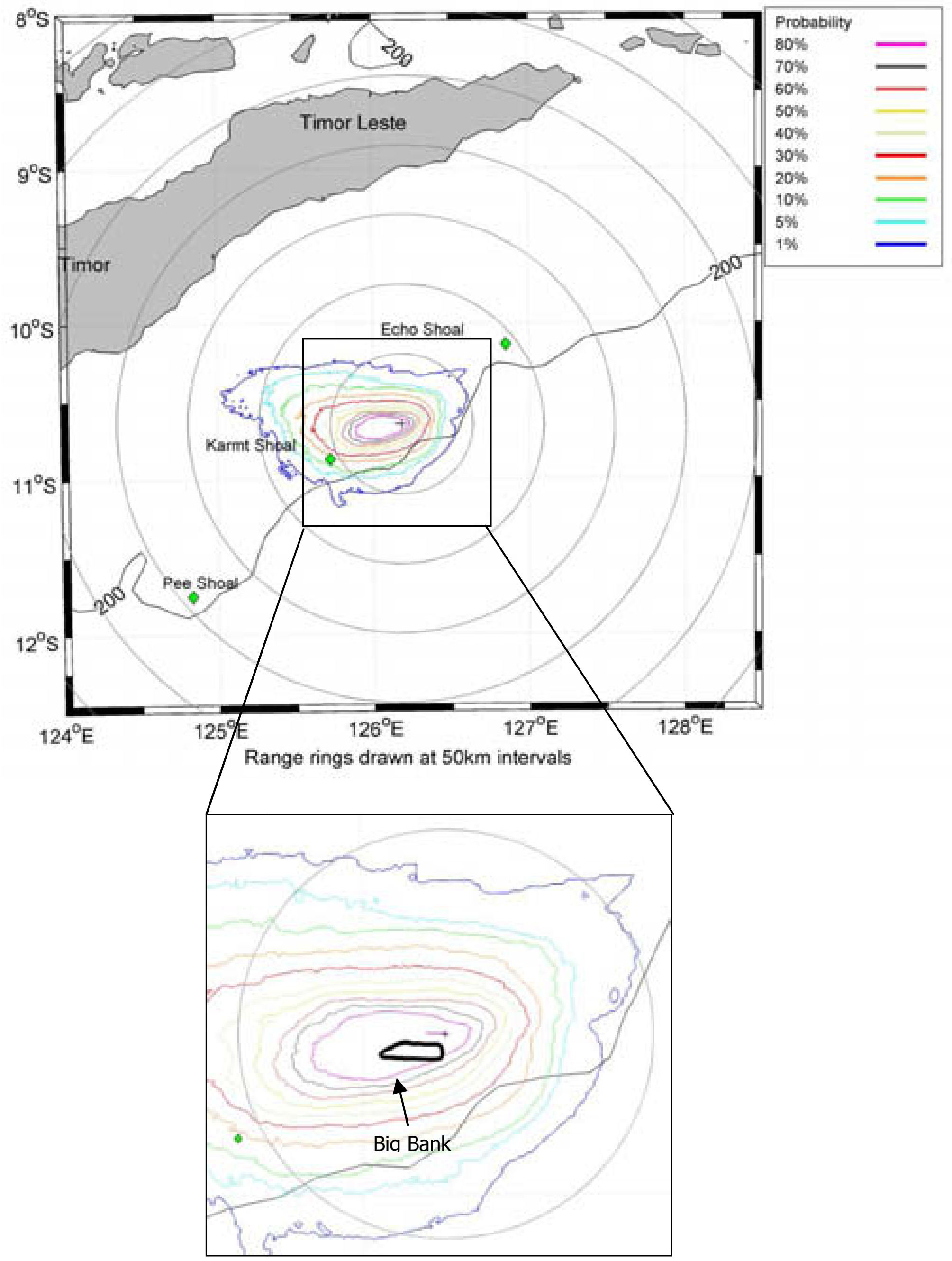
Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.3 Probability of surface exposure at day 5 under summer conditions from a $7000m^3$ spill of crude oil occurring over a 24 hour period



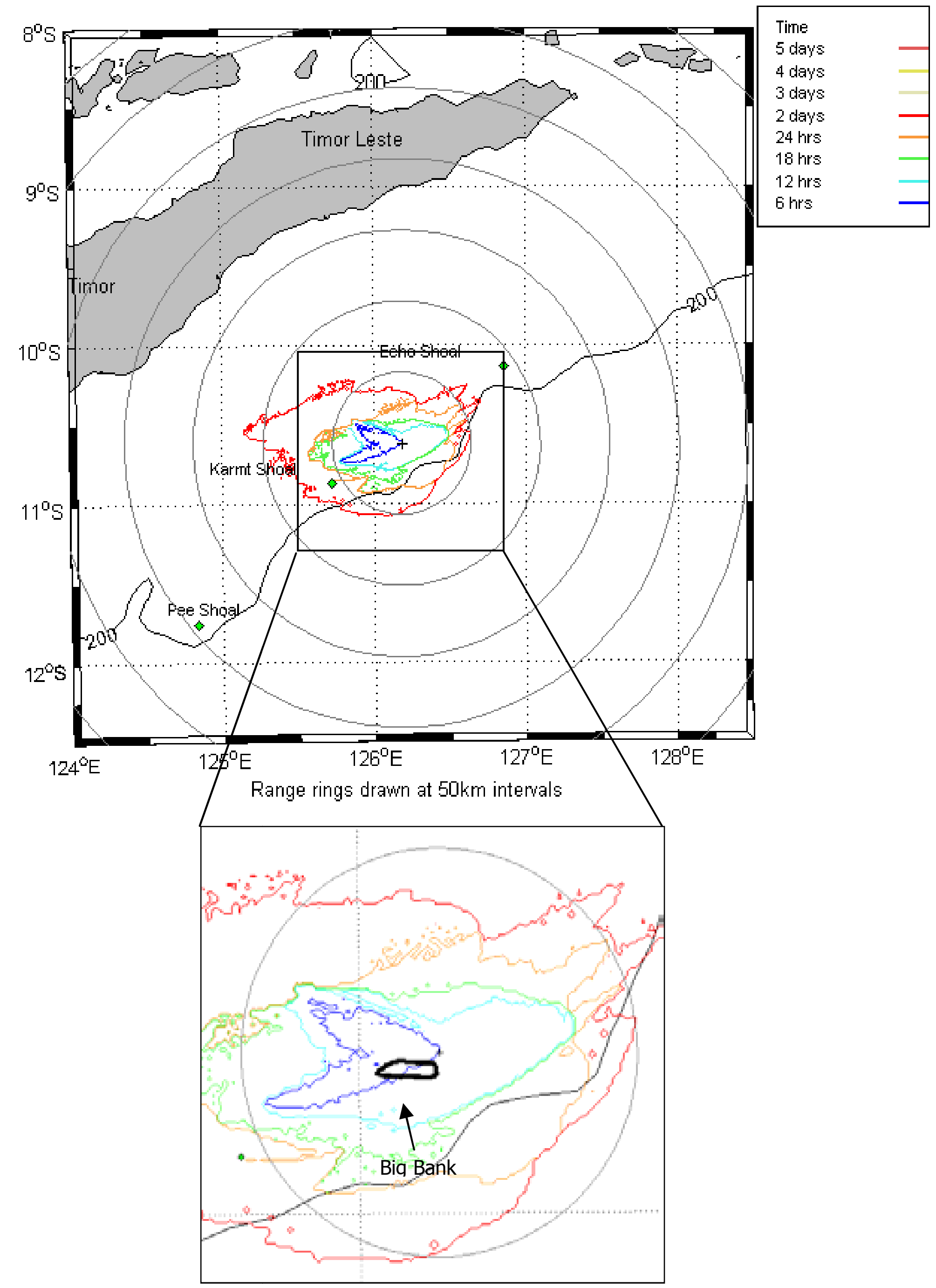
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.4 Predicted minimum time to exposure under summer conditions from a 7000m^3 spill of crude oil occurring over a 24 hour period



Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.5 Probability of surface exposure at day 5 under winter conditions from a 7000m^3 spill of crude oil occurring over a 24 hour period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.6 Predicted minimum time to exposure under winter conditions from a 7000m^3 spill of crude oil occurring over a 24 hour period

4.2 EVENT 2: LOSS OF 1800M^3/DAY OF CRUDE OVER 56 DAYS

4.2.1 Predicted Weathering Behaviour

Under light winds (4ms^{-1}), approximately 72% of the oil is predicted to evaporate within 24 hours and 2% is predicted to become entrained into the water column leaving 26% on the sea surface (Figure 4.7). After five days, evaporation accounts for 80% of the spill volume, entrainment into the water column accounts for 3%, leaving 17% on the sea surface.

Under strong winds (10ms^{-1}), approximately 73% of the original spill volume is predicted to evaporate within 24 hours, 7% is predicted to become entrained into the water column leaving 20% on the sea surface (Figure 4.8). After five days, oil is continually removed from the surface through evaporation and entrainment, leaving about 15% on the sea surface.

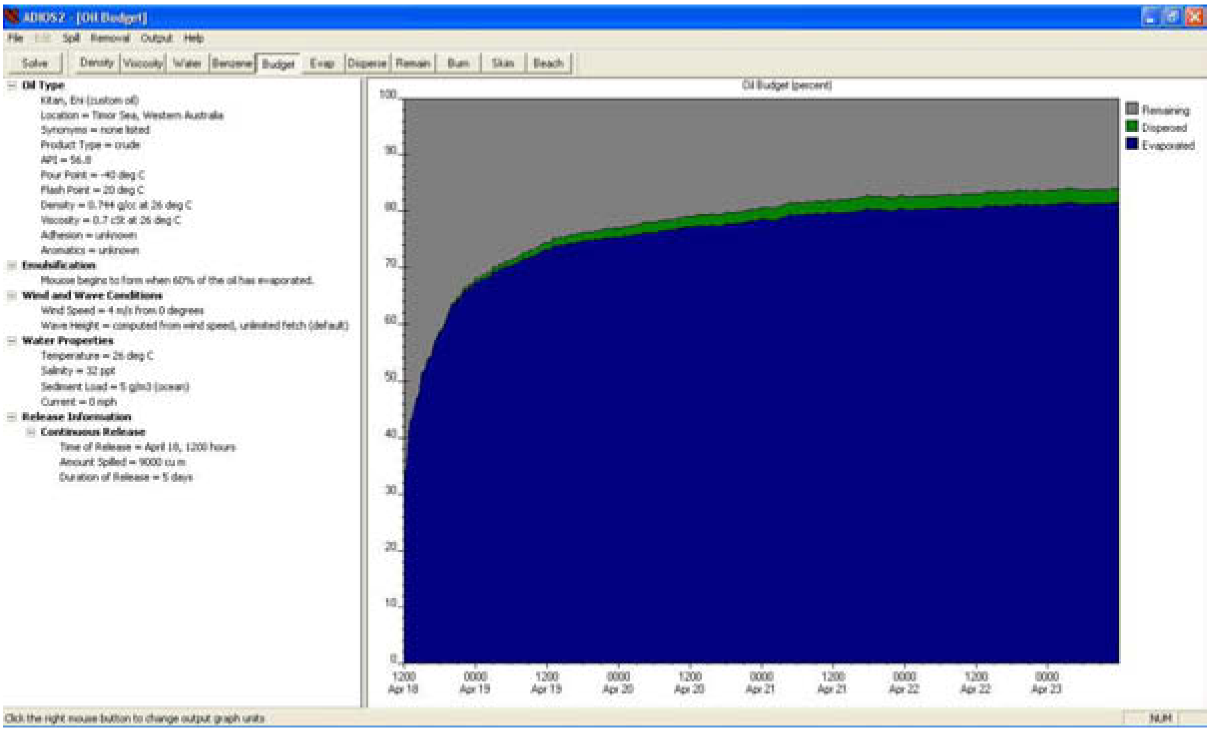


Figure 4.7 Predicted weathering of Kitan oil for a continuous release of 1800m^3/day spill for a 4ms^{-1} wind

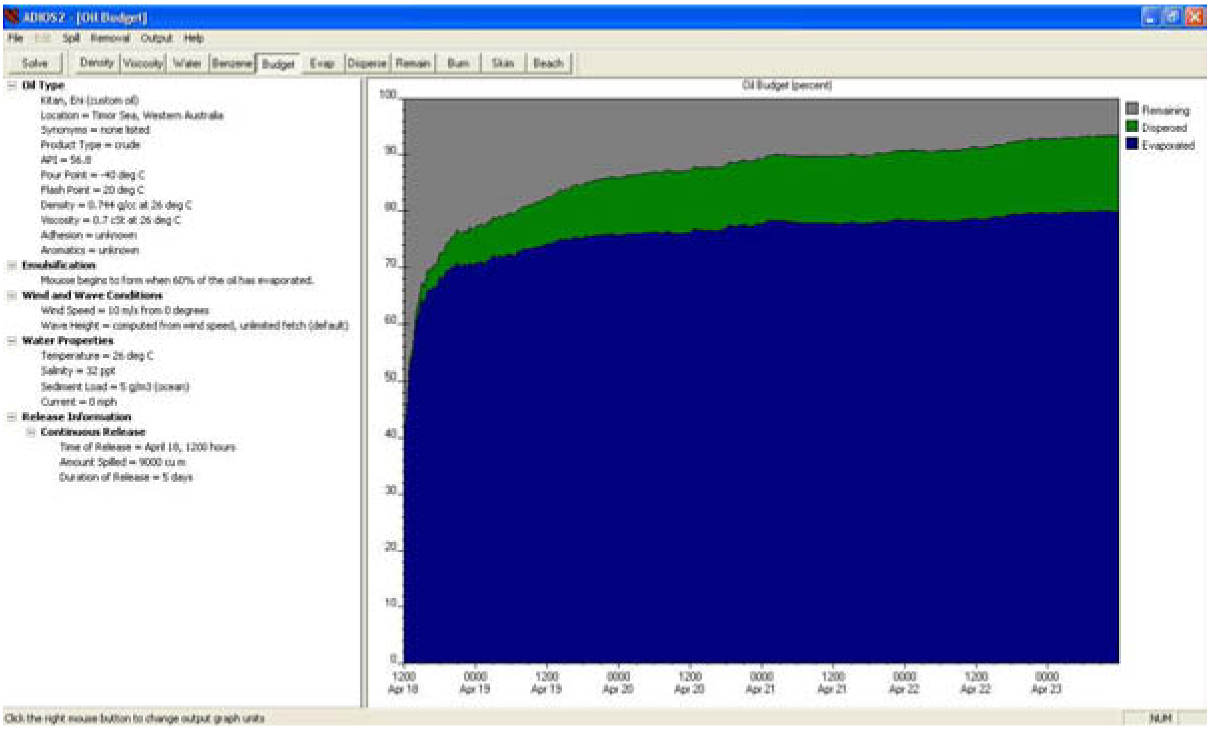
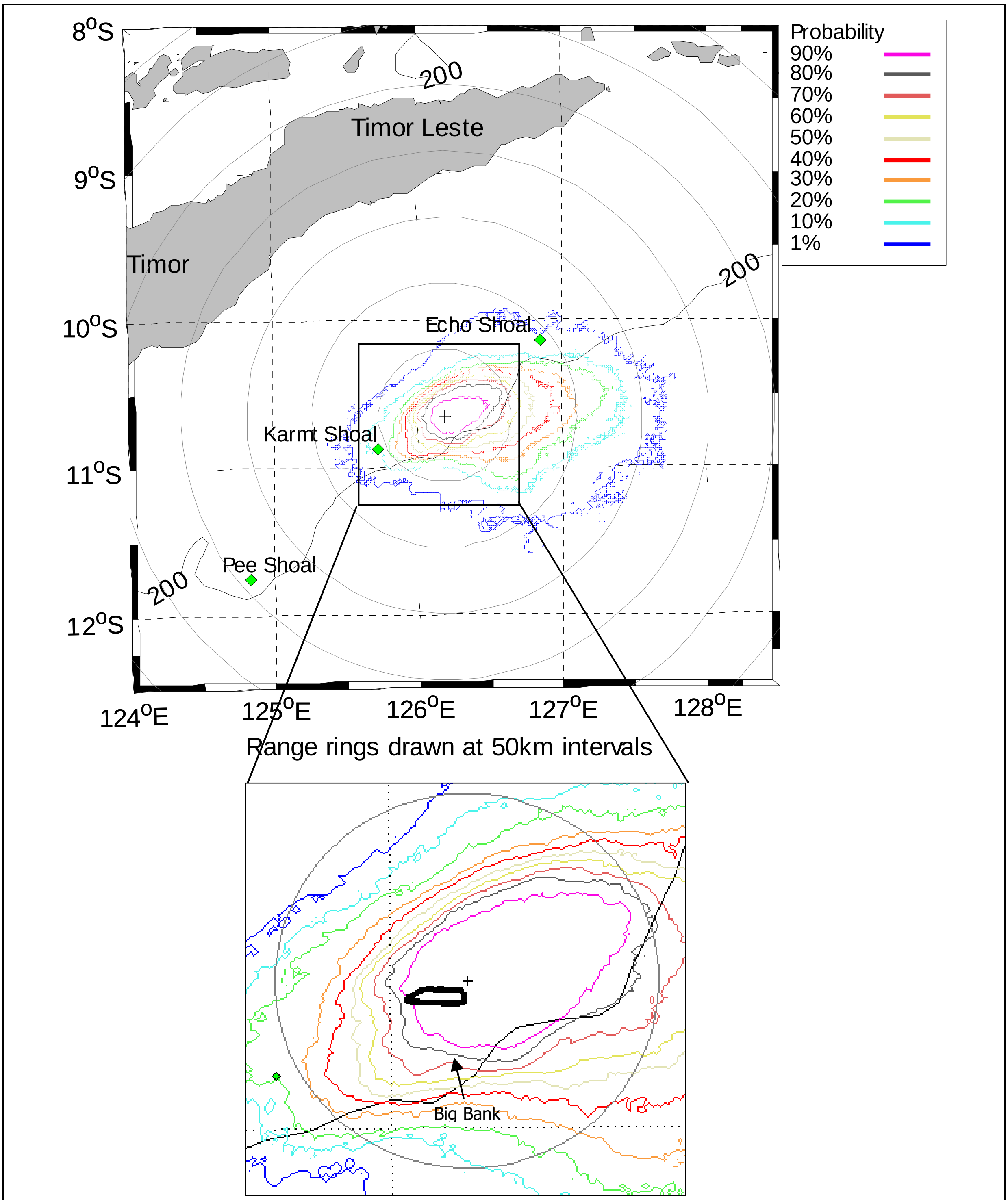


Figure 4.8 **Predicted weathering of Kitan oil for a continuous release of 1800m^3/day spill for a 10ms^{-1} wind**

4.2.2 Stochastic Modelling

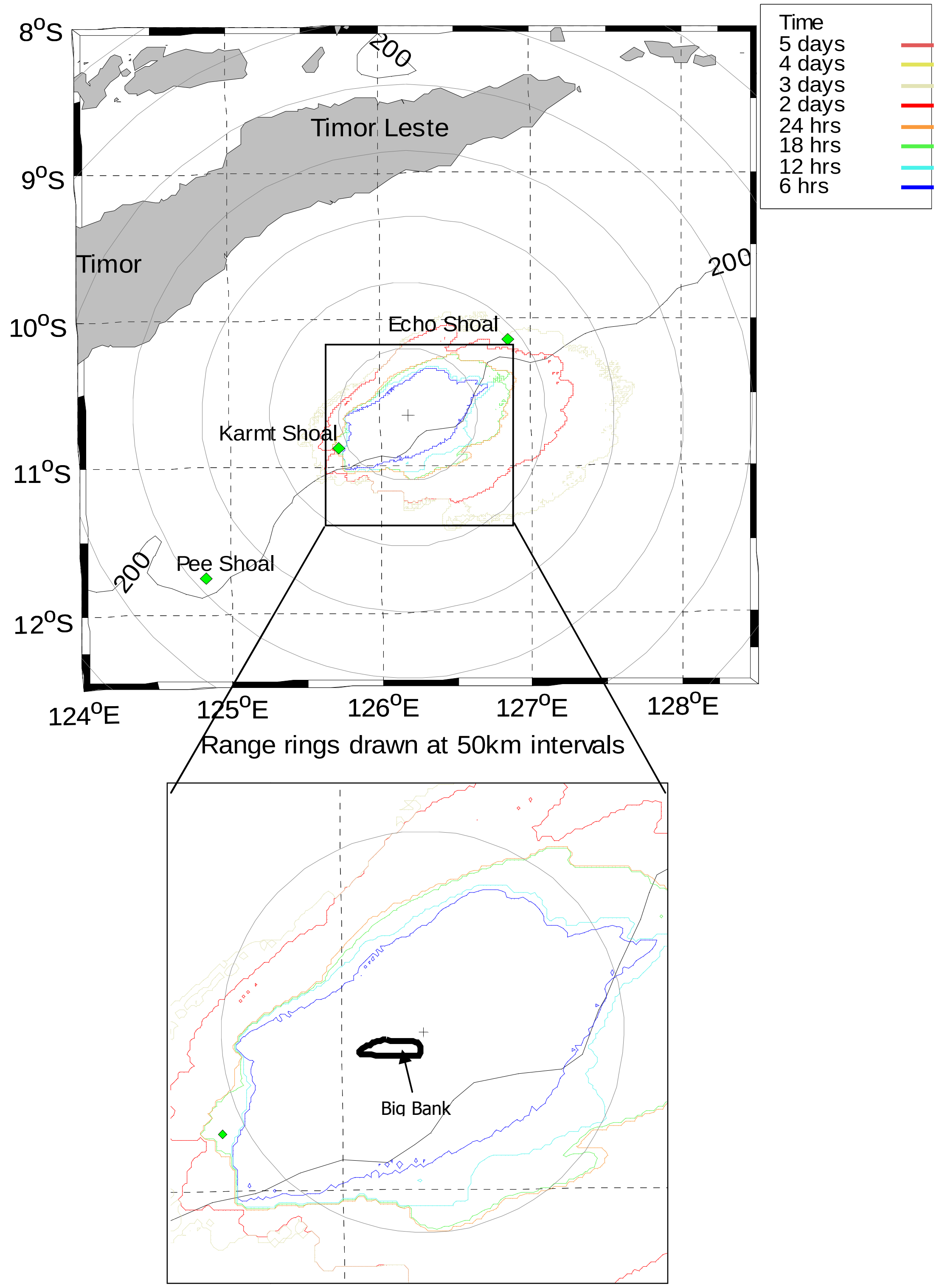
Under summer conditions, the outer (1%) probability envelope extended 170km to the east and 90km to the west of Kitan (Figure 4.9), reflecting the predominant wind direction during this season. Under this scenario, there was a >80% probability that oil would reach the Big Bank Shoals and 10% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was within three hours (Figure 4.10) by which time the spill would have evaporated by about 50% of its original volume. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 170km to the west and 50km to the east of Kitan, reflecting the predominant wind direction during this season (Figure 4.11). Under this scenario, there was a >80% probability that oil would reach the Big Bank Shoals and 40% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was within three hours (Figure 4.12) by which time the spill would have evaporated by 50% of its original volume. The spill was not predicted to make contact with land.



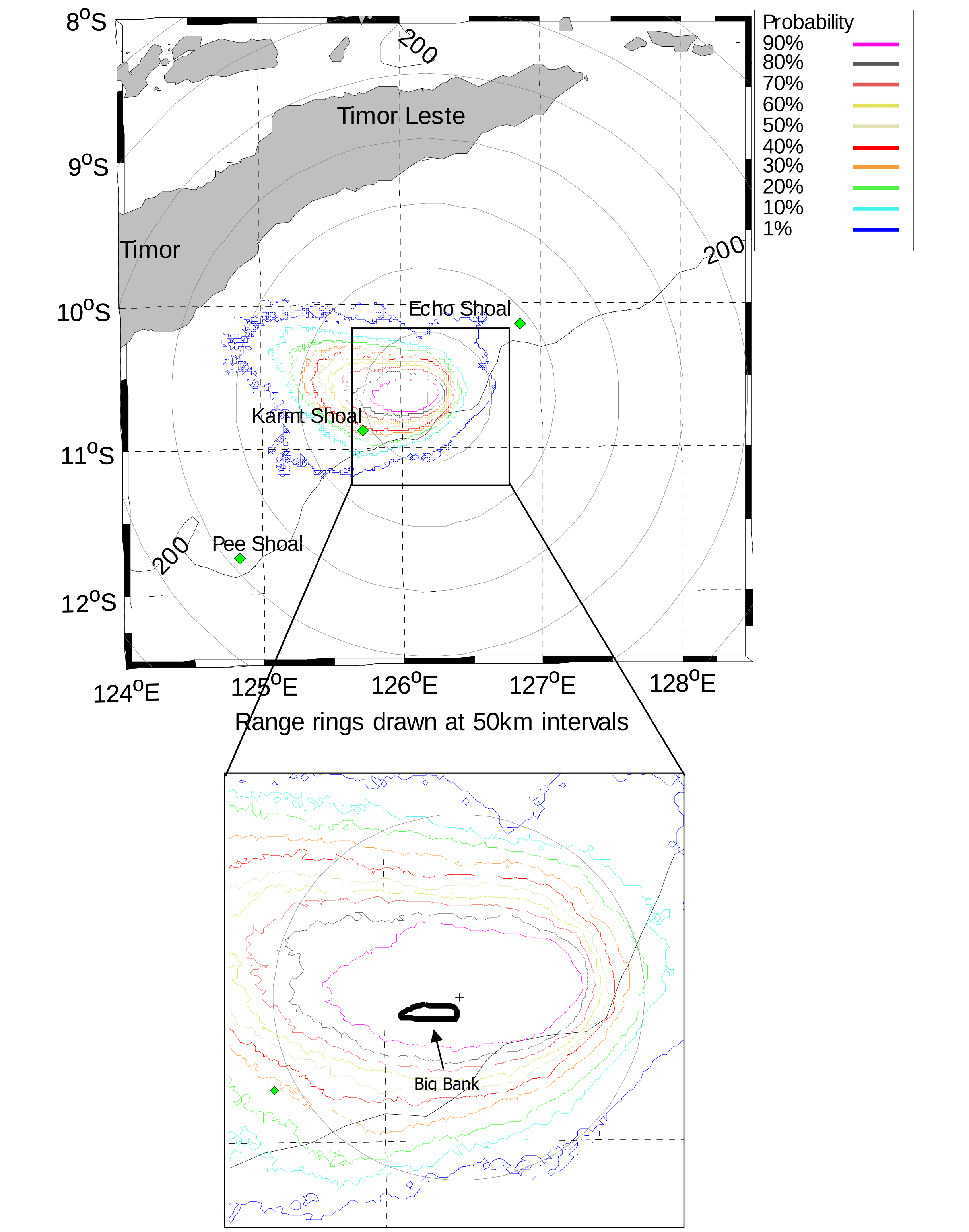
Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.9 Predicted probability of surface exposure under summer conditions from a continuous 1800m^3/day spill of crude oil occurring over a 56 day period



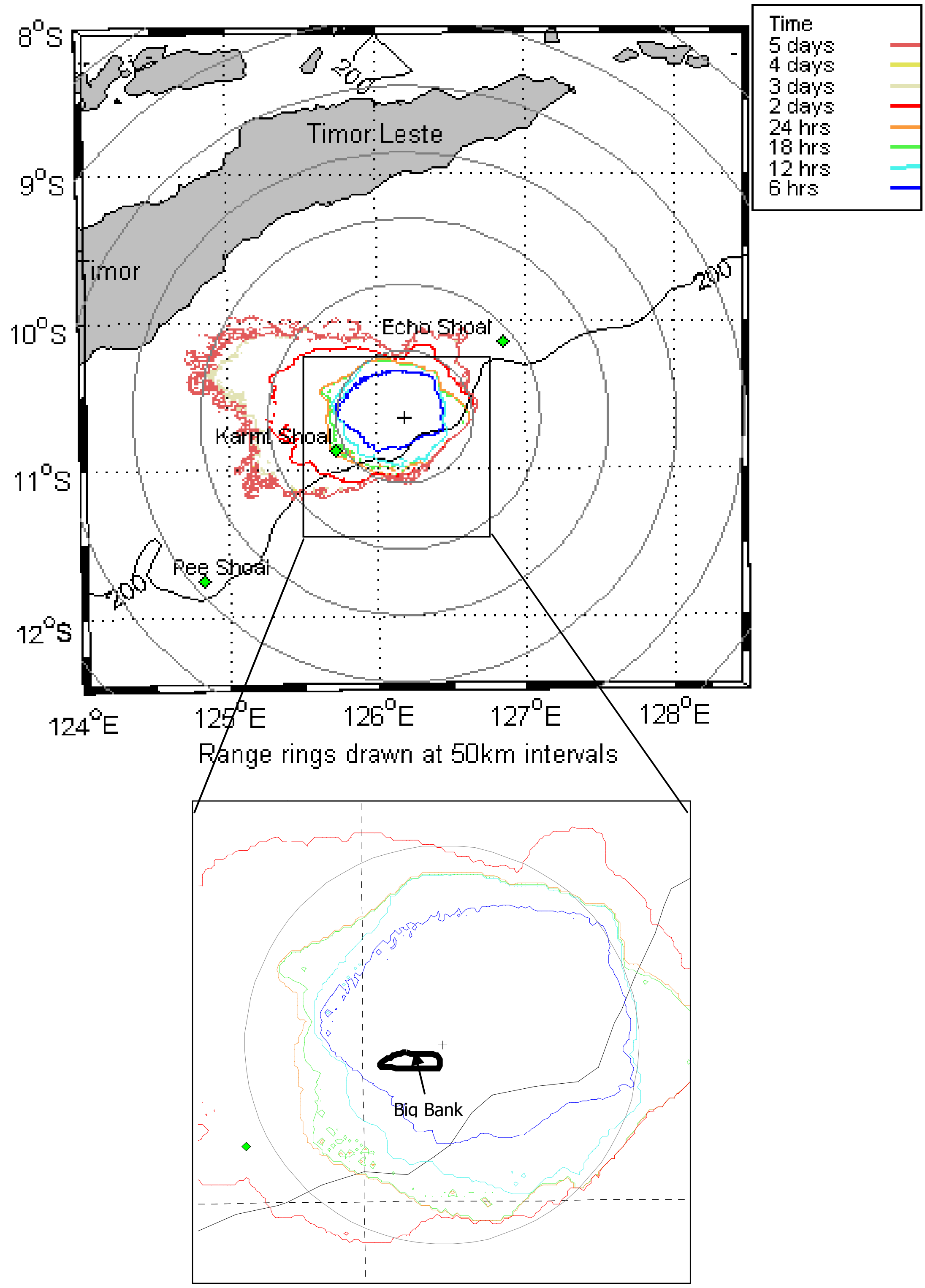
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.10 Predicted minimum time to exposure under summer conditions from a continuous 1800m^3/day spill of crude oil occurring over a 56 day period



Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.11 Predicted probability of surface exposure under winter conditions from a continuous 1800m³/day spill of crude oil occurring over a 56 day period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.12 Predicted minimum time to exposure under winter conditions from a continuous 1800m^3/day spill of crude oil occurring over a 56 day period

4.2.3 Deterministic Modelling

Deterministic modelling predicted the trajectory and fate of a single, continuous oil spill of 1800m^3/day over five consecutive days (Figure 4.13a-d). Using deterministic mode, the vertical distribution of oil in the water column can be predicted (note that the minimum vertical resolution of the model is 1m).

Figures 4-13a-d present examples from the deterministic simulation. The plots show the dynamic nature of the slick as it is transported by the ambient currents. Under certain hydrodynamic conditions the slick sweeps over Big Bank, however, the vertical profiles show that the oil remains at the surface and will not make contact with the sensitive benthic habitats and communities some 20m below the sea surface.

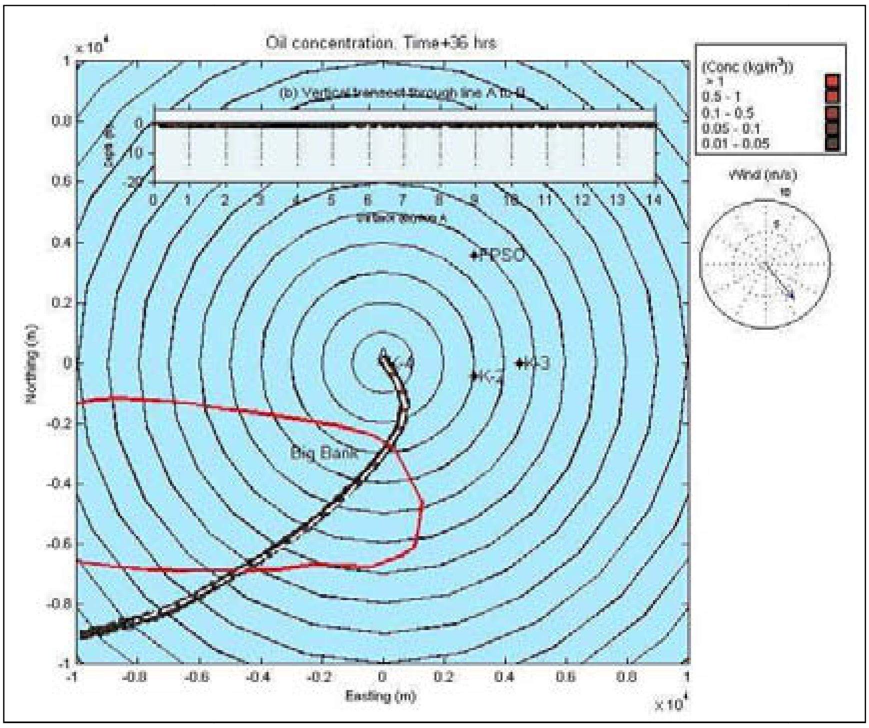


Figure 4.13 Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical well blowout scenario (Scenario 2)

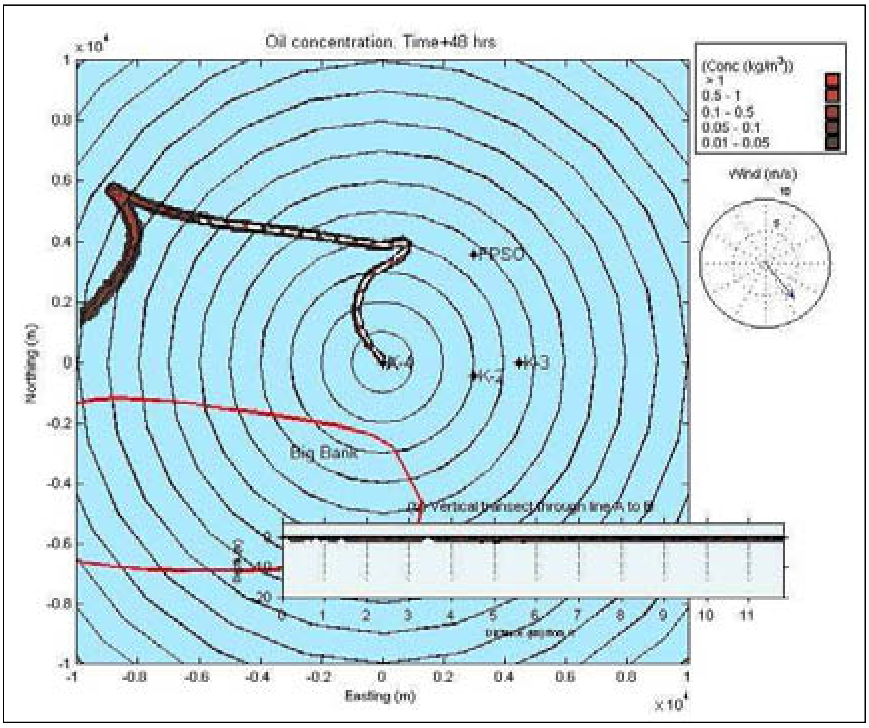


Figure 4.13b Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical well blowout scenario (Scenario 2)

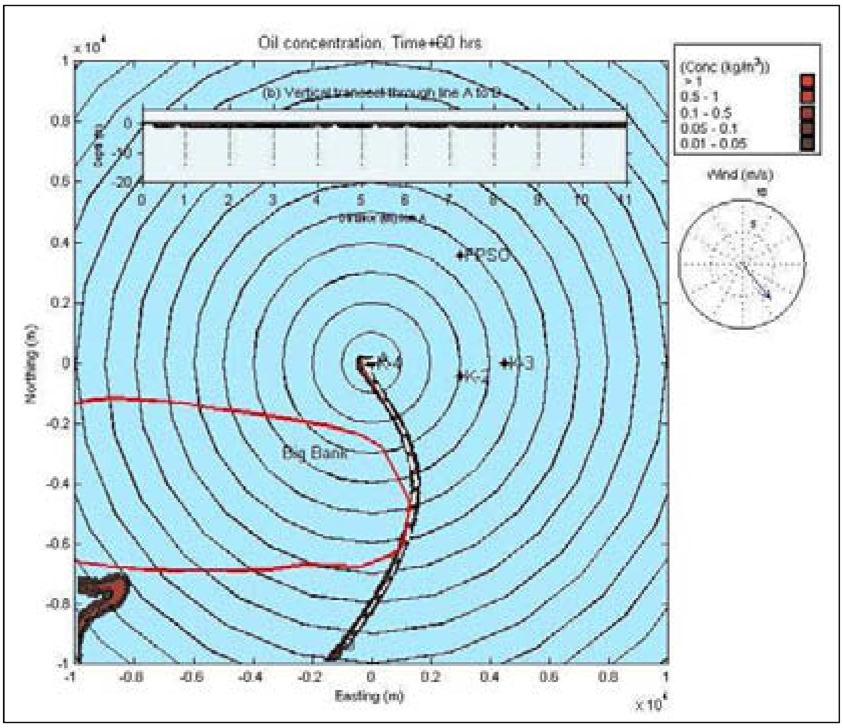


Figure 4.13c Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical well blowout scenario (Scenario 2)

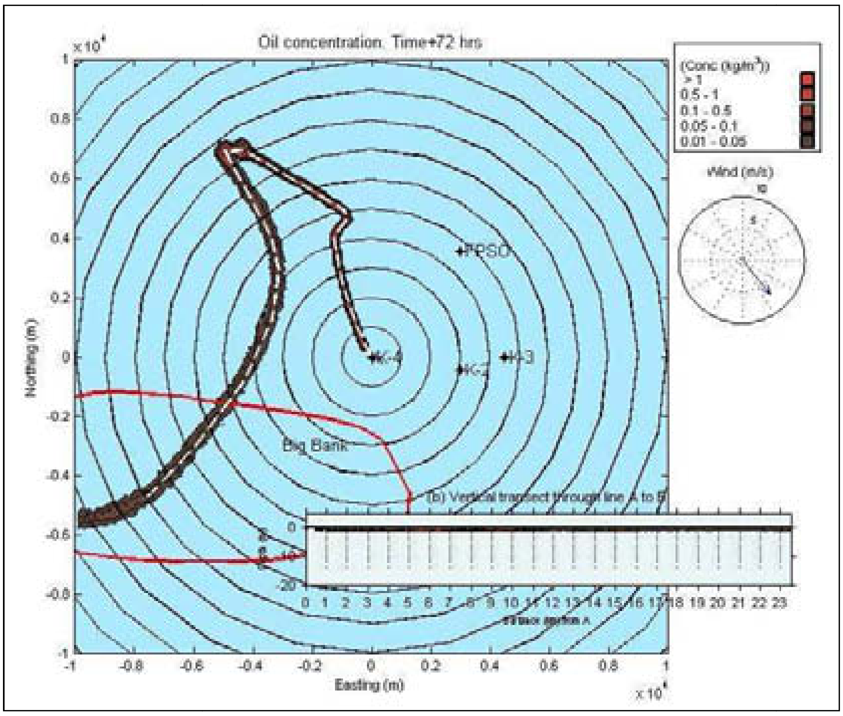


Figure 4.13d Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical well blowout scenario (Scenario 2)

4.3 EVENT 3: LOSS OF 100M^3 OF CRUDE OVER SIX HOURS

4.3.1 Predicted Weathering Behaviour

Under light winds (4ms^{-1}), approximately 82% of the oil is predicted to evaporate after 24 hours, with a further 2% evaporating over the following four days (Figure 4.14). Four percent is predicted to become entrained into the water column leaving 14% on the sea surface.

Under strong winds (10ms^{-1}), again 82% of the original spill volume is predicted to evaporate after 24 hours (Figure 4.15). Twelve percent is predicted to become entrained into the water column leaving 6% on the sea surface. The proportion entrained into the water column increases the longer the oil is at sea.

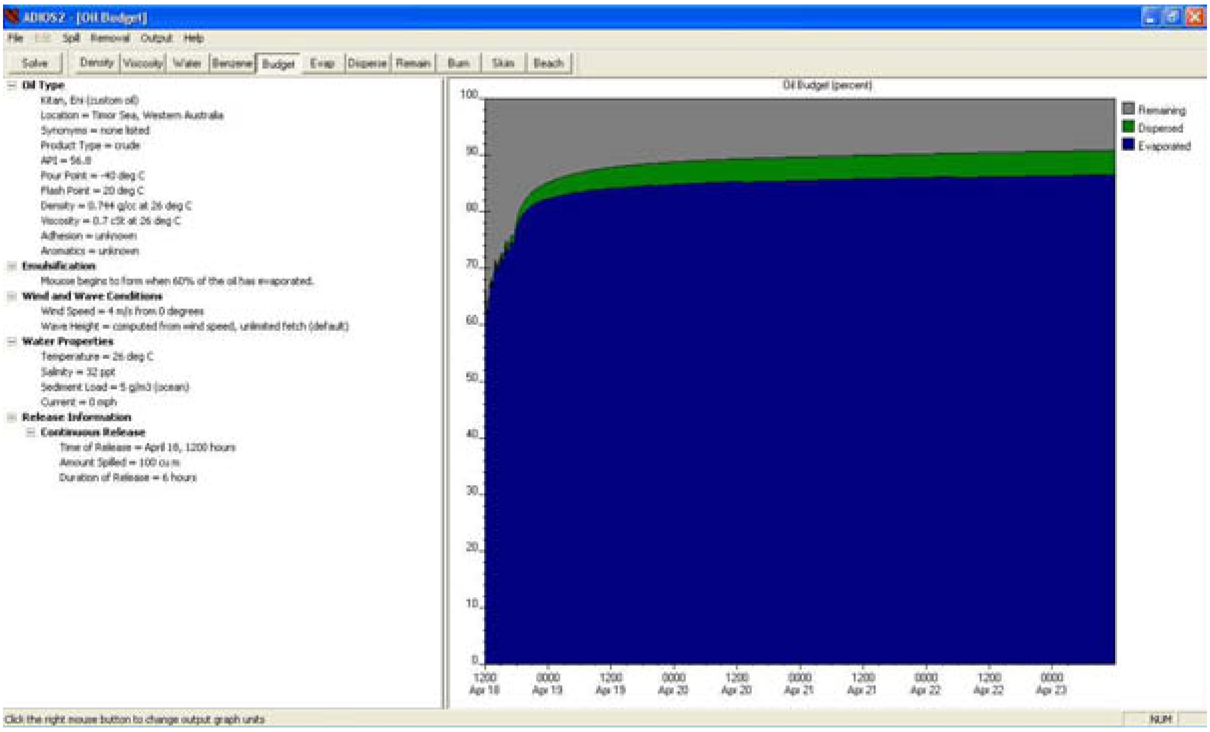


Figure 4.14 **Predicted weathering of Kitan oil for a continuous release of 100m^3 over 6 hours for a 4ms^{-1} wind**

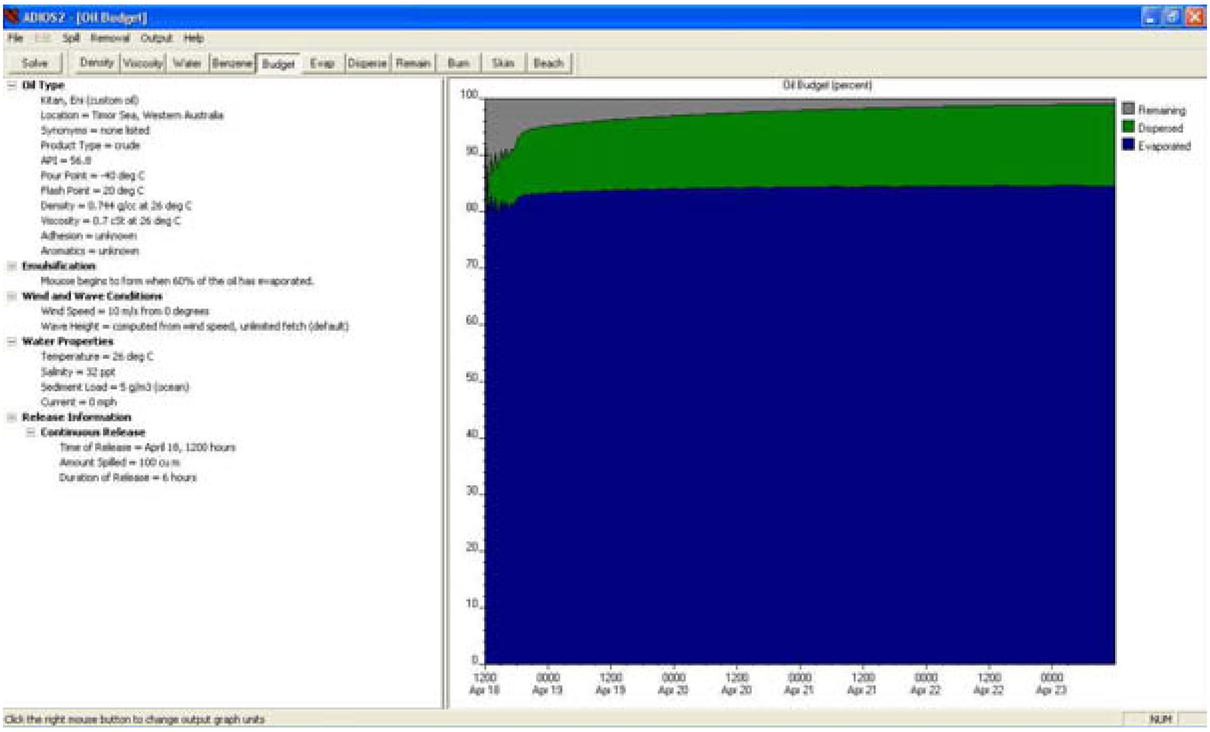
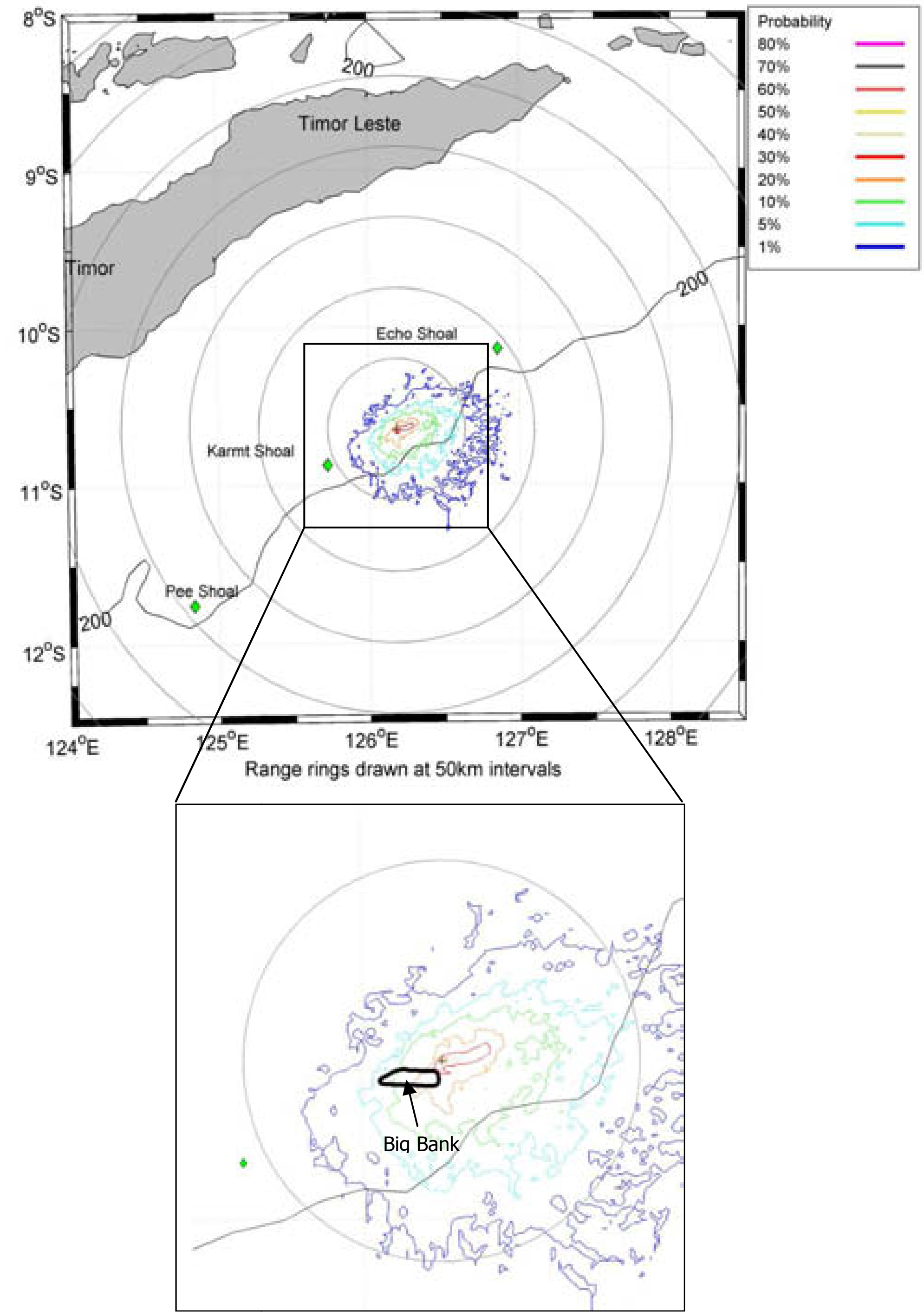


Figure 4.15 **Predicted weathering of Kitan oil for a continuous release of 100m^3 over 6 hours for a 10ms^{-1} wind**

4.3.2 Stochastic Modelling

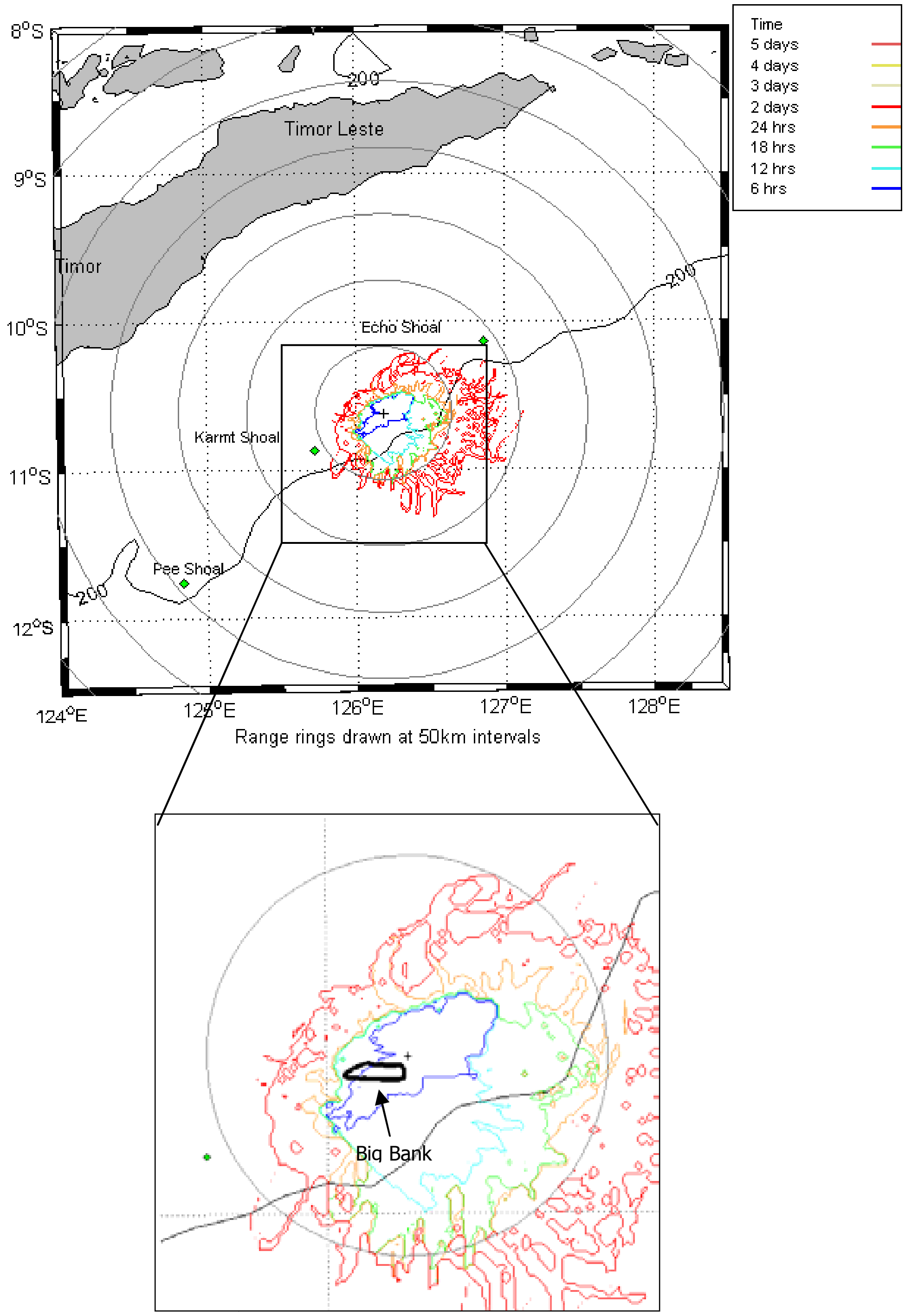
Under summer conditions, the outer (1%) probability envelope extended 75km to the east, 50km to the south and approximately 30km to the west, reflecting the predominant wind direction during this season (Figure 4.16). Under this scenario, there was a 30% probability that oil would reach the Big Bank Shoals. The predicted minimum time to exposure at Big Bank Shoals was within three hours (Figure 4.17) by which time the oil would have evaporated by 80%. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 40km around from the northeast to the southwest (Figure 4.18). Under this scenario, there was an 80% probability that oil would reach the Big Bank Shoals. The predicted minimum time to exposure at Big Bank Shoals is three hours (Figure 4.19) by which time the spill would have evaporated by 80% of its original volume. The spill is not predicted to make contact with land.



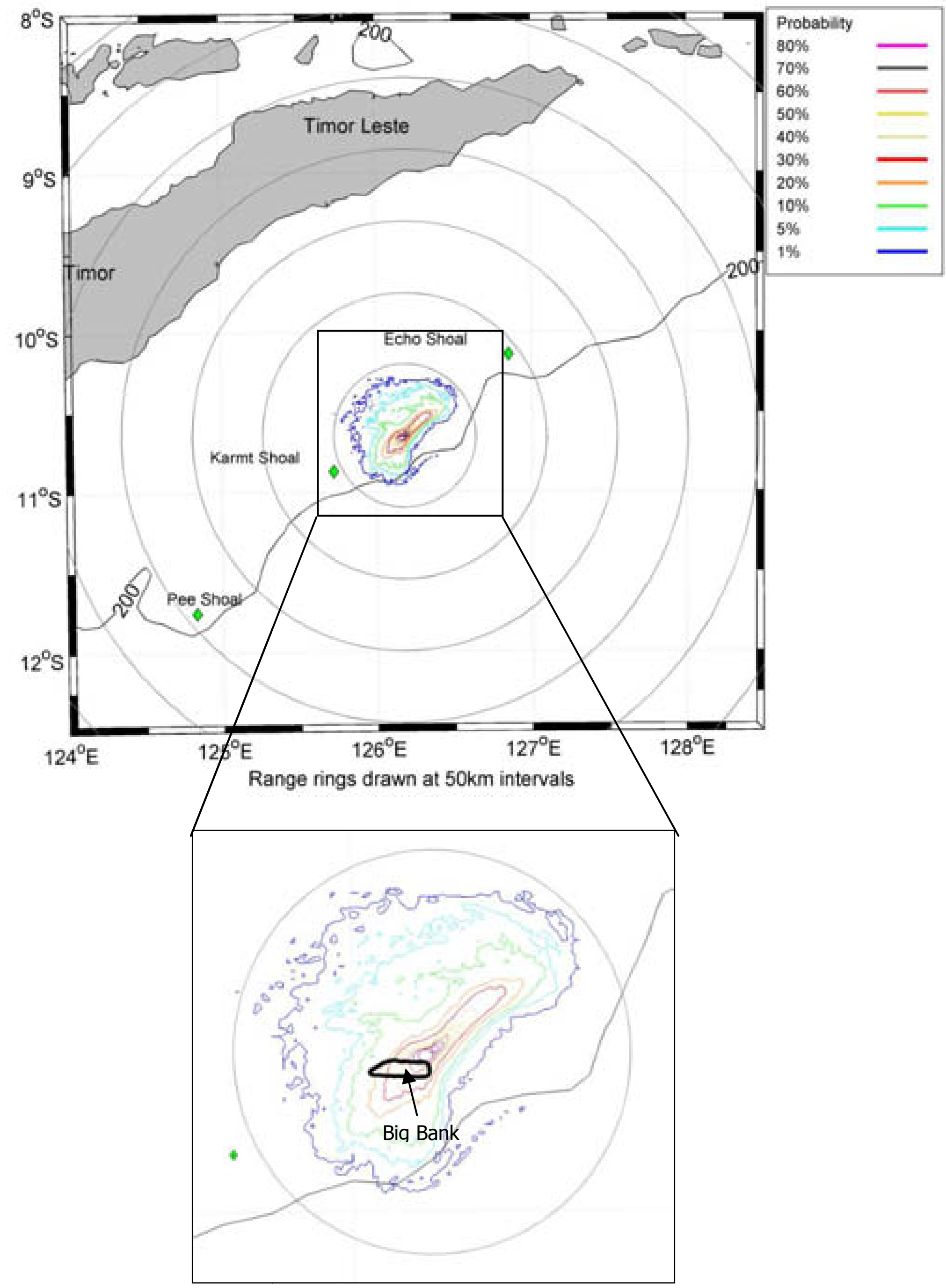
Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.16 Probability of surface exposure at day 5 under summer conditions from a 100m³ spill of crude oil occurring over a 6 hour period



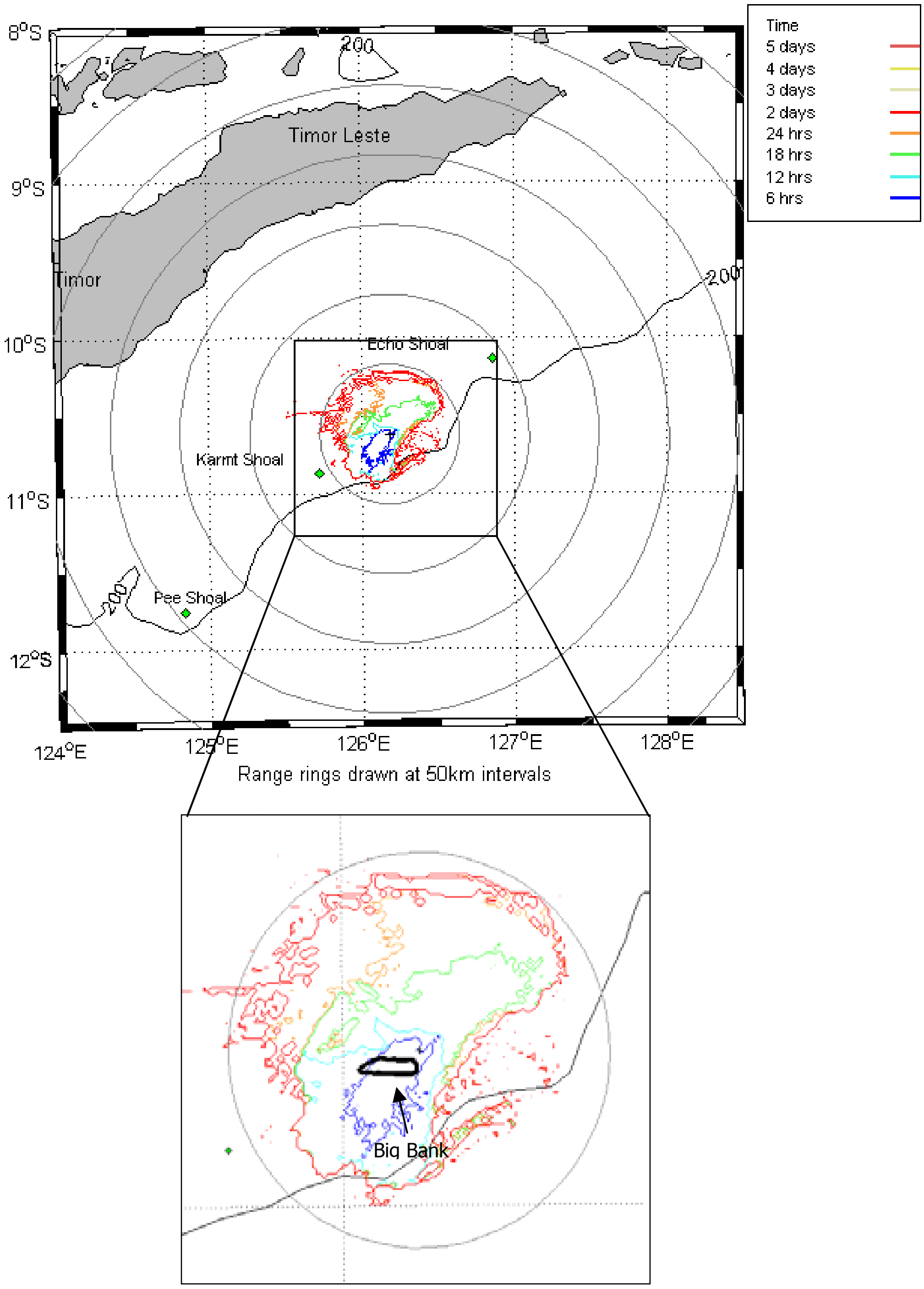
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.17 Predicted minimum time to exposure under summer conditions from a $100m^3$ spill of crude oil occurring over a 6 hour period



Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.18 Probability of surface exposure at day 5 under winter conditions from a 100m^3 spill of crude oil occurring over a 6 hour period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.19 Predicted minimum time to exposure under winter conditions from a 100m^3 spill of crude oil occurring over a 6 hour period

4.4 EVENT 4: INSTANTANEOUS SPILL OF 10M^3 OF CRUDE

4.4.1 Predicted Weathering Behaviour

Under light winds (4ms^{-1}), approximately 85% of the oil is predicted to evaporate within 24 hours, 4% is predicted to become entrained into the water column leaving 11% on the sea surface (Figure 4.20).

Under strong winds (10ms^{-1}), approximately 88% of the original spill volume is predicted to evaporate within 3 hours, 9% is predicted to become entrained into the water column leaving just 3% on the sea surface (Figure 4.21).

4.4.2 Stochastic Modelling

Under summer conditions, the outer (1%) probability envelope extended <30km to the east and west (Figure 4.22). Under this scenario, there was a 40% probability that oil would reach the Big Bank Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.23) by which time the spill would have evaporated by 85% of its original volume. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 40km to the west (Figure 4.24). Under this scenario, there was a 40% probability that oil would reach the Big Bank Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.25) by which time the spill would have evaporated by 85% of its original volume. The spill is not predicted to make contact with land.

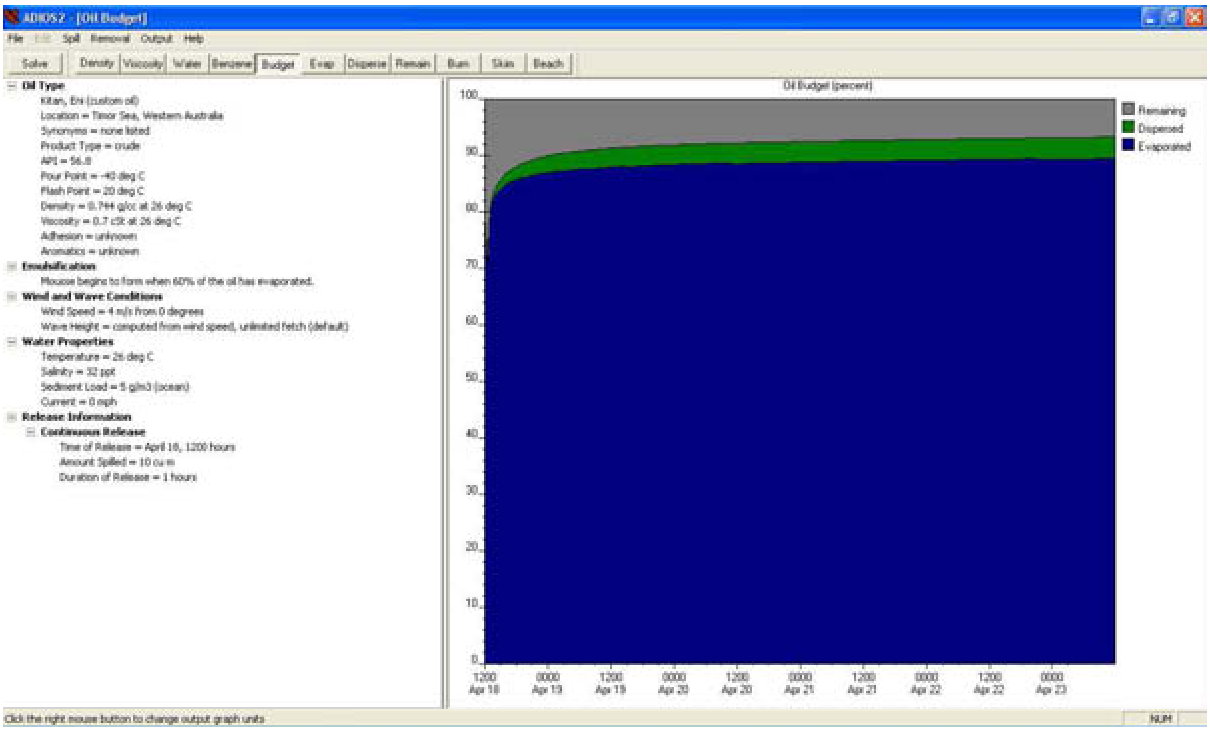


Figure 4.20 **Predicted weathering of Kitan oil for an instantaneous release of $10m^3$ and $4ms^{-1}$ wind**

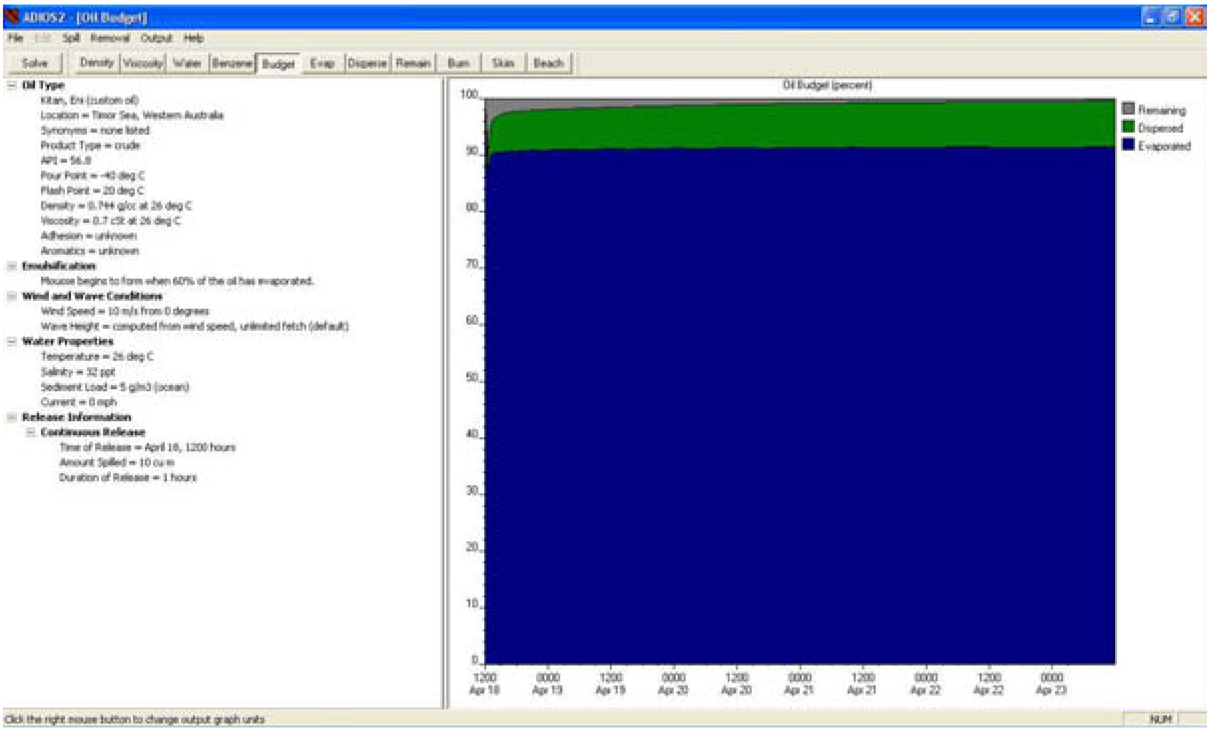
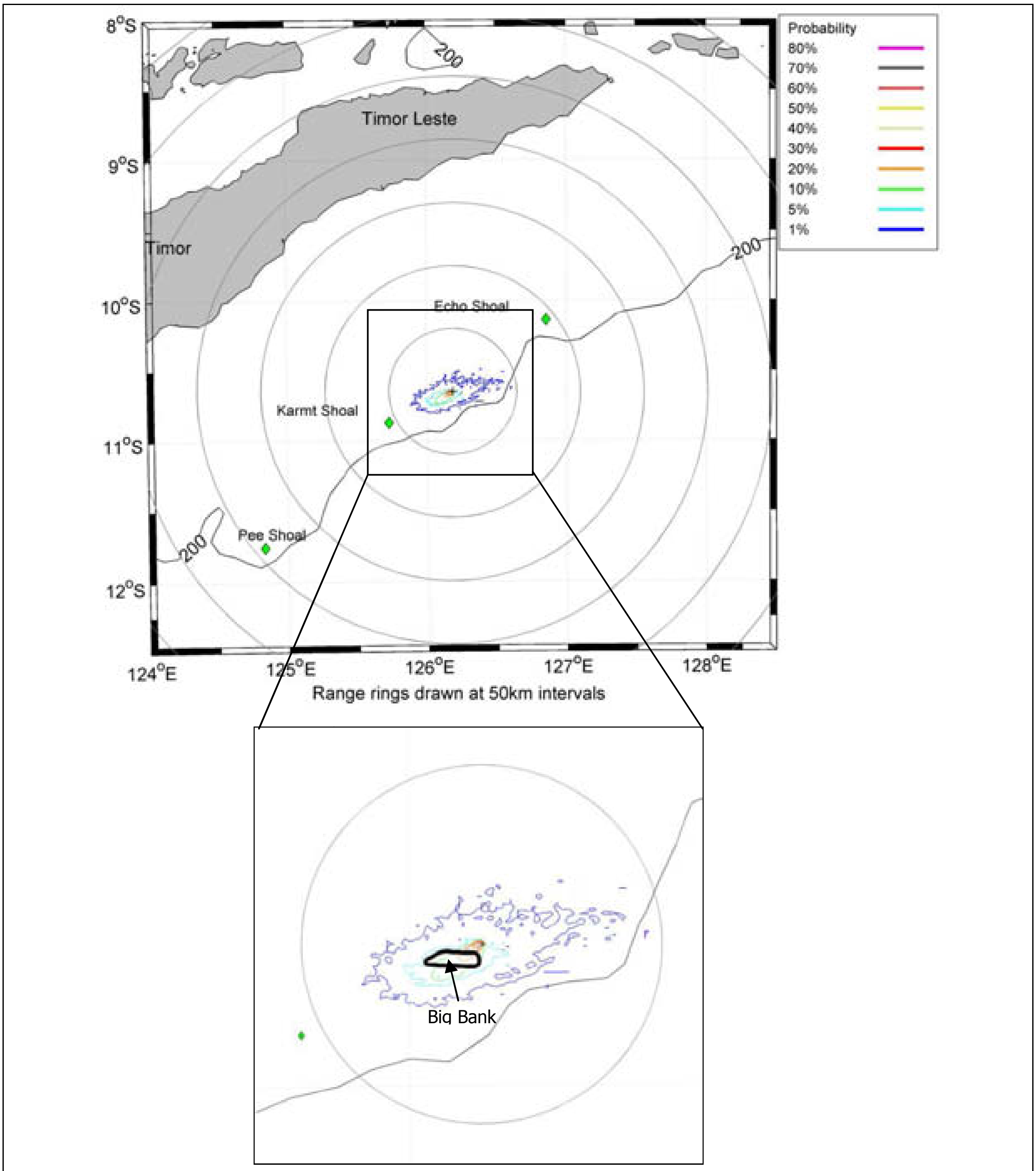
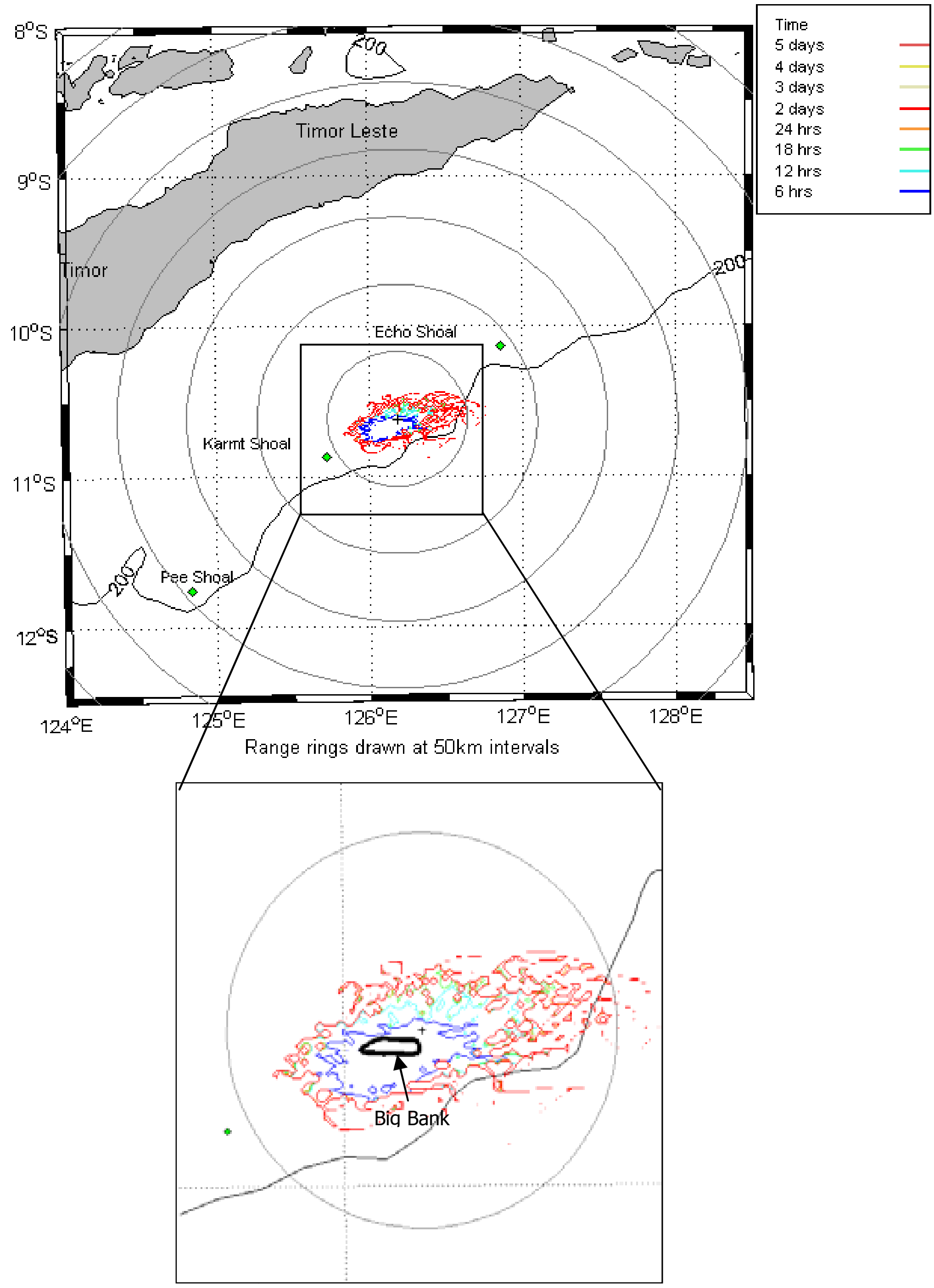


Figure 4.21 **Predicted weathering of Kitan oil for an instantaneous release of $10m^3$ and $10ms^{-1}$ wind**



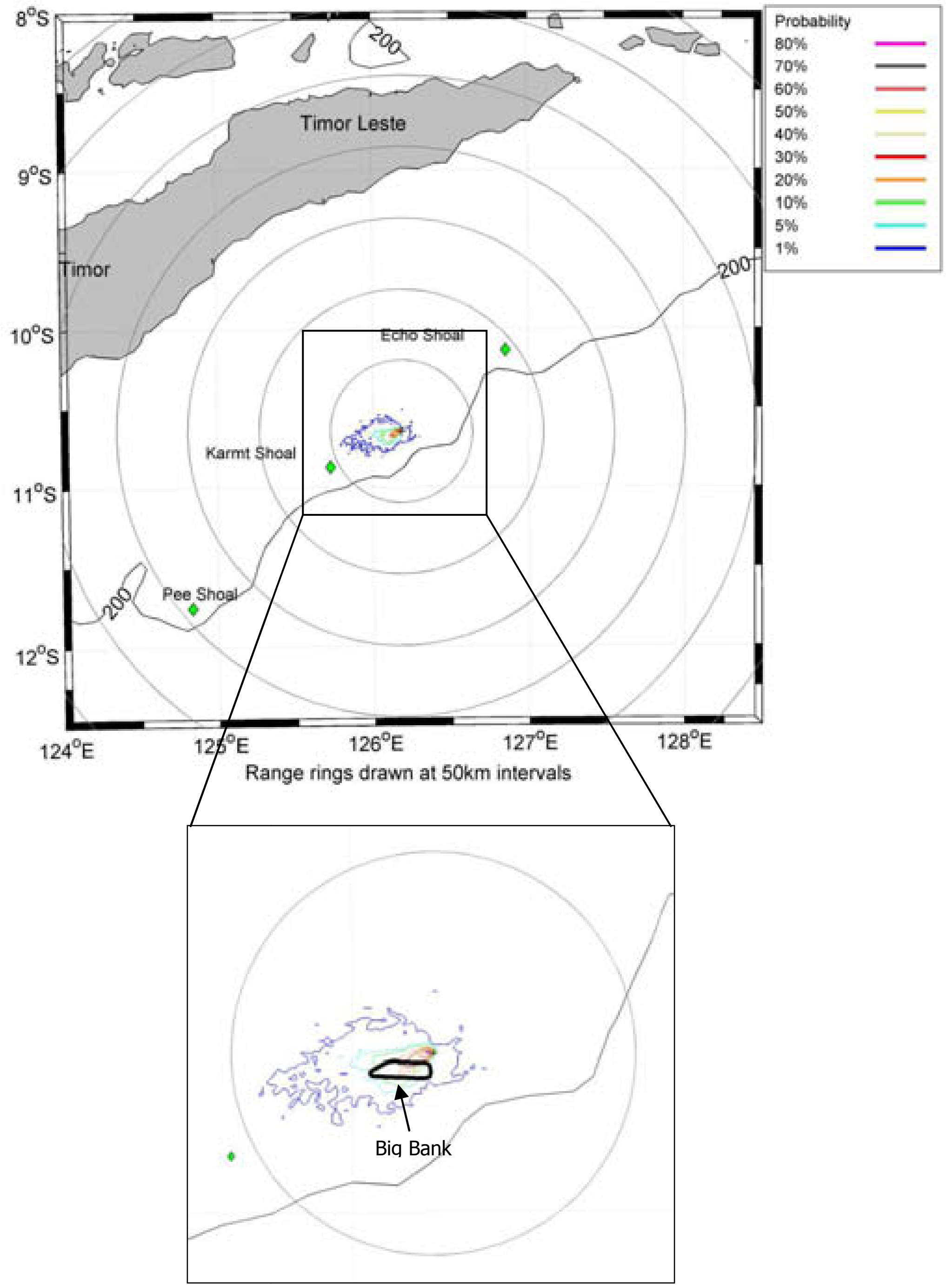
Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.22 Probability of surface exposure at day 5 under summer conditions from an instantaneous 10m^3 spill of crude oil



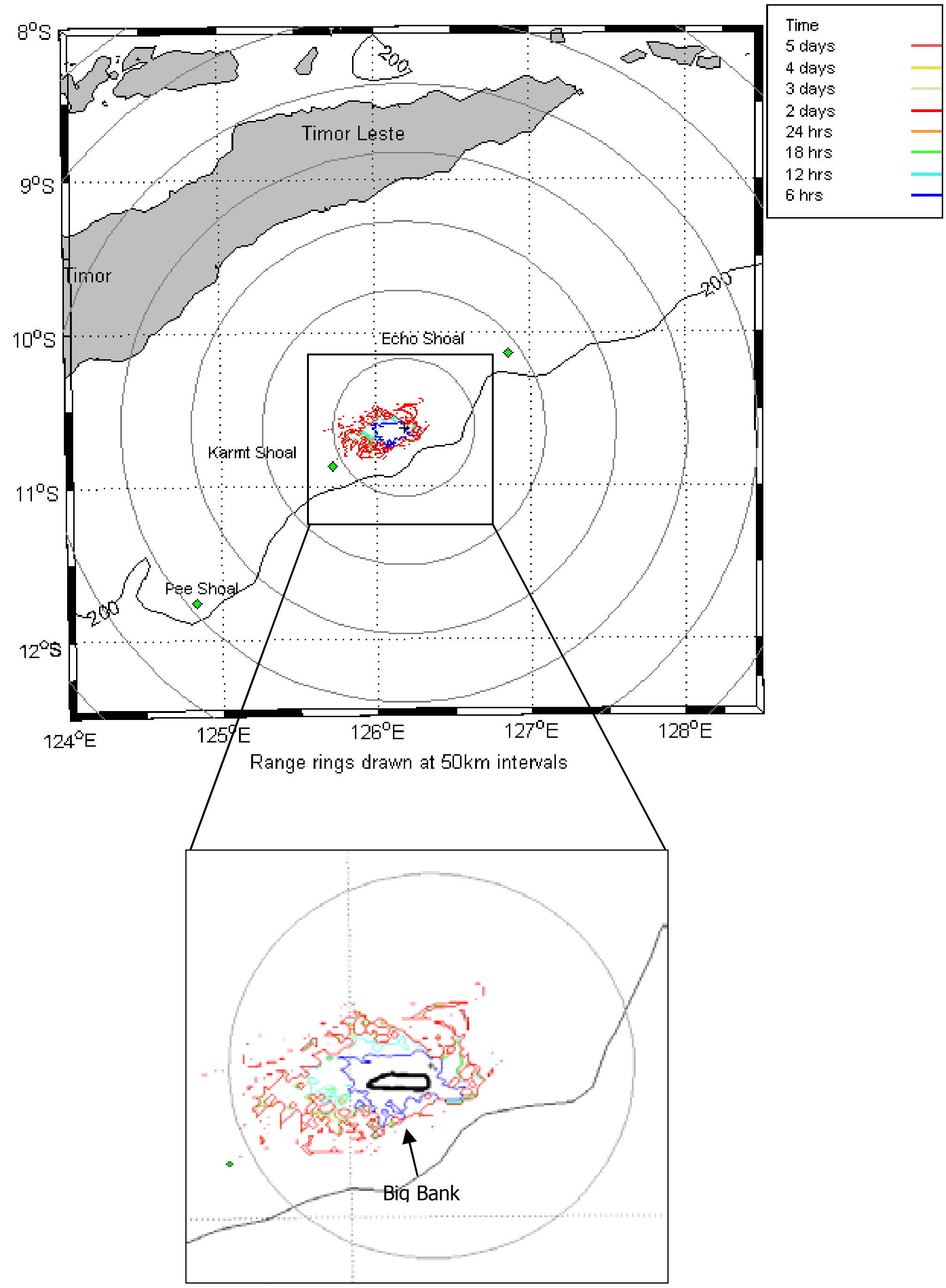
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.23 Predicted minimum time to exposure under summer conditions from an instantaneous 10m^3 spill of crude oil



Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.24 Probability of surface exposure at day 5 under winter conditions from an instantaneous 10m^3 spill of crude oil



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period

Figure 4.25 Predicted minimum time to exposure under winter conditions from an instantaneous 10m³ spill of crude oil

4.5 EVENT 5: LOSS OF 80M^3 OF DIESEL OVER 6 HOURS

4.5.1 Predicted Weathering Behaviour

Figure 4.26 shows the predicted weathering behaviour from the ADIOS2 model for a constant wind speed of 4ms^{-1}. Evaporation rates are initially high with just under 50% evaporating within the first 24 hours. The rate of dispersion into the water column is also high with the majority of diesel being removed from the sea surface within three days.

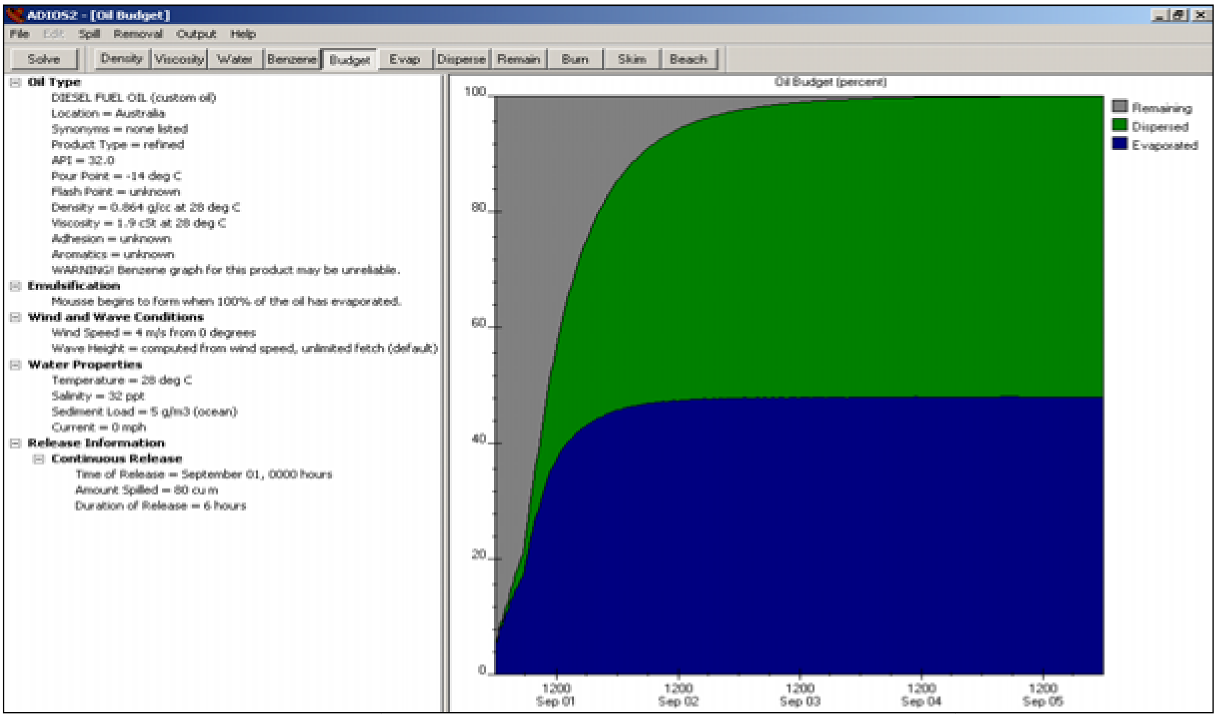


Figure 4.26 Predicted weathering of diesel fuel oil for a continuous release of 80m3 over 6 hours for a 4ms^{-1} wind

4.5.2 Stochastic Modelling

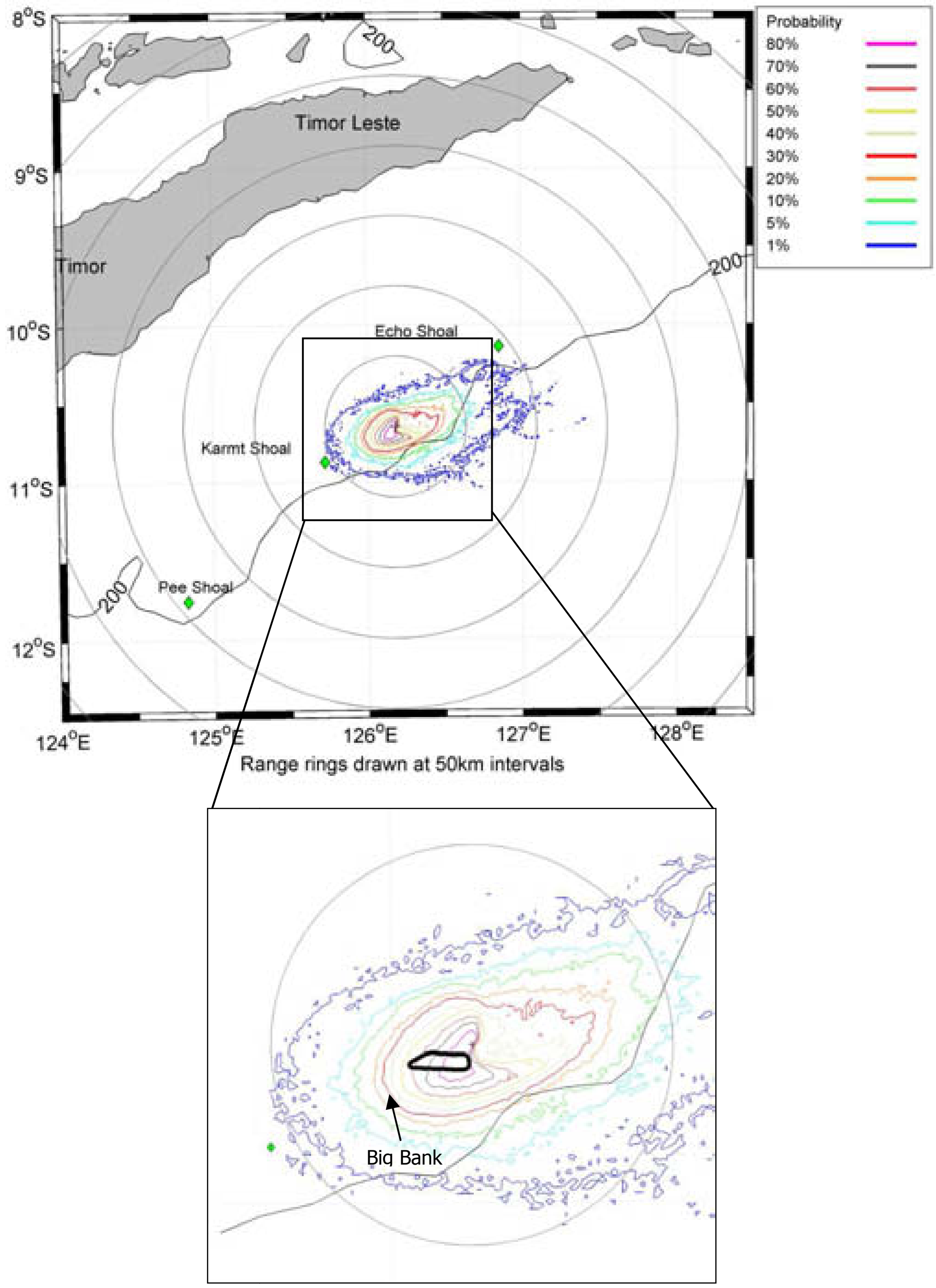
Under summer conditions, the outer (1%) probability envelope extended 100km to the east and 50km to the west, reflecting the predominant wind direction during this season (Figure 4.27). Under this scenario, there was a >80% probability that oil would reach the Big Bank Shoals and 1% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.28) by which time the spill would have evaporated by about 50% of its original volume. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 80km to the west and <50km to the east, reflecting the predominant wind direction during this season (Figure 4.29). Under this scenario, there was a 80% probability that oil would reach the Big Bank Shoals and 1% probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was three hours (Figure 4.30) by which time the spill would have evaporated by 50% of its original volume. The spill was not predicted to make contact with land.

4.5.3 Deterministic Modelling

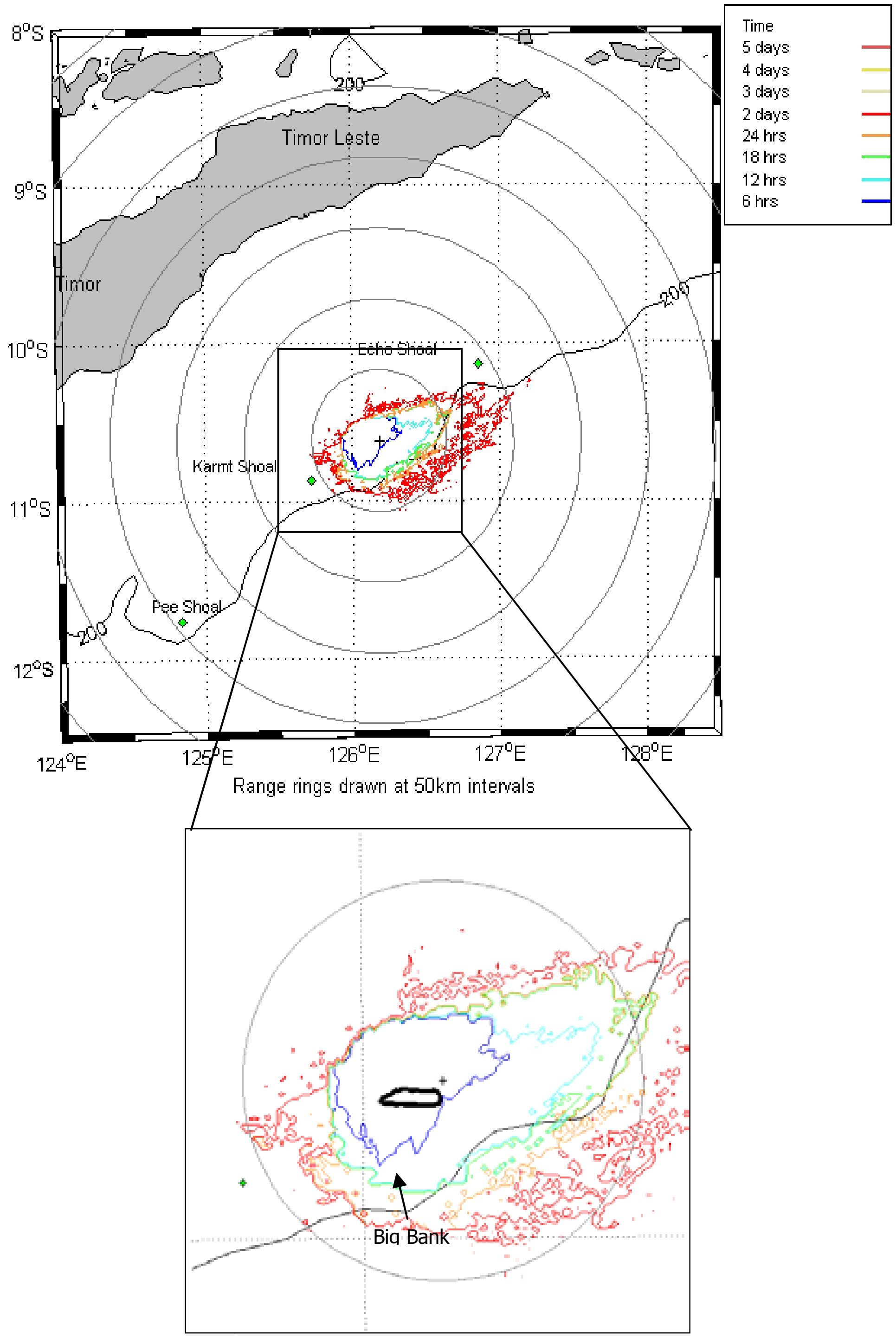
Deterministic modelling predicted the trajectory and fate of a single oil spill of $80m^3$ occurring over six hours (Figure 4.31a-d). Using deterministic mode, the vertical distribution of oil in the water column can be predicted (note that the minimum vertical resolution of the model is 1m).

Figures 4-31a-d present examples from the deterministic simulation. The plots show the dynamic nature of the slick as it is transported by the ambient currents. Under certain hydrodynamic conditions the slick sweeps over Big Bank, however, the vertical profiles show that the oil remains at the surface and will not make contact with the sensitive benthic habitats and communities some 20m below the sea surface.



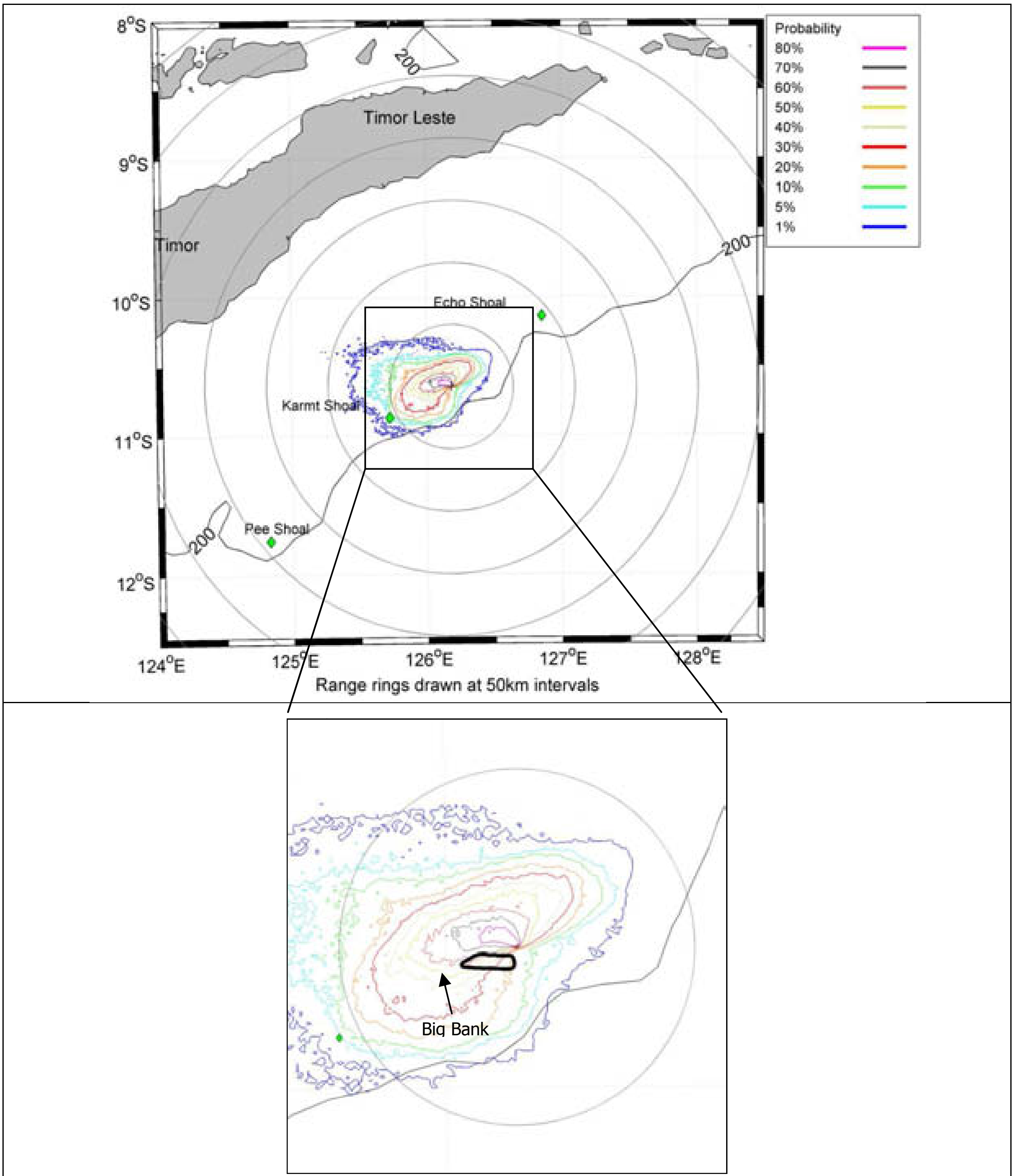
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.27 Probability of surface exposure at day 5 under summer conditions from a 80m^3 spill of diesel occurring over a 6 hour period



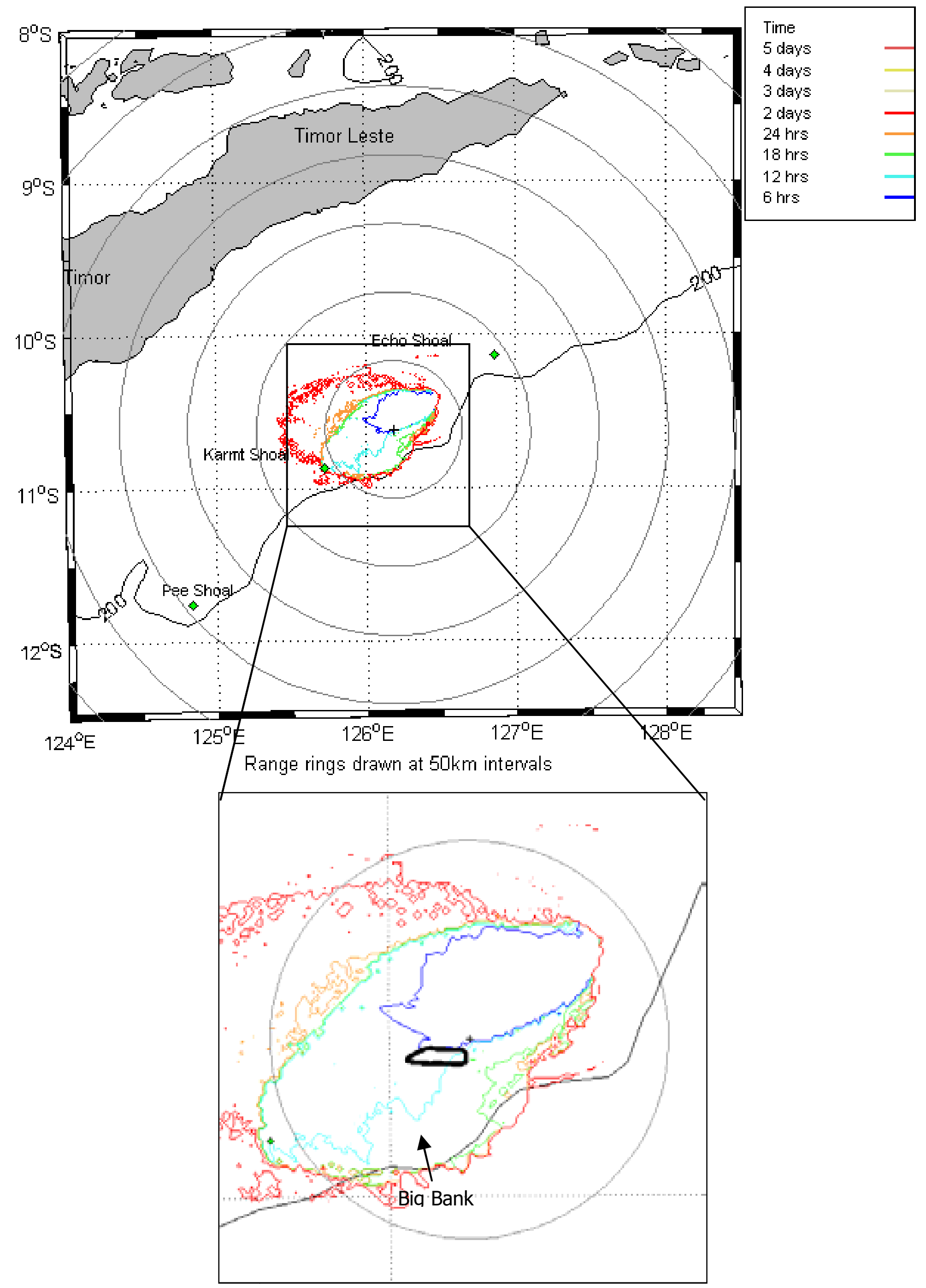
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.28 Predicted minimum time to exposure under summer conditions from a 80m^3 spill of diesel occurring over a 6 hour period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.29 Probability of surface exposure at day 5 under winter conditions from a 80m^3 spill of diesel occurring over a 6 hour period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.30 Predicted minimum time to exposure under winter conditions from a 80m^3 spill of diesel occurring over a 6 hour period

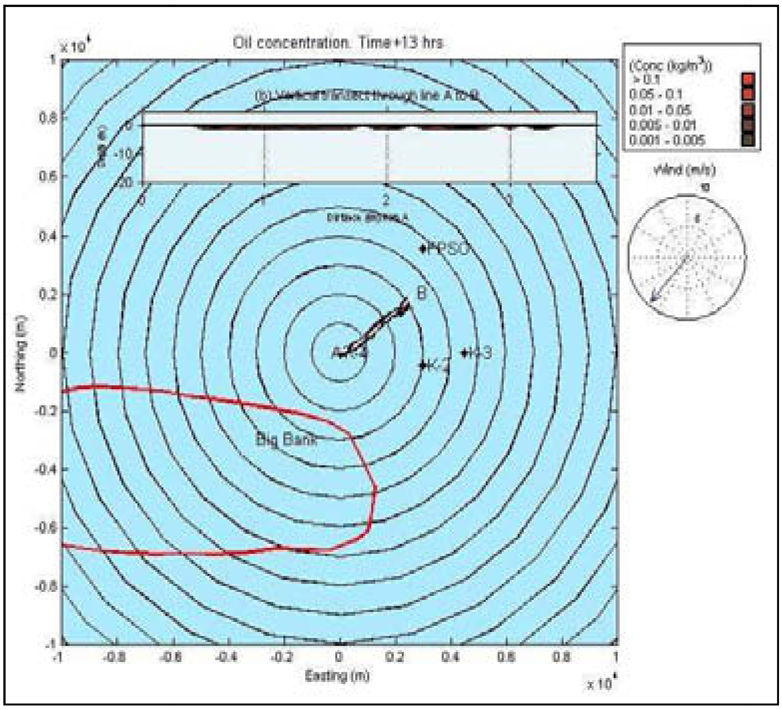


Figure 4.31 **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

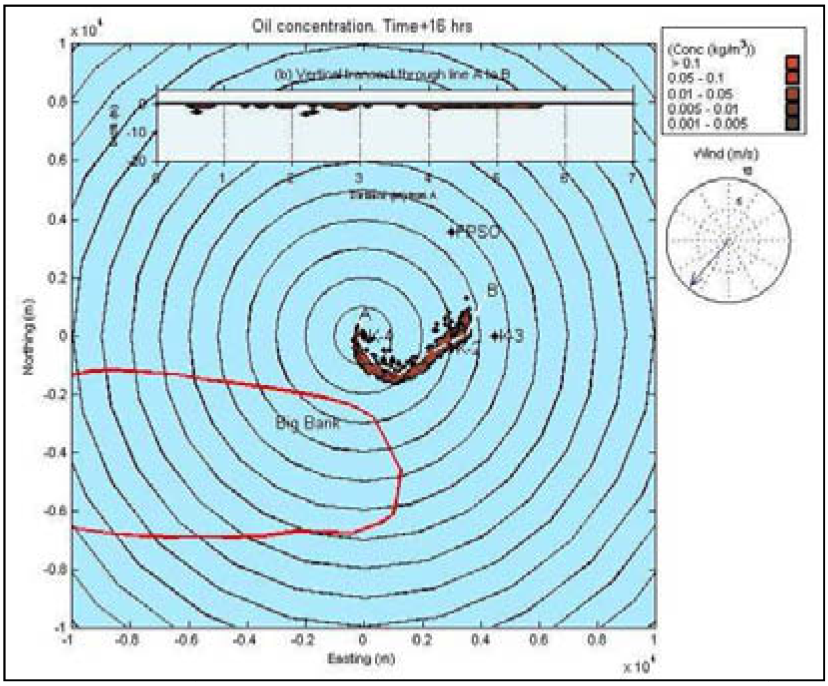


Figure 4.31b **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

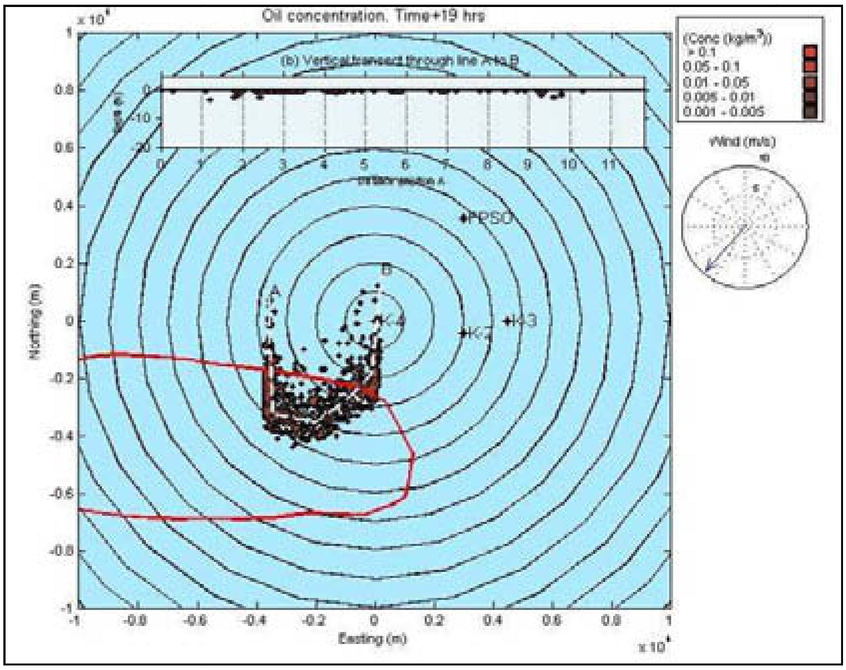


Figure 4.31c **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

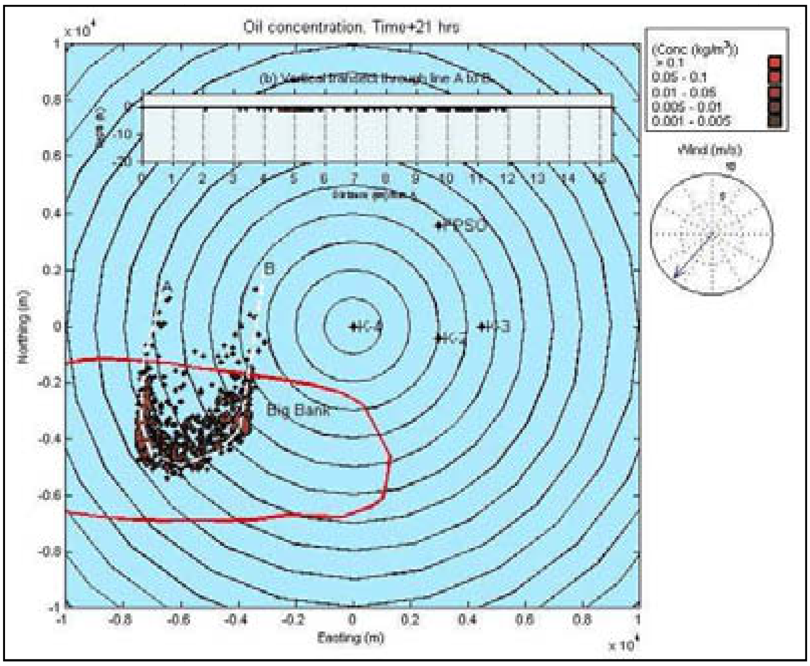


Figure 4.31d **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

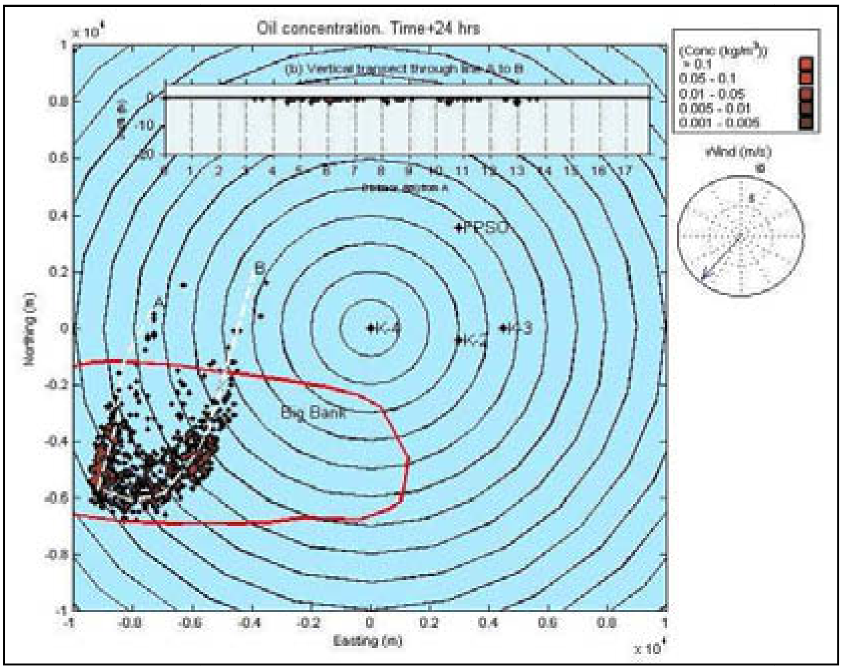


Figure 4.31e **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

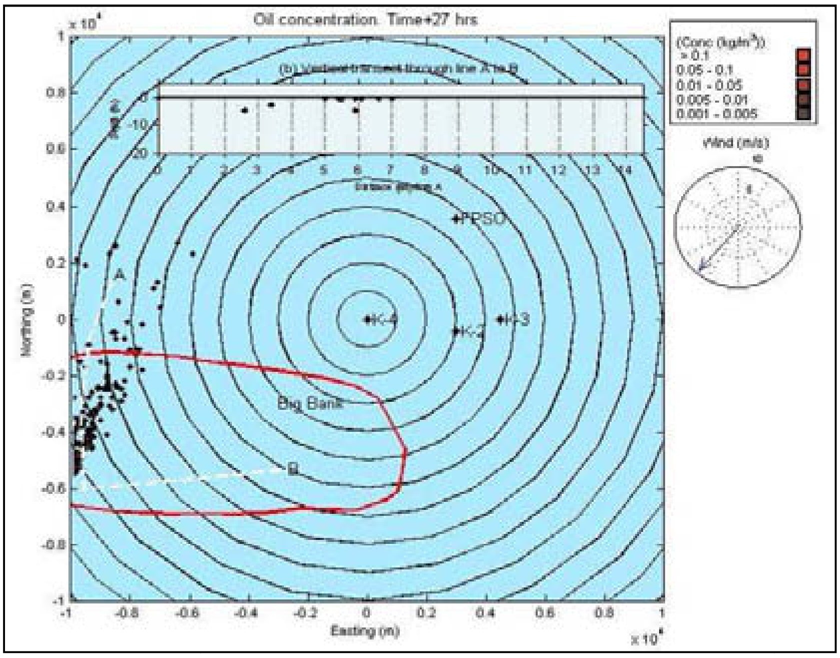


Figure 4.31f **Predicted oil spill trajectory and vertical oil concentration (kg/m^3) for a single hypothetical loss of 80m^3 of diesel (Scenario 5)**

4.6 EVENT 6: LOSS OF 2.5M^3 OF DIESEL OVER 1 HOUR

4.6.1 Predicted Weathering Behaviour

For a refuelling accident the volume of diesel was set at 2.5m^3 over a duration of 1 hour. Figure 4.32 shows the predicted weathering behaviour from the ADIOS2 model for a wind speed of 4ms^{-1}. Evaporation rates are initially high with just under 50% evaporating within the first 24 hours. The rate of dispersion into the water column is also high with the majority of diesel being removed from the sea surface within three days.

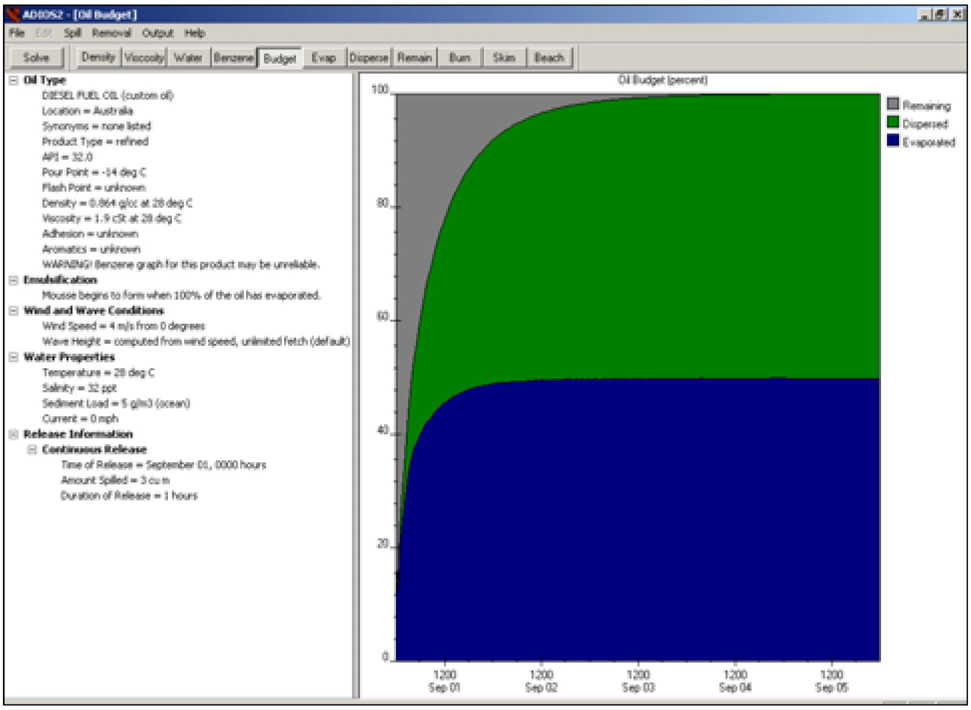
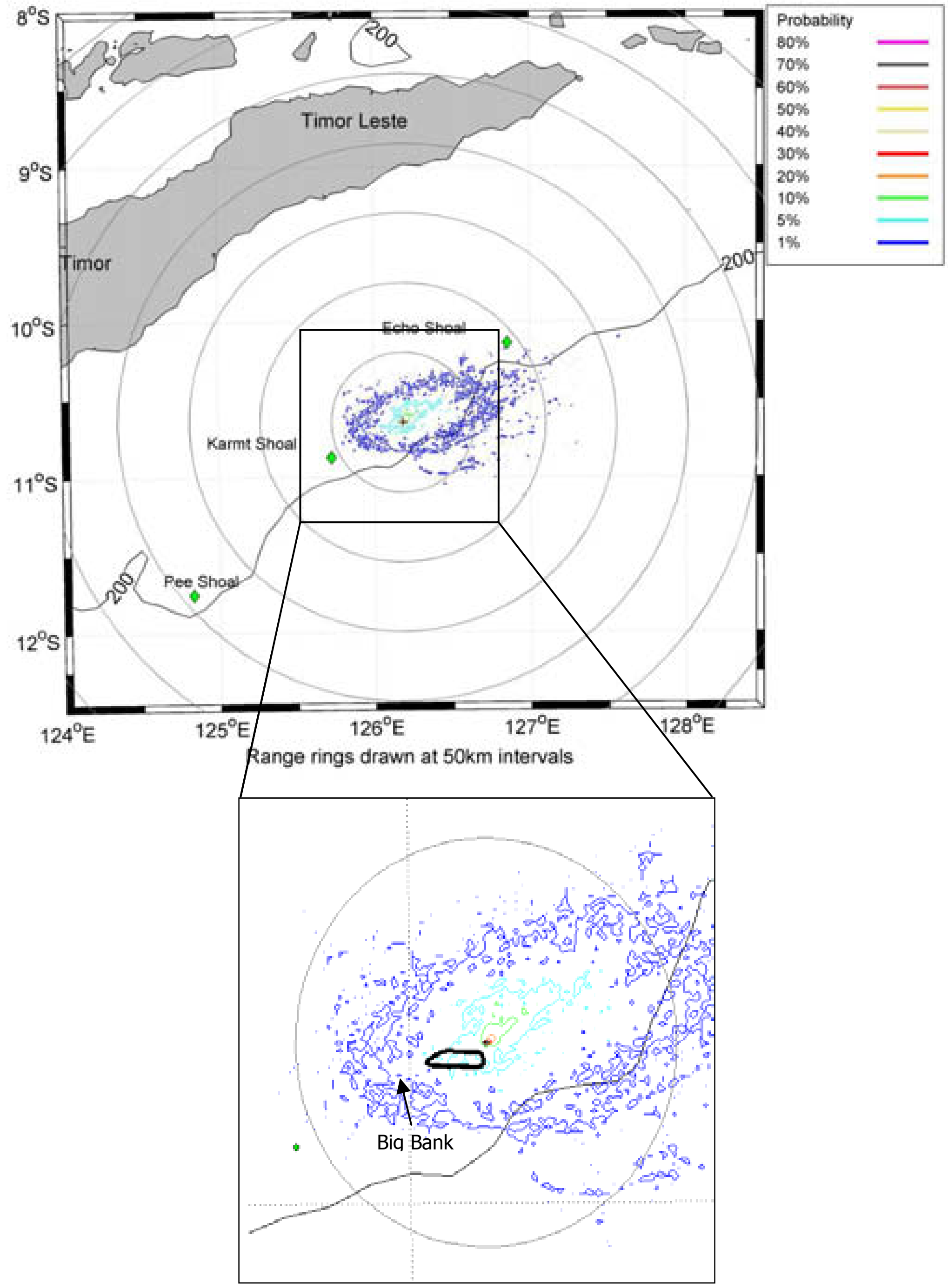


Figure 4.32 Predicted weathering of diesel oil for a continuous release of 2.5m^3 over 1 hour for a 4ms^{-1} wind

4.6.2 Stochastic Risk Assessment Modelling

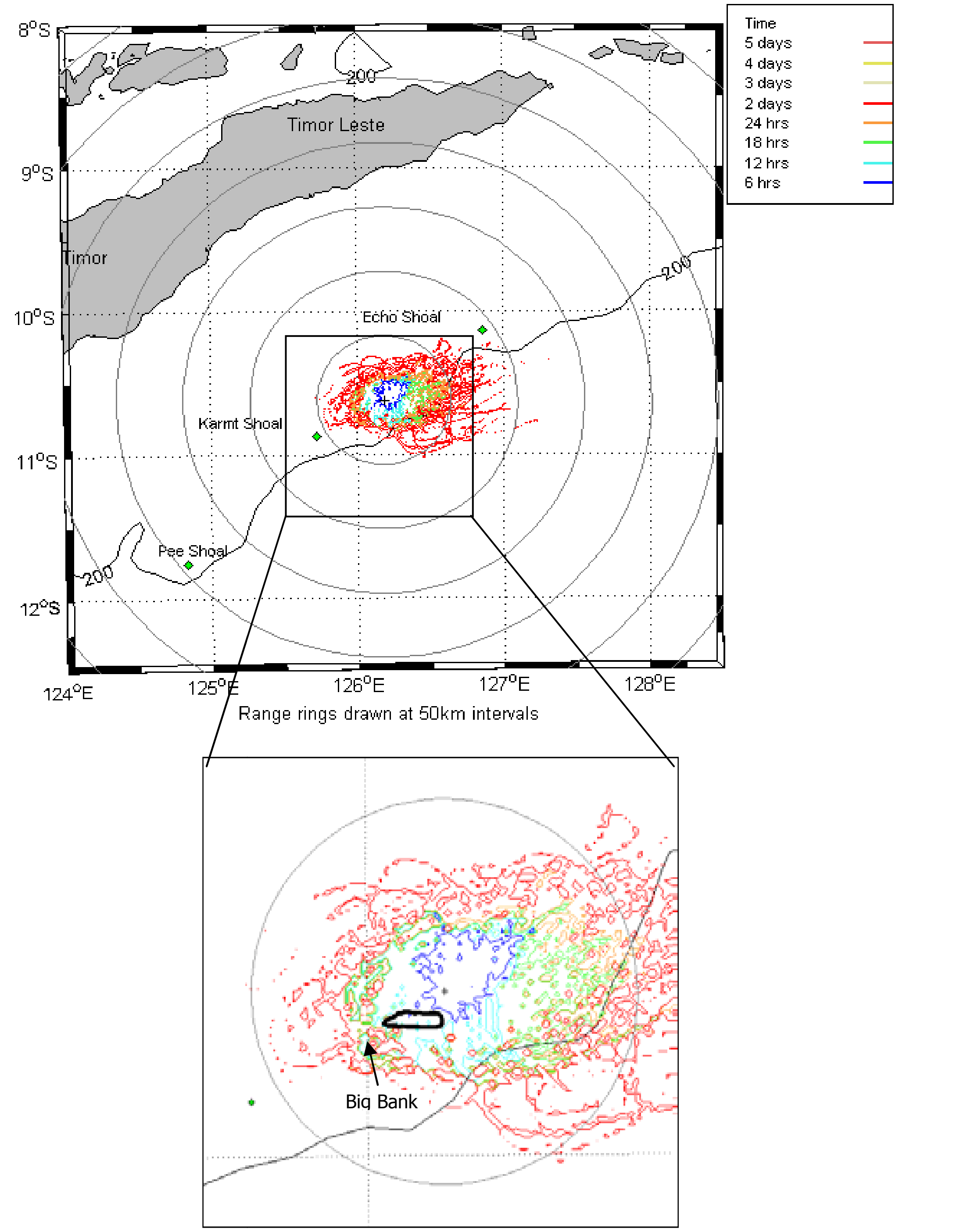
Under summer conditions, the outer (1%) probability envelope extended 70km to the east and 30km to the west of Kitan, reflecting the predominant wind direction during this season (Figure 4.33). Under this scenario, there was a 5% probability that oil would reach the Big Bank Shoals and no chance of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was six hours (Figure 4.34) by which time the spill would have evaporated by about 50% of its original volume. The spill was not predicted to make contact with land.

Under winter conditions, the outer (1%) probability envelope extended 50km to the west and <10km to the east of Kitan, reflecting the predominant wind direction during this season (Figure 4.35). Under this scenario, there was a <5% probability that oil would reach the Big Bank Shoals and zero probability of reaching the Karmt Shoals. The predicted minimum time to exposure at Big Bank Shoals was six hours (Figure 4.36) by which time the spill would have evaporated by 50% of its original volume. The spill was not predicted to make contact with land.



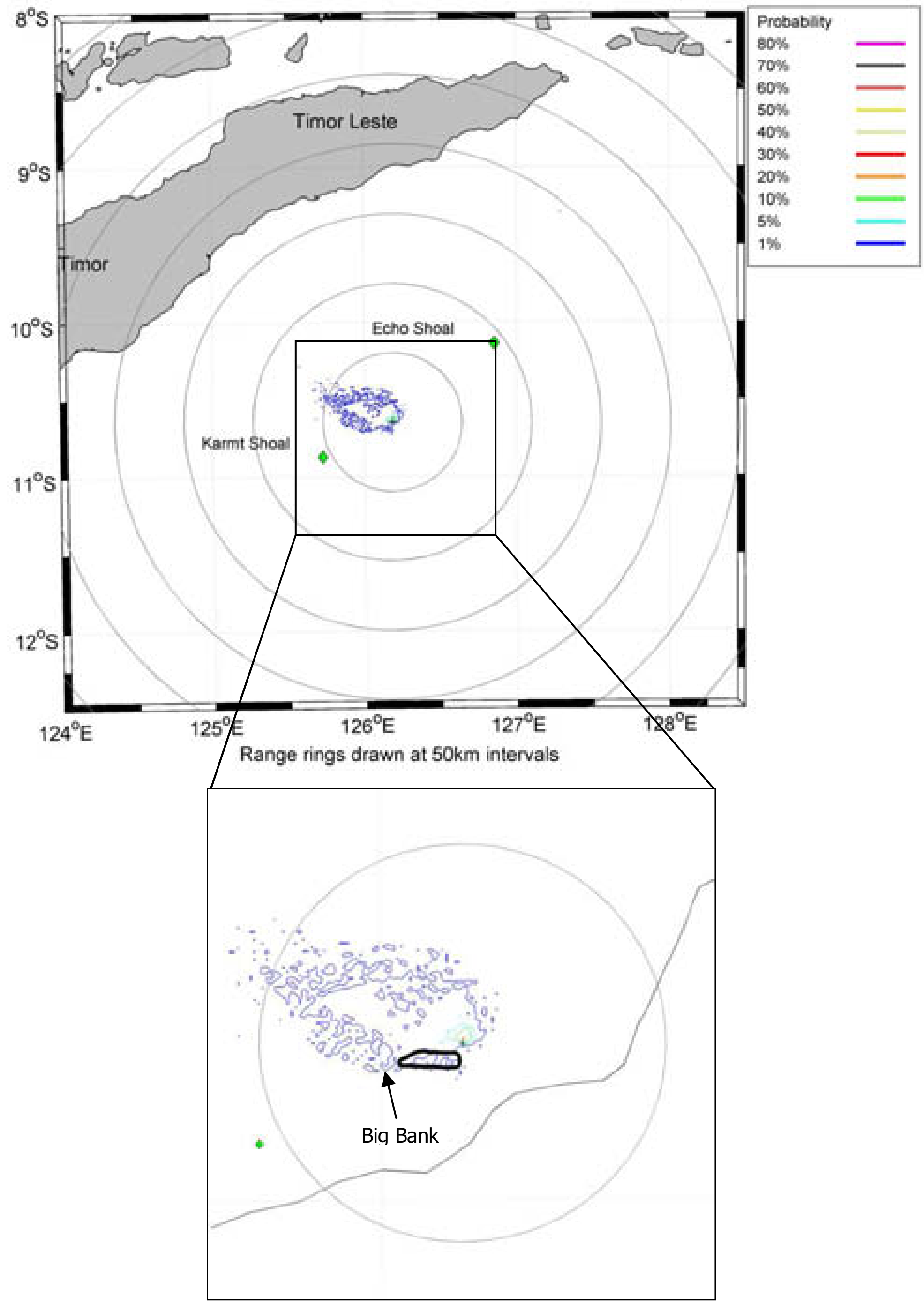
Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.33 Probability of surface exposure at day 5 under summer conditions from a 2.5m^3 spill of diesel occurring over a 1 hour period



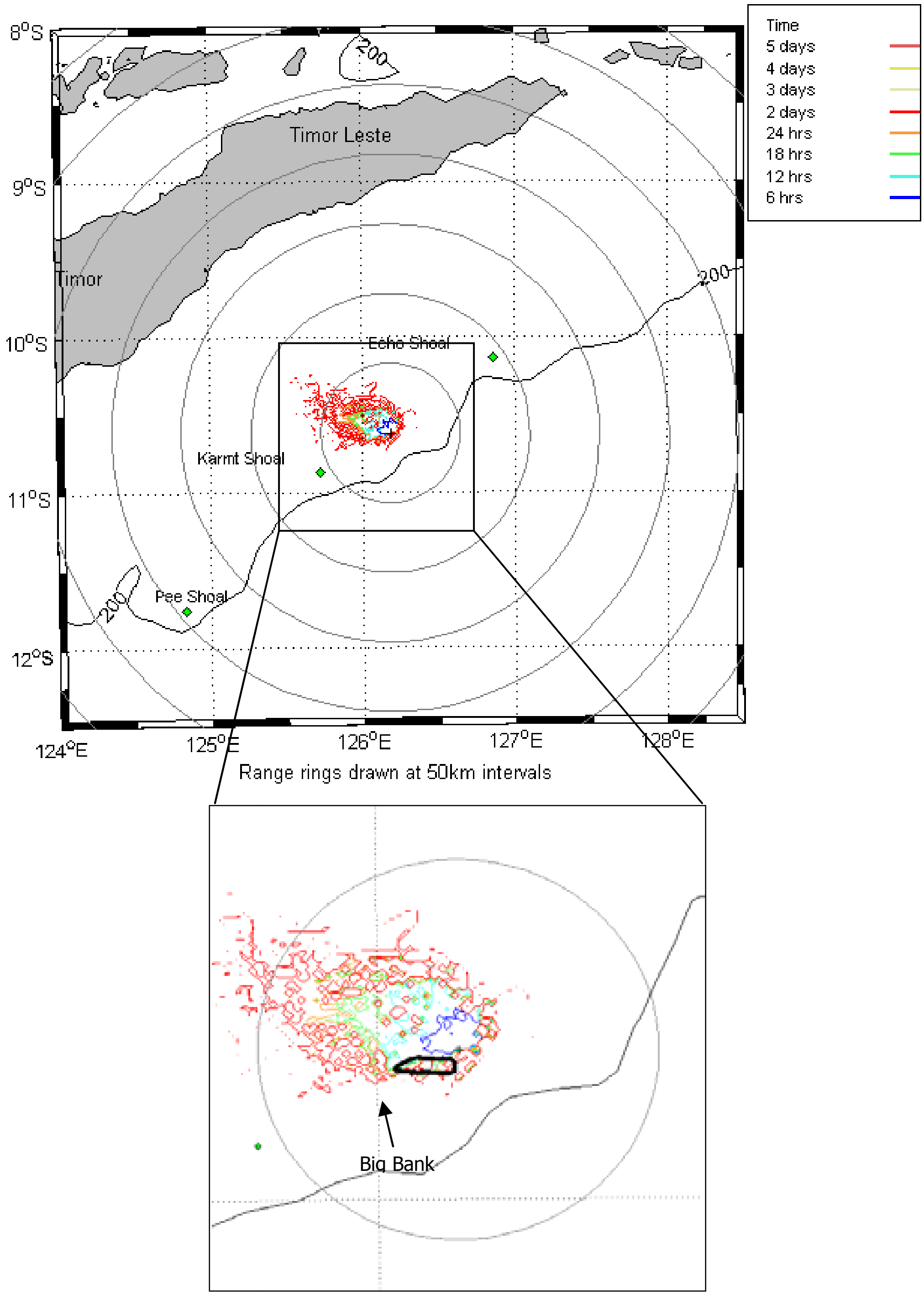
Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.34 Predicted minimum time to exposure under summer conditions from a 2.5m^3 spill of diesel occurring over a 1 hour period



Notes: Probability contours calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.35 Probability of surface exposure at day 5 under winter conditions from a 2.5m^3 spill of diesel occurring over a 1 hour period



Notes: Minimum time to contact contours were calculated from 200 oil spill simulations using randomly selected wind and circulation data for the period of drilling

Figure 4.36 Predicted minimum time to exposure under winter conditions from a 2.5m^3 spill of diesel occurring over a 6 hour period

5. DISCUSSION

5.1 KITAN CRUDE OIL

Kitan crude oil is light and evaporates readily from the sea surface. For example, a large spill would be expected to evaporate by over 60% of its original volume after 24hours. Under low wind conditions across all for crude oil spill scenarios, evaporation accounted for between 60% and 85% of weathering whereas entrainment into the water column accounted for between 1% and 4%. In contrast, under strong wind conditions, entrainment accounted for between 4% and 12% of weathering across the four crude oil spill scenarios.

Under strong winds, oil droplets of less than 100µm would become entrained rapidly into the water column. As wind strength and surface wave intensity increases, oil droplets of greater than 100µm would also become mixed into the water column. Kitan oil has a low wax content and low asphaltene concentrations suggesting that it is unlikely to form a stable emulsion. This has been confirmed by studies on a sample of Kitan oil (EAL, 2009).

The oil dispersion probability envelopes reflected the prevailing seasonal wind patterns. During summer, winds are predominantly from the west and the probability envelopes extended to the east whereas for winter, the reverse was true.

The probability of crude oil spreading to the Big Bank Shoals was over 70% to 80% under the large spill size scenarios (7000m^3 over 24hrs and 1800m^3/day over 56 days) and 30% for the smaller scenarios (Table 5.1). The minimum time to reach Big Bank Shoals was less than six hours during which time it would be most likely to degrade by between 50% and 80% of its initial volume. Deterministic modelling indicated that spilled oil would remain at the sea surface. Thus, although oil may become entrained into the water column overlying the nearby Big Bank Shoals (particularly in winter), impacts on the benthic communities would not be expected to occur due to the water depth (≥20m water depth LAT), distance from the Kitan oilfield, and the degree of weathering and dilution that would occur prior to any potential contact.

Crude oil was not predicted to reach land under any of the spill volume and season scenarios, reflecting the light nature of the oil and its tendency to weather rapidly. Any spill occurring at the Kitan oilfield would be most likely to biodegrade at sea and should therefore be monitored and allowed to degrade naturally without the use of dispersants.

Table 5.1: Summary of oil spill trajectory modelling results

Scenario	Description	Location	Maximum Probability of Reaching	Minimum Time to Reach
1	Rupture of a crude storage tank on the FPSO (7000m^3 over 24hrs)	Big Bank	70% - 100%	<6hrs
		Karmt Shoals	<1% - 20%	4 – 5 days
		Echo Shoals	0%	Not applicable
2	Well Blowout (1800m^3 over 56 days)	Big Bank	>80%	<6hrs
		Karmt Shoals	40%	2 days
		Echo Shoals	1%	2.5 days
3	Upper end of an accidental spill such as a transfer hose rupture or process leak (100m^3 over 6 hrs)	Big Bank	30% - 80%	<6hrs
		Karmt Shoals	0%	Not applicable
		Echo Shoals	0%	Not applicable
4	Lower end of a significant accidental spill (10m^3 instantaneous)	Big Bank	30%	<6hrs
		Karmt Shoals	0%	Not applicable
		Echo Shoals	0%	Not applicable
5	Fuel Tank Rupture (80m^3 over 6 hrs)	Big Bank	90%	<3hrs
		Karmt Shoals	3%	3 days
		Echo Shoals	4%	2.5 days
6	Refuelling Spill (2.5m^3 over 1hr)	Big Bank	90%	<3hrs
		Karmt Shoals	1%	3 days
		Echo Shoals	4%	2.5 days

5.2 DIESEL

Diesel is a light petroleum distillate and would be expected to undergo a rapid spreading with moderate evaporative loss in tropical waters. Diesel oils tend not to form emulsions at the temperatures likely to be found in the Timor Sea and so these will not inhibit spreading of the slick or evaporation rates.

Unlike Kitan crude oil, only 50% of the diesel would be expected to evaporate after 24hrs, with the remaining 50% spreading out as a surface slick. Diesel would not be expected to form an emulsion. Stochastic modelling indicated that there is a 90% probability of a diesel spill spreading to the nearby Big Bank Shoals within 3 hours of release (Table 5.1). Although a diesel slick has a high probability of being transported over Big Bank Shoals, deterministic modelling indicated that most of the oil would remain at the sea surface. Vertical turbulence generated by waves only mixes the oil particles to a depth of no more than 5m below the surface.

Like the Kitan crude oil, diesel was not predicted to reach land under any of the spill volume and season scenarios. Any diesel spill occurring at the Kitan oilfield would be most likely to biodegrade at sea and should therefore be monitored and allowed to degrade naturally without the use of dispersants.

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7. ABBREVIATIONS

ADIOS2	Automated Data Inquiry for Oil Spills
AHD	Australian Height Datum
API	American Petroleum Institute
Eni	ENI-JPDA-06-105 PTY LTD
EMP	Environmental Management Plan
HAT	Highest Astronomic Tide
HYCOM	HYbrid Coordinate Ocean Model
JPDA	Joint Petroleum Development Authority
LAT	Lowest Astronomical Tide
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
NCEP	National Center for Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
OSCP	Oil Spill Contingency Plan
SOI	Southern Oscillation Index