MONTARA WELL RELEASE MONITORING STUDY S7.1

OIL FATE AND EFFECTS ASSESSMENT:

SPILL TRAJECTORY ANALYSIS

Final

4th October 2010

Prepared for:
PTTEP Australasia

Asia-Pacific asa

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Document control form

Document draft	*Originated by*	*Edit & review*	*Authorized for release by*	*Date*
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Draft 2 - Issued for client review	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett* *Jeremie Bernard*	*Dr Brian King*	*16th March 2010*
Draft 3 - Issued to client	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett* *Jeremie Bernard*	*Dr Brian King*	*25th March 2010*
Draft 4 - Issued to client	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett* *Jeremie Bernard*	*Dr Brian King*	*10th May 2010*
Draft 5 - Issued to client	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett* *Jeremie Bernard*	*Dr Brian King*	*18th June 2010*
Draft 6 – Issued to client	*Trevor Gilbert* *Dr Brian King*	*Rean Gilbert*	*Dr Brian King*	*24th June 2010*
Draft 7 –l Issued to client	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett*	*Dr Brian King*	*29th June 2010* *Figures updated 6th August 2010*
Draft 8 - Final Issued to client	*Trevor Gilbert* *Dr Brian King*	*Ben Brushett*	*Dr Brian King*	*4th October 2010*

Document name: PTTEP Montara Study S71 (Final).doc

APASA Project Number: S148

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DISCLAIMER:

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EXECUTIVE SUMMARY

This document is the report of Study 7.1 being part of the PTTEP/DEWHA (PTTEP Australasia and Department of the Environment, Water, Heritage and the Arts) Montara Monitoring Plan Study. Study 7.1 was commissioned (amongst others) in response to the loss of well control and consequent oil spill at the Montara Well Head Platform in the later part of 2009. This study aimed to document all oil spill positions from field and overflight data, from satellite observations and integrated hindcast oil spill trajectory modelling. The findings from this study will be used to identify areas of oil exposure and areas not exposed to oil which could act as potential environmental monitoring control sites.

During the response to the Montara Incident, extensive daily overflight observations were undertaken by the Australian Maritime Safety Authority (AMSA). This overflight data made it possible to accurately map daily slick positions and to interpret observations made by the MODIS (Aqua and Terra) and LandSat (5 and 7) satellites when these were available. These satellite observations and overflight data were also collated as part of this project and combined into the OILMAP oil spill model to provide surface oil locations at hourly intervals throughout the entire incident (from 21st August 2009 until late November when no more surface oil was observed within the Timor Sea). The hourly data over this period of time produced over 2,000 individual snapshots in time of surface oil locations. This extensive dataset was then combined into oil occurrence maps which were further analysed to determine duration of exposure from any type of surface oil, from fresh oil to highly weathered waxy residuals from the spill event.

The combinations of these various datasets highlighted that the highest occurrence of oil was within a distance of 22.8 km (12.3 NM) of the release site and was mostly comprised of thick and relatively fresh oil. It was also the extent of the AMSA dispersant and recovery operations. On occasions, highly weathered oil was returned to this location due to the presence of circular current eddies that were evident in the Timor Sea at the time of this spill event.

Beyond this zone surrounding the immediate spill area, oil occurrences were generally patchy and more highly weathered (often changing colour). Indeed, images of the slick at extents beyond 22.8 km were predominantly sheens/waxy films even waxy solids and surface coverage was significantly less which is typical of oil spill dynamics at these distances from the source.

The duration of the spill incident ensured some patches of oil eventually drifted into deep waters where fast moving currents associated with the Indonesian Thru-Flow carried weathered oil patches some significant distances from the source. These were typically small patches that were observed to continue to weather until ultimately becoming waxy residues including solidified waxy residues.

Using the methodology described herein, this study ultimately quantifies that the area swept by 99% of the oil was limited to an approximate radial distance of 82 km (44 NM) from the spill site, and 98.6% of the swept area remained within Australian Territorial Waters.

This approach of combining trajectory modelling, overflight data and satellite images provides the most comprehensive (hourly) understanding of the spill over time and may be important for determining the likelihood, extent and magnitude of any potential adverse effects from the spill.

1 INTRODUCTION

PTTEP Australasia (Ashmore Cartier) Pty Ltd (hereafter PTTEPAA) is the operator of the Montara oil field, located in the Timor Sea, approximately 200 km offshore from the Australian mainland (see Figure 1).

Table 1 details the location of the Montara wellhead platform (WHP).

On the 21st August 2009, Montara reservoir fluids and gases were accidently released from the Montara WHP due to the accidental loss of control of the H1 well. As a result, crude oil was released via the rig decking to the environment as part of the uncontrolled flow. Reservoir formation water gas and hydrocarbon liquids were released above the water surface at temperatures expected to exceed 80 degrees Celsius. At these temperatures it is estimated that condensates were in a gaseous form and that liquid impacted the sea surface without its expected condensate composition, hence as a partially-weathered crude (i.e. without many of the lighter volatile hydrocarbons). Indeed AMSA (2009a,b,c) studies indicated that split surface oil did not contain any traces of BTEX or other light hydrocarbons (C6-C10) that would typically be in this crude oil under a normal production operation which allows for light hydrocarbon condensing, but not under this uncontrolled release scenario, as a reservoir fluid exceeding 80 degrees Celsius, from the top of the riser pipe.

Overflight observations by response personnel of the slick which developed on the water's surface within the first 24 hours indicated that the spill rate of the crude oil component of the uncontrolled release was initially 400 bbls (64,000L) per day as a 'worst-case' estimate.

The crude oil continued to be released for 72 days. The well was brought under control on the 3rd November 2009.

The response to the spill was undertaken under the direction of the Australian Maritime Safety Authority (AMSA) and included both containment and recovery and dispersant application strategies. The spill response commenced on the morning of the 21st August, 2009 and was focussed around the Montara Well Head Platform in open waters.

Daily overflight observations, computer simulations (modelling) of slick trajectories and the use of satellite images were also undertaken by AMSA for planning and operational monitoring purposes throughout the incident. The surveillance and modelling indicated that surface oil was not detectable in the Timor Sea after the 19th November 2009.

It is important to note that the spill modelling effort during the response was designed to provide 'search areas for oil' and used forecast metocean datasets. It assumed worst-case parameters and overestimated possible oil positions to minimise the chances of loosing track of oil. For this study, the modeling of slick trajectories was updated to utilize reanalyzed metocean data which incorporated field measurements where possible. For monitoring purposes, the combinations of hindcast spill modelling, the daily overflight observations and the use of satellite images and the integration of these three different types of monitoring methods, ensures the most detailed understanding of the movement and fate of the spilt Montara oil throughout the entire incident.

This refining of the field observation was undertaken at the request of PTTEPAA and is described herein. The findings from this study will be used to identify areas of oil exposure

and areas not exposed to oil (potential environmental monitoring control sites). Specifically, this study has integrated all the essential oil observation and modelling information into a consistent overview of visible oil locations and movement over time for use in guiding the post spill scientific monitoring program.

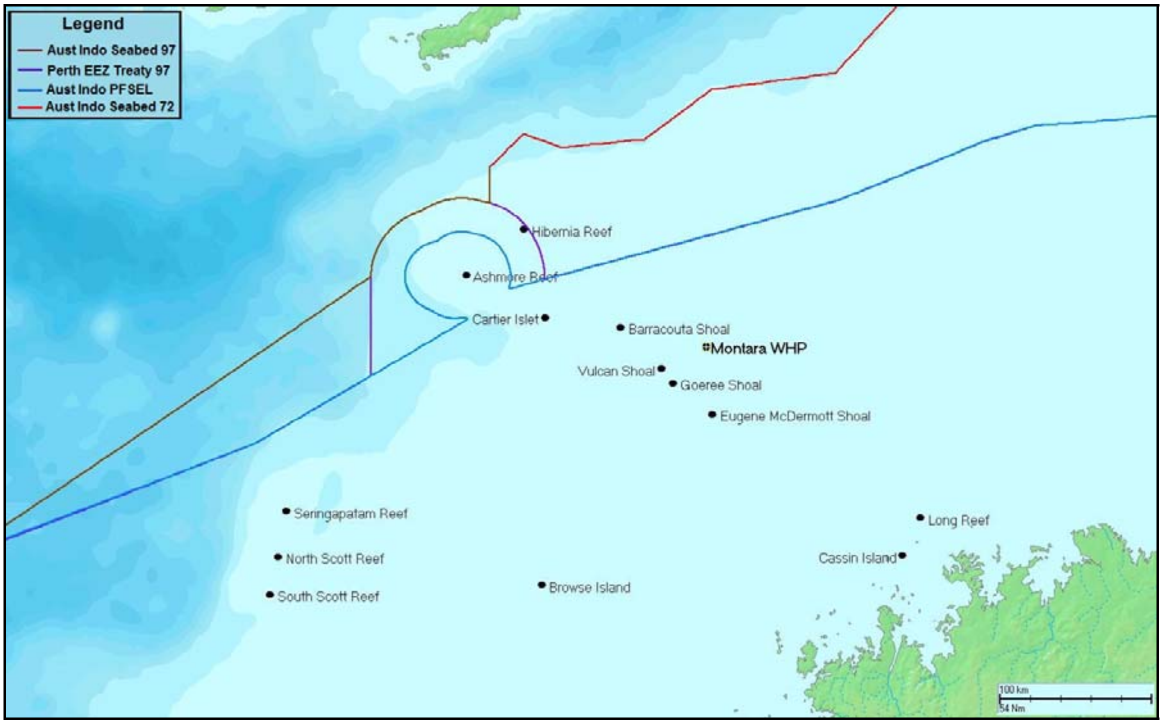

Figure 1: Map showing location of the Montara Well Head Platform (WHP), Timor Sea.

Table 1: Location of the Montara Well Head Platform.

Location	Latitude South (DMS)	Longitude East (DMS)	Water Depth (m)
Well Head Platform (Montara)	12° 40’ 20.5”	124° 32’ 22.3”	80 m

2 SCOPE OF WORK

To integrate all the essential oil observations and modelling information into a consistent overview of visible oil locations and movement over time for use by PTTEPAA in guiding the monitoring programs and any spill impact assessment. The analysis undertaken herein included:

1. Aerial surveillance reports and photography;
2. Recorded observations from vessels and the media;
3. Trajectory modelling outputs using hindcast metocean datasets;

4. Satellite imagery.

3 METHODS

3.1 Overview

The modelling of slick trajectories for this study was undertaken using the OILMAP software. The meteorological and oceanographic (metocean) datasets used for the hindcast simulation of the spill event are detailed below. In summary, OILMAP slick trajectories were undertaken using all combinations of available reanalysed current datasets, being NCOM+Tides, Oceanmaps+Tides (BLUElink), and GLSA+Tides (see Section 3.2-3.4). Reanalysed winds from the National Oceanographic and Atmospheric Administration (NOAA) Global Forecast System (GFS) data provided the spatially varying wind fields for the duration of the event. Note that NCOM+Tides, BLUElink+Tides, and GLSA+Tides and GFS were used throughout the response to the Montara Incident. Spill model results using all datasets were examined to determine how well they agreed with each other. They were also then compared with overflight, satellite and ship observational data on a daily basis and a level of confidence was established for each dataset for each day of the incident.

Overflight data and ship positional data in a GIS format was supplied by AMSA. This observational data included locations of highly weathered oil patches and solid wax rafts as well as fresh oil locations adjacent to the Montara WHP. Self Locating Datum Marker Buoys were also deployed by the response team on occasions throughout the response to independently check the current and wind data as additional quality control measures. The overflight data was incorporated into the modelling effort to refine the model estimated oil locations over time using the most accurate datasets for each day.

MODIS satellite data was more problematic to utilize due to cloud cover and slight daily changes in satellite over-pass times. On average, about one satellite image per week provided a wide area view of the spill region that enabled any slicks to be observed. Satellite data was more easily interpreted when the AMSA geo-referenced overflight data was overlayed upon the geo-referenced image. By incorporating the field observations over the satellite images, it was possible to indentify what features evident within the satellite image were spill related. Features that could be seen within the satellite image that did not correspond to an overflight observation were still assumed to be spill related. Note that the pixel resolution of the MODIS (Aqua & Terra) sensors is approximately 250m x 250m.

Additional LandSat imagery was available less frequently and usually 2 to 3 weeks after the acquisition date but at a higher resolution to the MODIS sensors. The pixel resolution of the LandSat images shown herein are at 30m x 30m resolution, which is sufficient to better resolve thick oil patches amongst widely spread thinner sheen and waxy residues.

3.2 Tides

Tidal currents for the Timor Sea were recreated using the HYDROMAP software. HYDROMAP's model formulations and predicted current (current speed/direction) and sea levels outputs have been verified through various field investigations globally during the past 23 years (Isaji and Spaulding, 1984; Zigic et al., 2003). HYDROMAP tidal current data has

been used as input to forecast (in the future) and hindcast (in the past) previous spills in Australian waters and forms part of the Australian national oil spill trajectory modelling system operated by AMSA. The model is also the hydrodynamic engine used by the Western Australian marine search and rescue system (WA Police) and New Zealand Maritime Safety (SAR and marine pollution response).

The numerical solution methodology of HYDROMAP follows that of Davies (1977a, b) with further developments for model efficiency by Owen (1980) and Gordon (1982). A more detailed presentation of the model can be found in Isaji and Spaulding (1984).

Figure 2 shows a time-series graph of the predicted tidal current speed and direction from August to November 2009 which indicates a significant 14 day Spring/Neap tidal cycle. The tidal current speeds had an average and maximum of 0.286 and 0.591 m/s, respectively. The major tidal axis at the site was essentially elliptical.

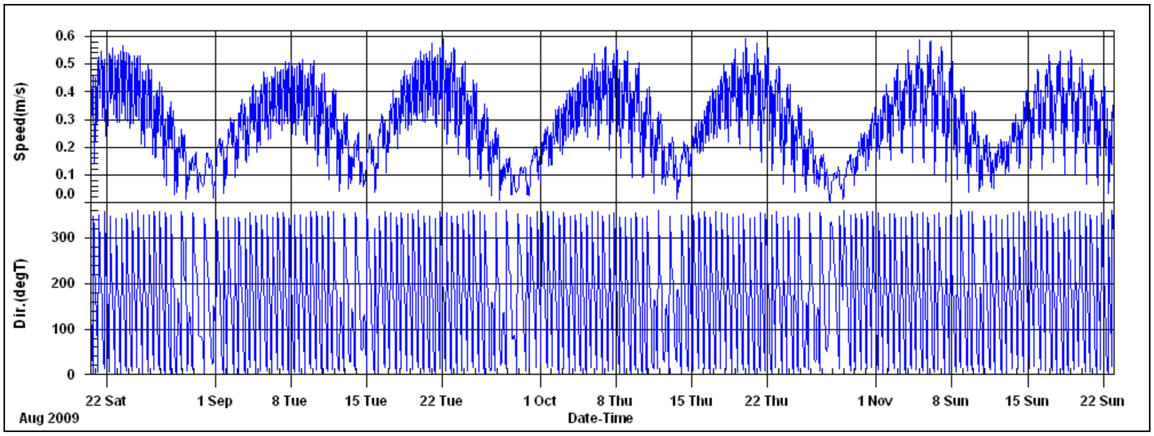

Figure 2: Time-series graph of the predicted tidal current speeds and directions for August to November (2009).

3.3 Satellite Derived Currents - Gridded Sea Level Anomaly Model

This dataset comprised of the Gridded Sea Level Anomaly (GSLA) deep ocean surface currents combined with the HYDROMAP tides. GSLA is primarily measured satellite derived data generated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The GSLA model includes altimeter estimates of sea level mapped in near-real-time to a lat-long grid. The model takes into account the geostrophic surface velocity which would result from satellite measured sea-level anomalies. This dataset is typically daily, but mapped hourly with the tidal currents for this study.

3.4 NCOM+Tides – Navy Coastal Ocean Model incorporating Tides

The NCOM+Tides dataset provides deep ocean and continental shelf surface currents from the USA Navy Coastal Ocean Model (NCOM) and tides. NCOM is a relatively new source of data that describes medium to large scale surface-currents over wide regions. There is a forecast version and a hindcast version available. NCOM is a 1/8° global model developed at the U.S. Naval Research Laboratory (NRL) for transition to operations at the Naval

Oceanographic Office (Barron et al., 2003). This dataset is typically 6 hourly, but mapped hourly onto the tidal component.

The physics and numerics of the NCOM model (Martin 2000) are fundamentally based on the Princeton Ocean Model (POM), with some features adopted from the Sigma/Z-level model (Martin et al., 1998) and a number of additional features. The boundary conditions for NCOM are hindcast winds, satellite measured sea levels, air temperature, water and salinity flux and solar radiation. The NCOM domain extends over continental shelves, coastal regions and the Arctic, providing global coverage with a minimum bottom depth of 5 m (Barron et al., 2007).

The model is spun-up from rest using surface and in-situ measured climatological data as initial conditions and forcings. The model data is then assimilated and compared to: mean sea surface height; kinetic energy; sea-surface temperature; and sea surface salinity with time series from tide gauge data, buoy data and Pathfinder sea surface temperature (SST) data (National Oceanic and Atmospheric Administration, National Oceanographic Data Center). The model has been validated for numerous locations around the world (Barron et al., 2003, Barron et al., 2007) and was successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Moreton Island in March 2009.

3.5 Ocean Model Analysis and Prediction System - OceanMAPS

The OCEANMAPS+Tides dataset provides ocean surface current data from the Ocean Model Analysis and Prediction System plus tides. OceanMaps was developed by a partnership between the Royal Australian Navy, the CSIRO and Australia's Bureau of Meteorology. The system is based on the Ocean Forecast Australia Model (OFAM), the BLUElink Ocean Data Assimilation System (BODAS), a data management system and enhanced surface winds from numerical wind prediction (NWP) and high-resolution SST products. This dataset is typically daily, but mapped hourly onto the tidal component. There is a forecast and hindcast version of this dataset, the forecast version was used extensively throughout the response effort. The hindcast version was used for this study extensively as well. This dataset was also successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Moreton Island in March 2009.

3.6 Global Forecast System Winds Data – GFS Winds

The Global Forecasting System (GFS) is a global spectral numerical model operationally run by the US National Oceanic and Atmospheric Administration (NOAA). The version used in this study provides global coverage with a horizontal resolution of 1/2° with 64 unequally spaced vertical layers. This dataset was also successfully used to predict the fate of the spill of oil from the Pacific Adventurer spill offshore Moreton Island in March 2009. There is a forecast and hindcast version of this dataset. The temporal resolution is 6 hours. The wind data from GFS was regularly compared with the wind measurements from Browse Island and Troughton Island to ensure it was representative of the wind fields over the Timor Sea.

4 MONTARA TIMELINE

The Montara well head leak started on the 21st August 2009, with a leak rate estimated at 400 barrels of Montara Crude oil per day.

The weather conditions were calm at this time with strong tidal currents and light winds. The resultant slick on the water surface was characterised by thick orange/brown oil, which was initially tidally dominated (flowing southward during the incoming flood tides and northward during outgoing ebb tides) with a slow eastward net drift. The slick oscillated back and forth past the well head with the tidal currents and maintained close proximity to the well head, as shown in Figure 3. Note that dispersant application operations commenced 23rd August, 2009.

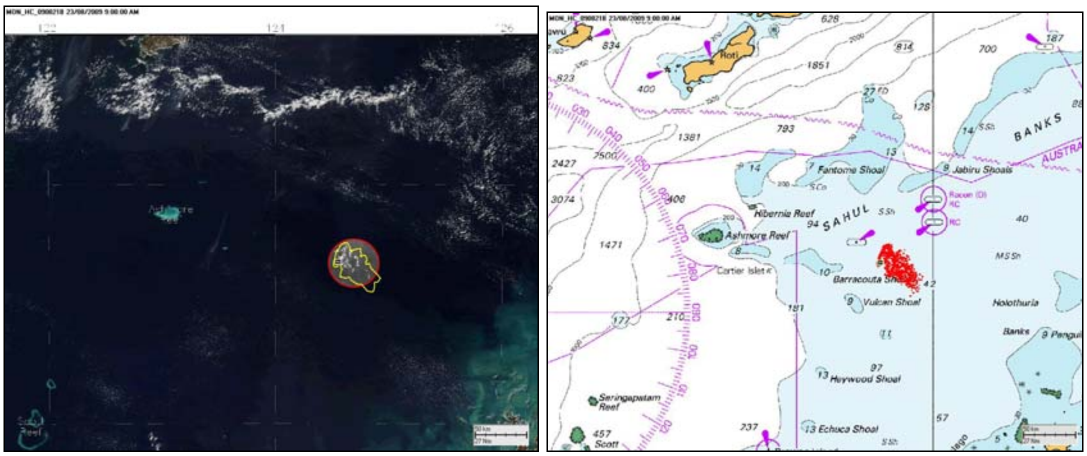

Figure 3: Comparison of the MODIS (AQUA) satellite images (left) with the hindcast modelling (right) on the 23rd August 2009 (9am). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

Leading up to the 30th August 2009, stronger winds and a shelf break anticlockwise eddy current set in pushing the slick further afield in a north-easterly direction, as indicated in Figure 5 and Figure 4. These figures shows the slick to be orange/brown in colour when fresh close to the Montara WHP while mainly lighter sheens and wax films with occasional thick oil (orange) patches beyond the immediate vicinity of the release site.

By the 3rd September 2009, AMSA overflight observations showed that oil on the water surface had formed into a wedge shaped extending from the well head and expanding towards the north east (Figure 6). It was described as thick oil surrounding the well head, with 100% coverage of sheen out to 12 Nm. From 12 Nm to 35 Nm the sea surface was characterised as having 50% sheen coverage, and from 35 Nm out to 60 Nm the sea surface consisted of roughly 10% coverage of sheens and weathered oil. This indicates that at this stage of the event, the thick oil was constrained to close proximity of the well head, and oil on the surface at a distance greater than 35 Nm was predominately clear water, containing some scattered weathered oil and waxy residue patches. Surface oil recovery operations using skimmers and booming strategies commenced onsite shortly after this observation.

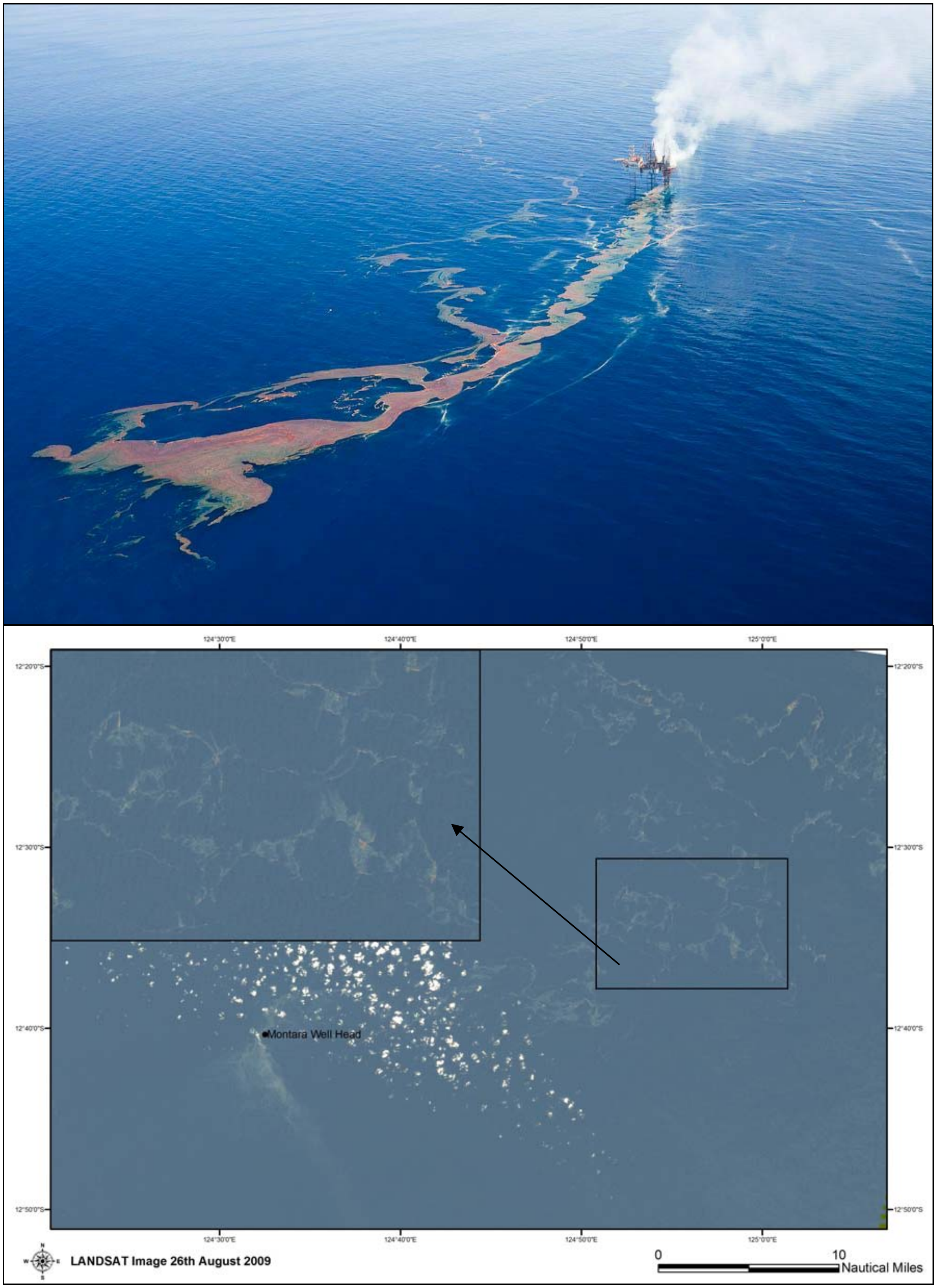

Figure 4: (Top) Aerial Photograph (courtesy of PTTEP) of the spill location showing the orange/brown fresh oil slick adjacent to the Montara WHP on 25th August 2009. (Bottom) LandSat (#5) satellite image of slick on the 26th August 2009. Note fresh oil to the south of the platform and broken slicks pushed towards the north east with small extents of thick orange/brown surface oil interspersed amongst thinner sheens / lighter waxy residues.

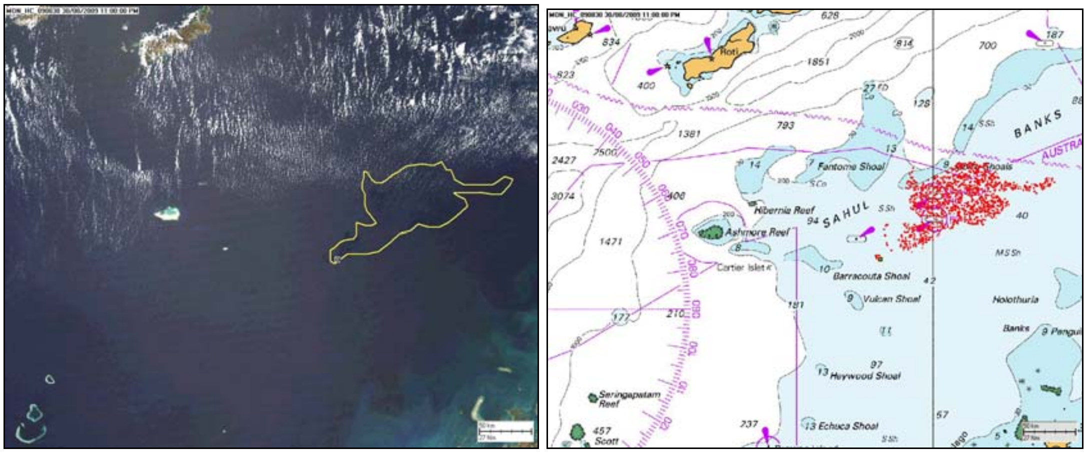

Figure 5: Comparison of the MODIS (AQUA) satellite images (left) with the hindcast modelling (right) on the 30th August 2009 (11pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

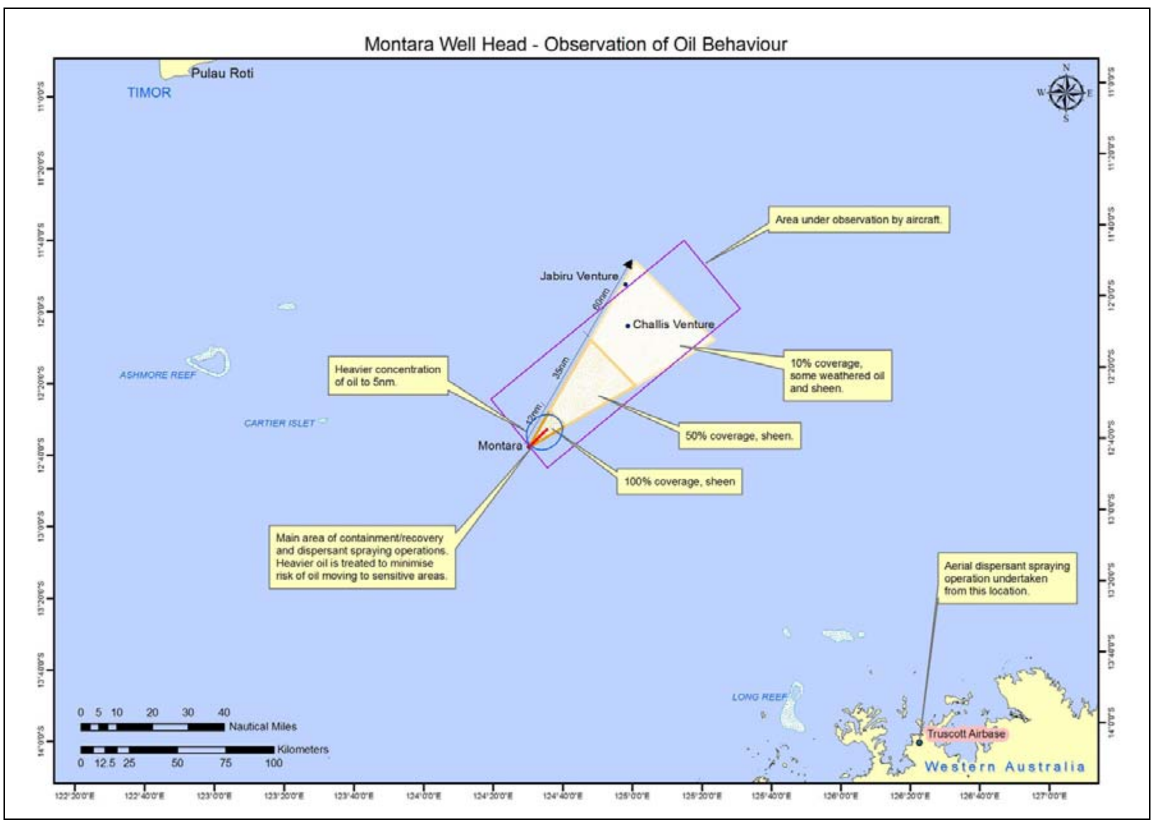

Figure 6: Over Flight observation map describing the oil state on the 3rd September 2009. Image courtesy of AMSA

On the 17th of September winds were again very light, and fresh oil was observed around the well head. The far field consisted of broken up patches, predominately consisting of weathered waxy residues, refer to Figure 7.

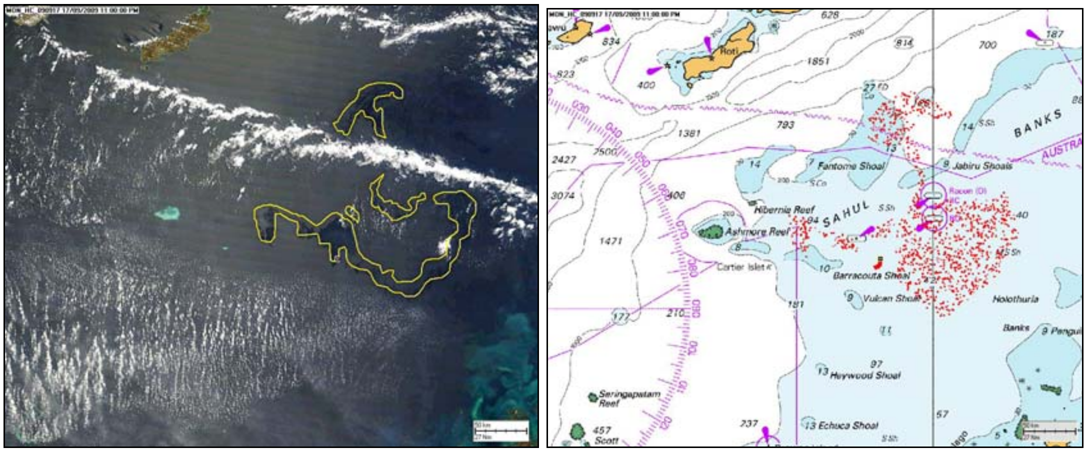

Figure 7: Comparison of the MODIS (TERRA) satellite images (left) with the hindcast modelling (right) on the 17th September 2009 (11pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

From mid to late September the winds again began to increase from the west and as a result, oil was observed to be moving from its initial northerly position towards the east, as indicated in Figure 8. Observations by the team on the Leeder Consulting cruise confirmed that the oil in the far field (to the east of the well head) adjacent to Van Cloon Shoal consisted mostly of patchy broken up slicks, see Figure 9. The high resolution LandSat image (Figure 10) also indicates that the oil in the far field is broken up and patchy.

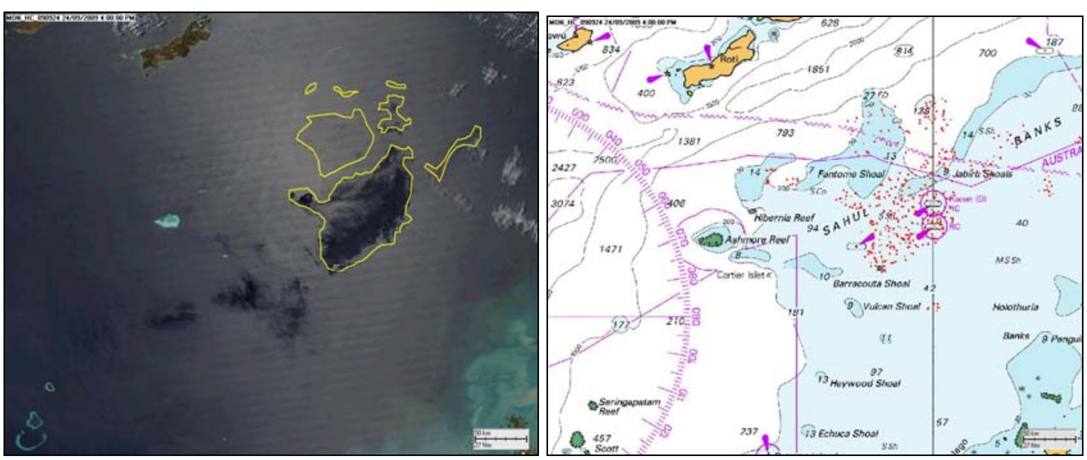

Figure 8: Comparison of the MODIS (AQUA) satellite images (left) with the hindcast modelling (right) on the 24th September 2009 (4pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

Figure 9: Broken slick adjacent to Van Cloon Shoal, at location: -12.5915S 126.9387E on the 30th September 2009. Image courtesy of AMSA (2009a,b,c) and Leeder Consulting, hereafter referred to as Leeder.

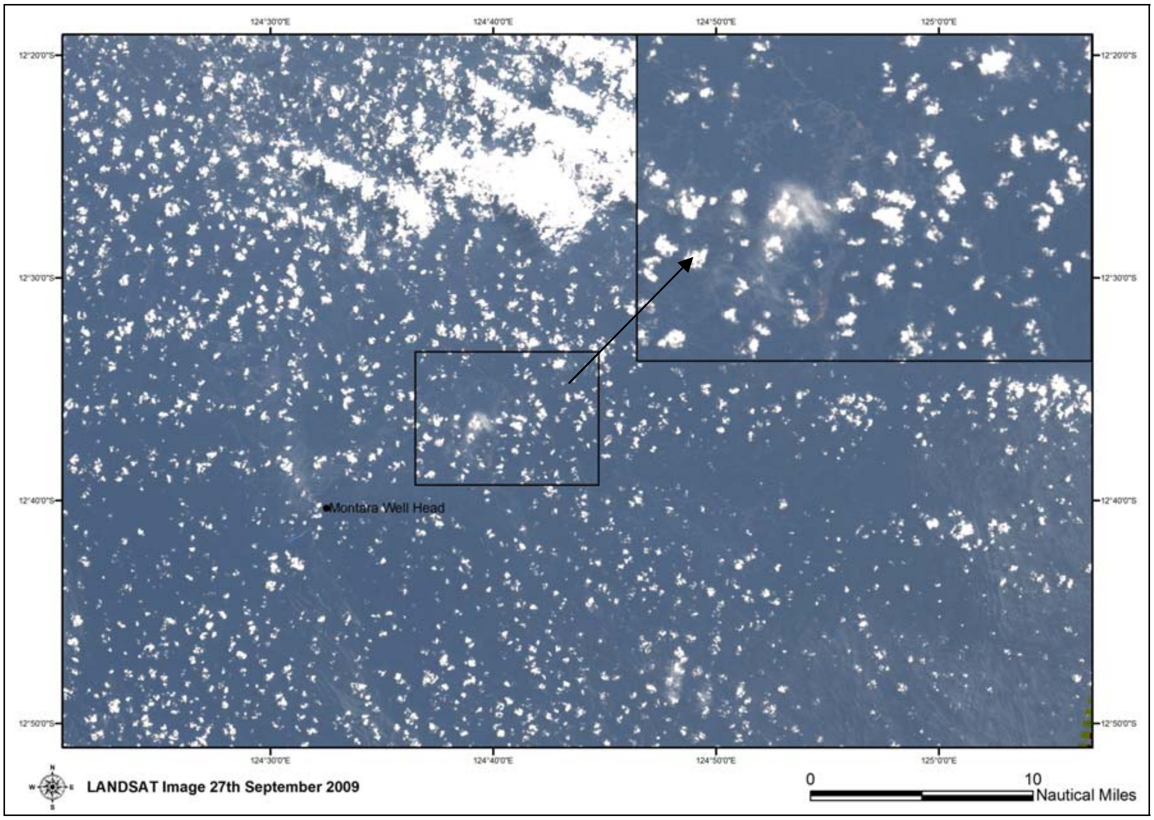

Figure 10: LandSat (#5) satellite image of slick on the 27th September 2009. Note scattered patchy slicks with very little thick oil apparent potentially due to dispersant and recovery operations.

Over the next few days oil predominately moved towards the north to north-west. The image below shows streaks of lightly weathered oil at an approximate distance 11Nm north-north-east of the well, on the 1st October 2009.

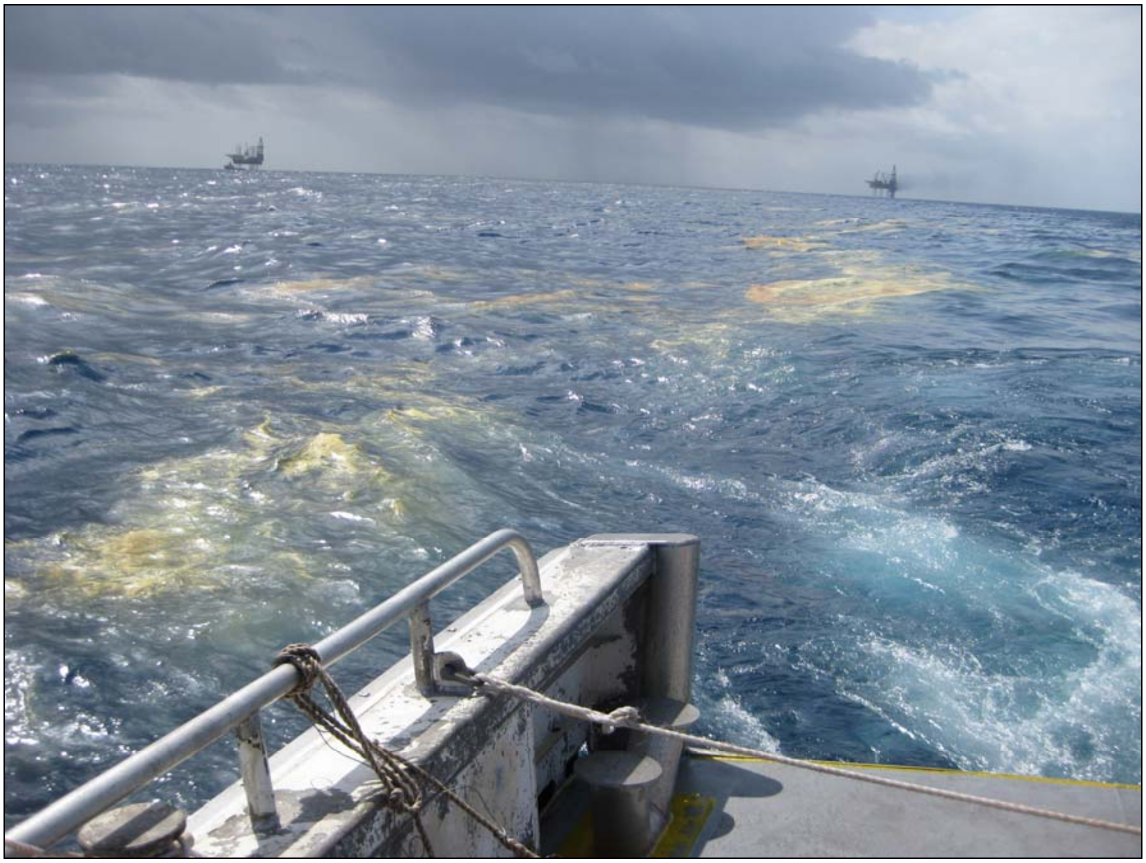

Figure 11: Lightly weathered slicks approximately 11nm NNE of well head, at location: -12.4958S 124.5867E on the 1st October 2009. Image courtesy of Leeder.

On the 3rd of October 2009 satellite imagery showed the slick to be in a U shape, extending north-west around to north-east of the well head, refer to Figure 12. Over flights indicated the presence of some orange patches (thicker fresh oil) on the western flank, and yellow patches (weathered oil) on the eastern flank of the slick. The closest oil to the Holothuria Reefs was the more weathered eastern flank, seen at this time to be 54Nm from East Holothuria Reef, in a north-north-westerly direction.

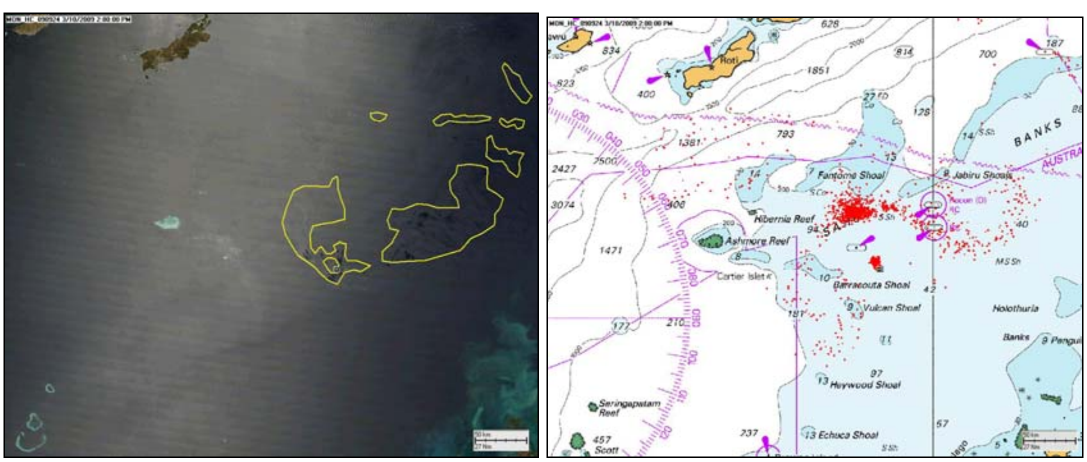

Figure 12: Comparison of the MODIS (TERRA) satellite images (left) with the hindcast modelling (right) on the 3rd October 2009 (2pm). Note: yellow polygons encircle identified visible oil patches and red spots represent modelled oil patches.

At a distance 6Nm north of the well head, an array of white waxy, well weathered solidified flakes was apparent (Figure 13). The highly weathered state of these wax flakes indicates that they had been afloat for some time, and may have indeed been old oil, which had been pushed back towards the well head from further afield by the Indonesian thru flow and the recirculating shelf-break eddy structures that are a feature of the current regime north of the Montara WHP.

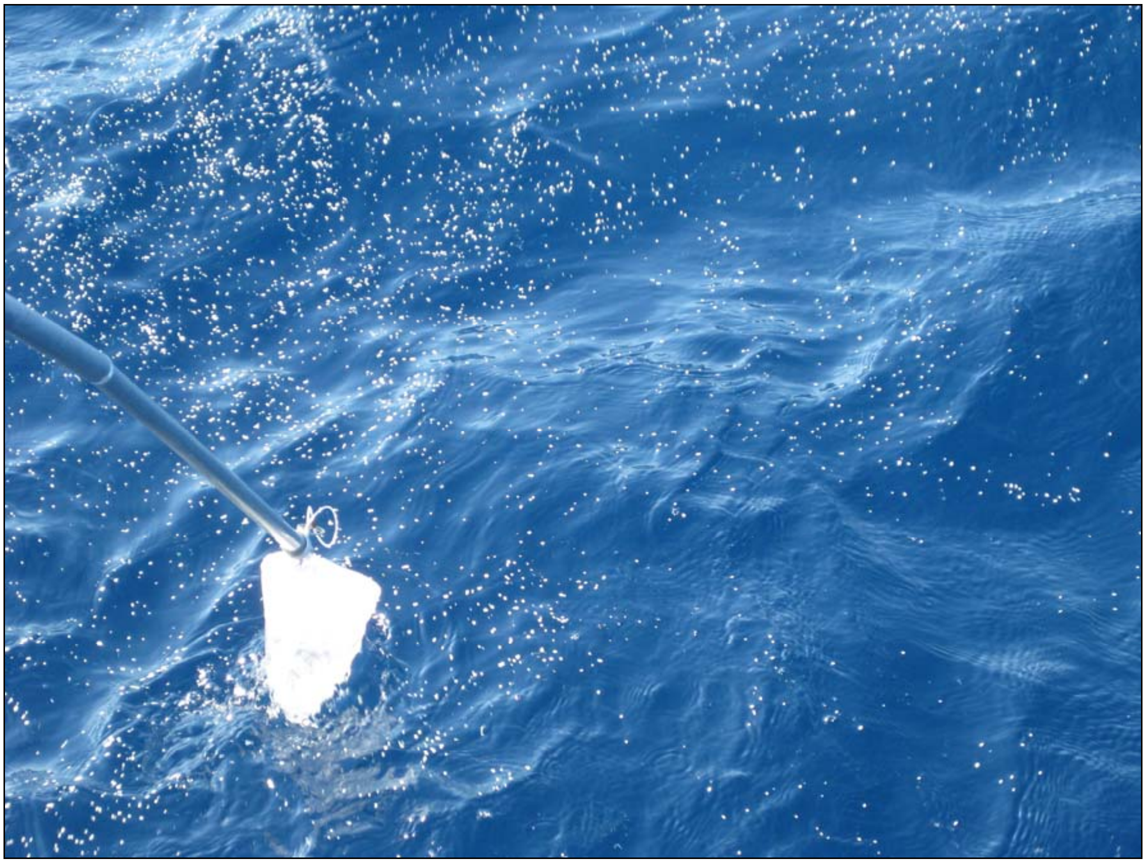

Figure 13: Highly weathered wax flakes, approximately 3.5nm NNE of well head, at location: 12.6147S 124.5617E on the 3rd October 2009. Image courtesy of Leeder.

By the 11th October 2009 scattered sheen/waxy residues were observed from Gale Bank (approximately 90Nm east of the well) increasing in density closer to the well. Thick oil was concentrated to the south of the well to a maximum distance of 20Nm (both over flight observations and modelling confirmed this, refer to Figure 14). Figure 15 shows the *Calypso Star* working on some of the broken slick, in amongst the sheen/waxy films.

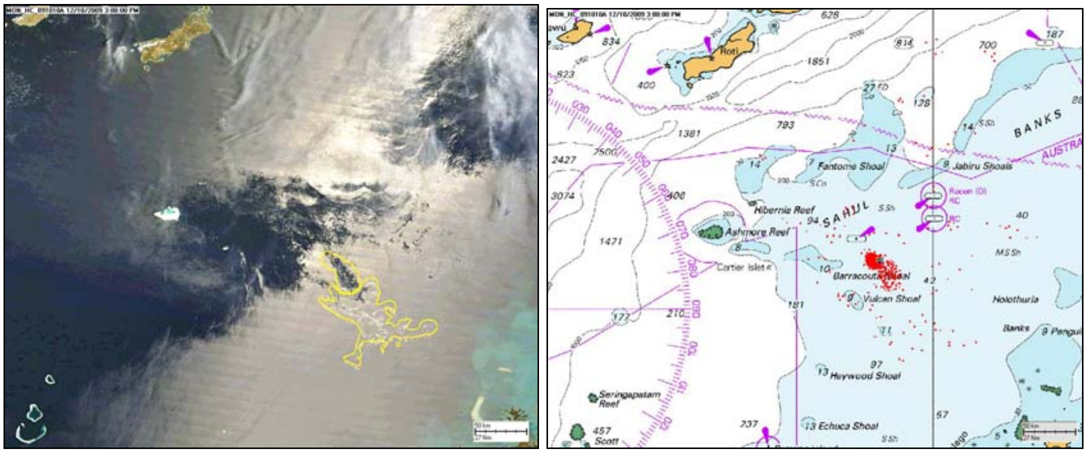

Figure 14: Comparison of the MODIS (TERRA) satellite images (left) with the hindcast modelling (right) on the 12th October 2009 (3pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

Figure 15: Calypso Star working on broken slick, amongst sheen. 26nm NW of well head, location 12.40S 124.35E11 11th October 2009. Image courtesy of AMSA.

On the 16th October 2009 fresh oil was still observed around the well head, moving towards the south for approximately 20nm. Beyond this, the slick was shown to be breaking up, predominately resulting in naturally weathered patches in the far field. Figure 16 below shows two vessels undertaking the containment and recovery process of one of the thicker slicks.

Figure 16: Lady Valissia and Lady Gerda working on containment operations, 16th October 2009. Image courtesy of AMSA.

Up to the 20th October 2009 the slick was observed to be thick orange oil up to approximately 2nm from the well head, where it became more dispersed. Once it reached a distance of 10nm from the well head it was thin sheen with only a few patches of thick orange oil. Figure 17 shows the *Pacific Protector* and *First Class* setting up for containment and recovery operations of a slick.

Figure 17: Pacific Protector and First Class involved in booming operations to the south of the well head, 20th October 2009. Image courtesy of AMSA.

By the 26th October 2009 MODIS (TERRA) satellite imagery showed there were patchy areas of visible oil/sheen to a distance of 55Nm south to south east of the well head. New oil was observed flowing from a south easterly to southerly direction. This was confirmed by over flight observations and modelling (refer to Figure 18). There were also some scattered weathered wax patches with sheen to their edges detected to the north east of the well. Figure 19 shows the *Pacific Protector* and *First Class* booming a large slick. High resolution LandSat satellite images taken on the 29th October 2009 (Figure 20) agreed with the MODIS (TERRA) images in identifying the patches of oil occurring to the east of the well.

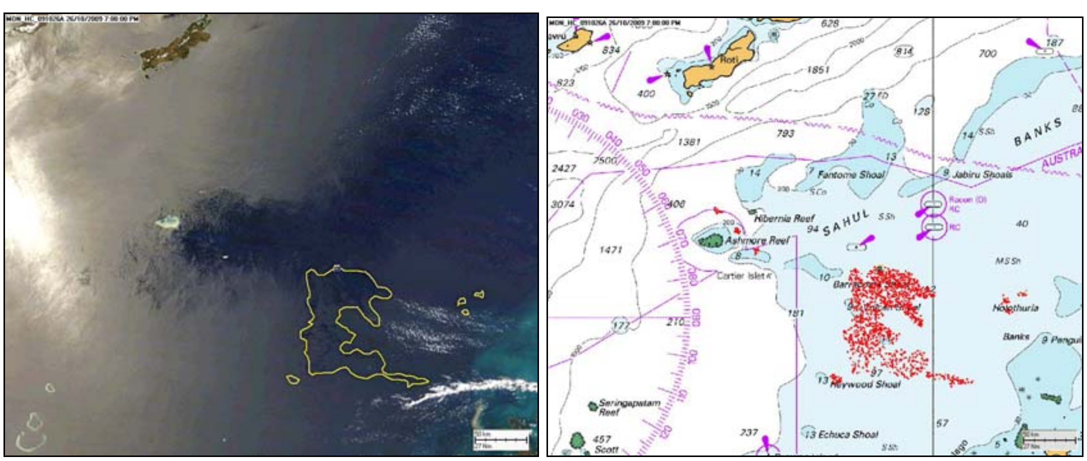

Figure 18: Comparison of the MODIS (TERRA) satellite images (left) with the hindcast modelling (right) on the 26th October 2009 (7pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and red spots in the modelled image represent modelled oil patches.

Figure 19: Heavy oil patch about to be boomed and skimmed by Pacific Protector and First Class, 26th October 2009. Image Courtesy of AMSA.

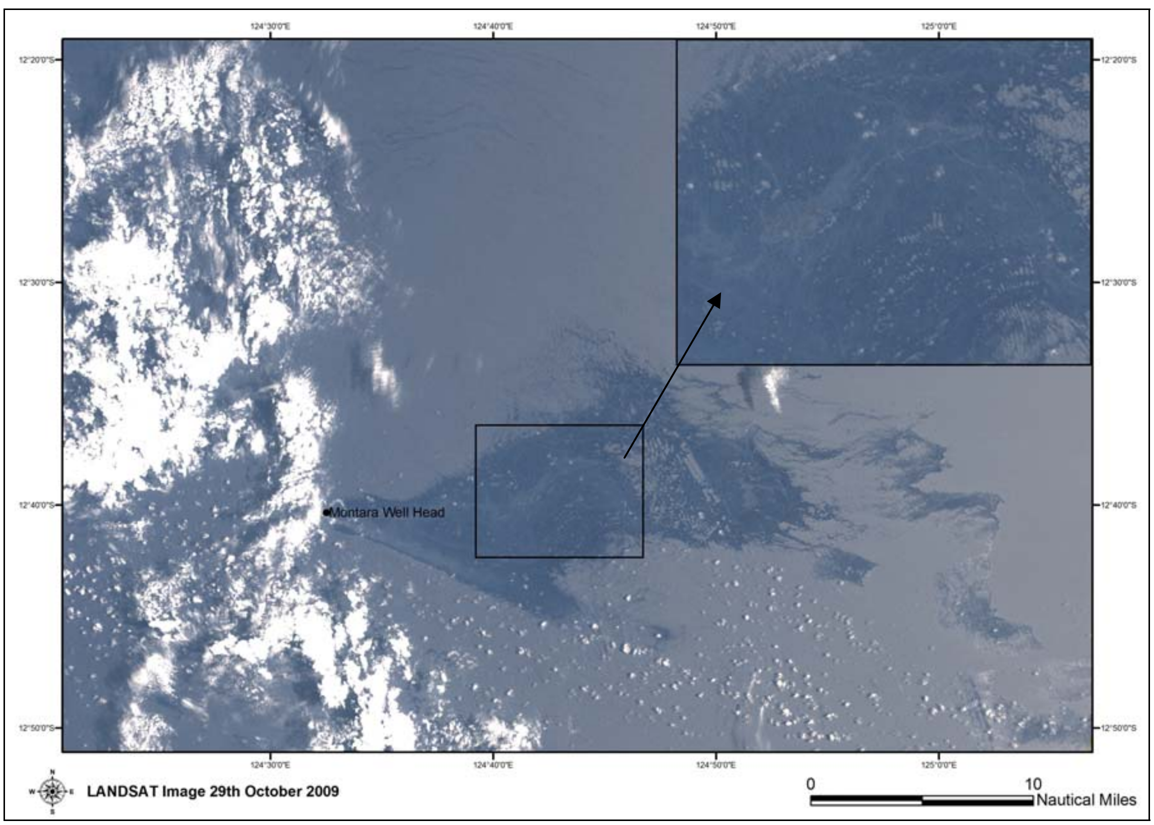

Figure 20: LandSat (#5) satellite image of a weathered part of the slick on the 29th October 2009. Note direction of flow is predominately easterly at this time.

The well was successfully "killed" on the 3rd of November 2009, and as such no fresh oil was being released to the environment. There was still persistent oil on the water surface, which was continually monitored. Oil detected in the satellite image on the 11th November was consistent with that observed in the over flights for that day (refer to Figure 21). Windrows of sheen were observed up to 35nm south west of the well. Yellow windrows of oil were spotted 10Nm to the north of Browse Island. Scattered waxy flakes, which appeared to be highly weathered residues, were apparent in proximity to the Holothuria reefs (refer to Figure 22).

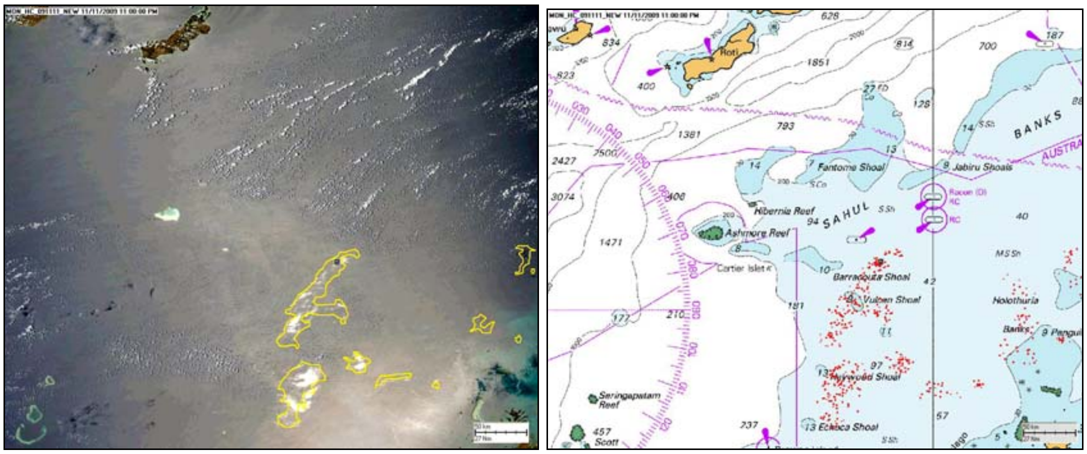

Figure 21: Comparison of the MODIS (AQUA) satellite image (left) with the hindcast modelling (right) on the 11th November 2009 (11pm). Note: yellow polygons in the satellite image encircle identified visible oil patches and films and red spots in the modelled image represent modelled patches

Figure 22: Patches of yellow oil surrounded by patches of sheen, near Holothuria Banks. 11th November 2009. Image courtesy of AMSA

Strong southerly winds (> 12 knots) kicked in on the 16th November 2009 and persisted for a few days. The wind strength was sufficient to create breaking waves in the Timor Sea which helped disperse the remnant patchy residues that were persistent on the waters surface up to this time. As a consequence, there were no visible oil slicks apparent on the water surface by the 29th November 2009, as indicated by the MODIS (TERRA) satellite image and trajectory modelling (Figure 23).

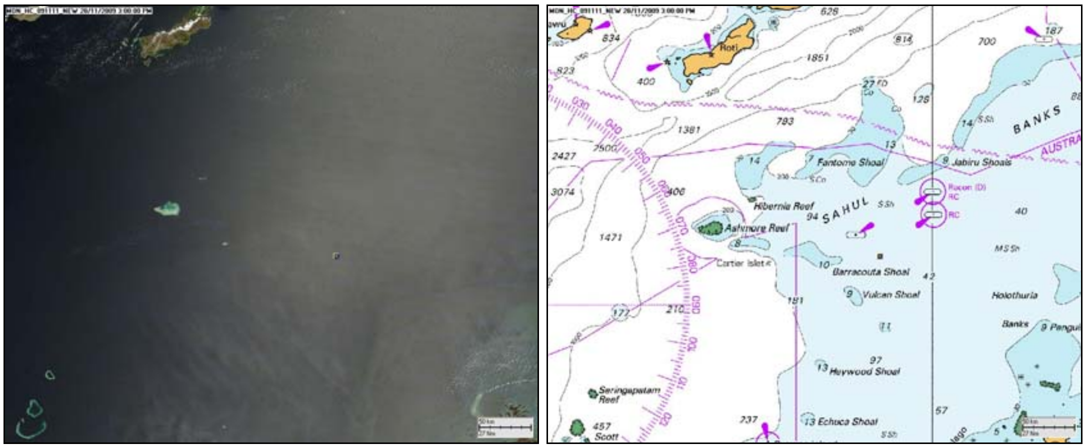

Figure 23: Comparison of the MODIS (TERRA) satellite images (left) with the hindcast modelling (right) on the 29th November 2009 (3pm). Note: there are no visible oil patches in the satellite image or the modelled image

5 RESULTS

The integration of overflight and ship observations, satellite images and hindcast metocean datasets, as well as dispersant and recovery operations into the OILMAP model, enabled all visible oil locations to be determined as accurately as possible. Visible oil included fresh oil, partially weather oil, highly weathered oil and solidified wax rafts and sheets. Normally, visible oil is detectable at levels which range from levels of concern when thick and fresh, to well below levels of concern when thin and highly weathered or solidified.

The results covered the entire 92 day duration of oil on the water's surface (21st August 2009 to 19th November 2009) at hourly intervals. These results from the hindcast model, which included the daily observations and the satellite data, were then loaded into a 0.01º x 0.01º (~1.1km x 1.1km) analysis grid which covered the entire Timor Sea. Using ArcGIS software for each hourly interval, the number of times any type of oil (ranging from fresh oil to highly weathered solidified waxy residues) was detected within a grid cell, it was counted to provide a relative measure of surface oil exposure. Consequently, the grid cell containing the spill site had the most significant number of occurrences of surface slicks, while grid cells with less than 0.01% of peak occurrences are not shown (see Figure 24 and Figure 25). A logarithmic colour key is used to highlight the relative amount of exposure over the duration of the spill.

It is important to note that Figure 24 and Figure 25 does not represent the extent of any oil slick observed at any one time during the spill incident (see Chapter 4 instead). It is a summation of the area within which isolated patches of surface oil but mostly patches of waxy residues were observed by aerial or satellite observations and oil spill trajectory modelling, and defines the area swept by all oil slicks and weathered wax patches of oil.

The results shown in Figure 24 demonstrate that most of the occurrences of surface oil were in the immediate vicinity of the Montara WHP (occurrence was 10% to 100% at the spill location) which was typically thick crude orange/brown oil. This location was also mostly within the safety exclusion zone setup around Montara WHP due to the associated gas leak from the uncontrolled flow. The number of occurrences then rapidly declines, due to the ongoing dispersant, recovery and containment operations undertaken by AMSA and the National Response Team. The closest submerged shoal to Montara was Vulcan Shoal which, being only 16 Nm from the spill location had the most occurrences of oil pass over, albeit a low 3% to 9% of occurrences. Barracouta Shoal and Eugene McDermott Shoal were also indicated to have had oil pass over them on occasions, but relatively infrequently (< 1% of occurrences).

The far-field distributions depicted in Figure 24 demonstrated less significant occurrences of oil. The overflight observations indicated that any hydrocarbons found in these far-field locations was typically small patches of highly weathered oil surrounded by wax sheets. One confirmed oil stranding on Ashmore Reef was analysed and found to be highly weathered wax residues indicating the nature of any occurrences at these distances from the Montara release site.

It is important to note that some persistent components of the spilt liquids (particularly its wax content) will persist and may travel outside of the extents shown in Figure 24, but at concentrations / coverage which was so low as to be difficult to accurately place or observe via the overflights or satellite images. Hence Figure 25 shows the full extent of the model estimated extents of the wax residues. The difference in extents between Figure 24 and

Figure 25 (shown as the dark blue band in Figure 25) show the area almost exclusively swept by wax residues (mostly in solid form). The dark blue extents in Figure 25 are characterised by one off occurrences with durations of less than 2 hours in any one location, often associated with fast moving current regimes of the Indonesia Thru-flow. The light blue areas also indicate extents of limited occurrences with durations of surface oil of less than 20 hours.

Table 2 shows the cumulative areas impacted by oil, wax and sheen over the duration of the spill event as per the hindcast modelling. Note that the size of the swept area reflects the duration of the spill event, rather than the volume spilt and indicates the natural dilution mechanisms that operate in the Timor Sea.

Table 2: Total area of coverage by surface oil, grid cells approximately 0.01º x 0.01º which, in the Timor Sea region, is approximately 1.2 km^2 per grid cell.

Percentile of total counts – number of modelled oil spillets.	Number of grid cells hit above nominated level	Square kilometres (number of cells x 1.2 km^2)
90.0 %	231	**277 km^2**
99.0 %	4708	**5,650 km^2**
99.9 %	30,338	**36,406 km^2**
99.99 %	79,628	**95,554 km^2**

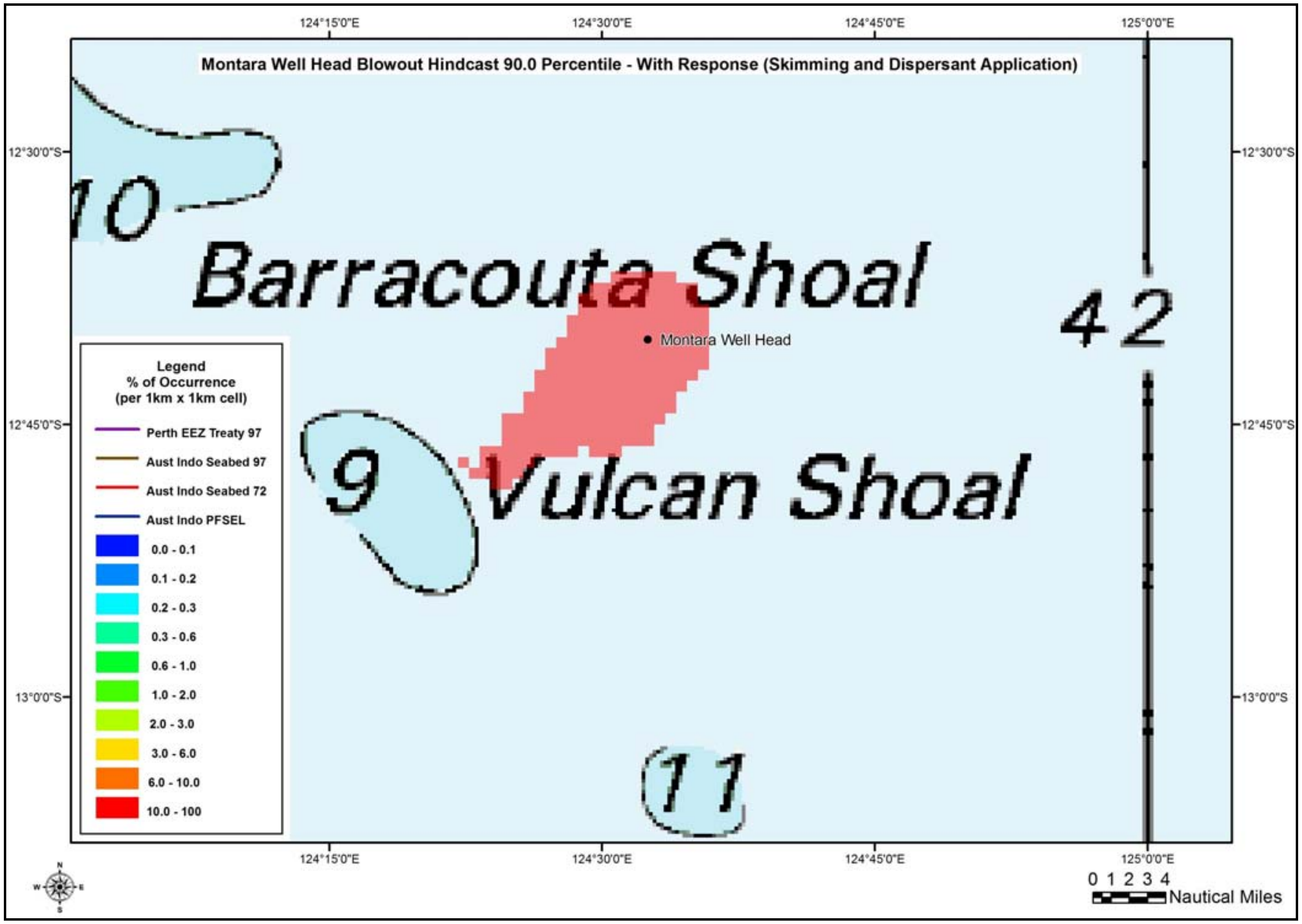

Figure 24a: Relative surface oil exposure map representing up to 90% of occurrences of visible surface oil associated with the Montara Incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling.

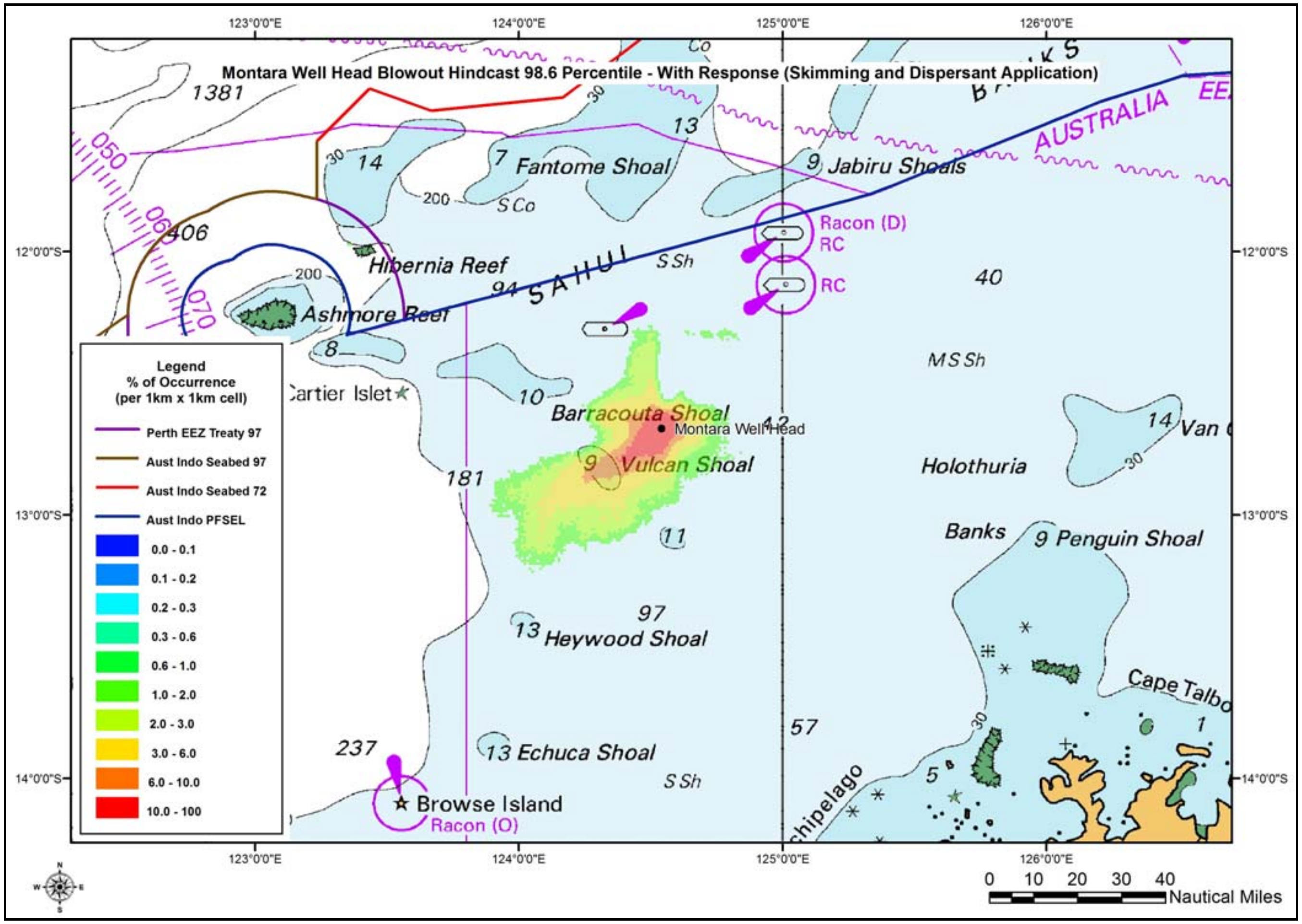

Figure 24b: Relative surface oil exposure map representing up to 98.6% of occurrences of visible surface oil associated with the Montara Incident. The 98.6% threshold helps identify that any slicks which moved into Indonesian Waters were fast moving isolated patches due to the stronger currents flows of the Indonesia Thru Flow Currents. It is also important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling.

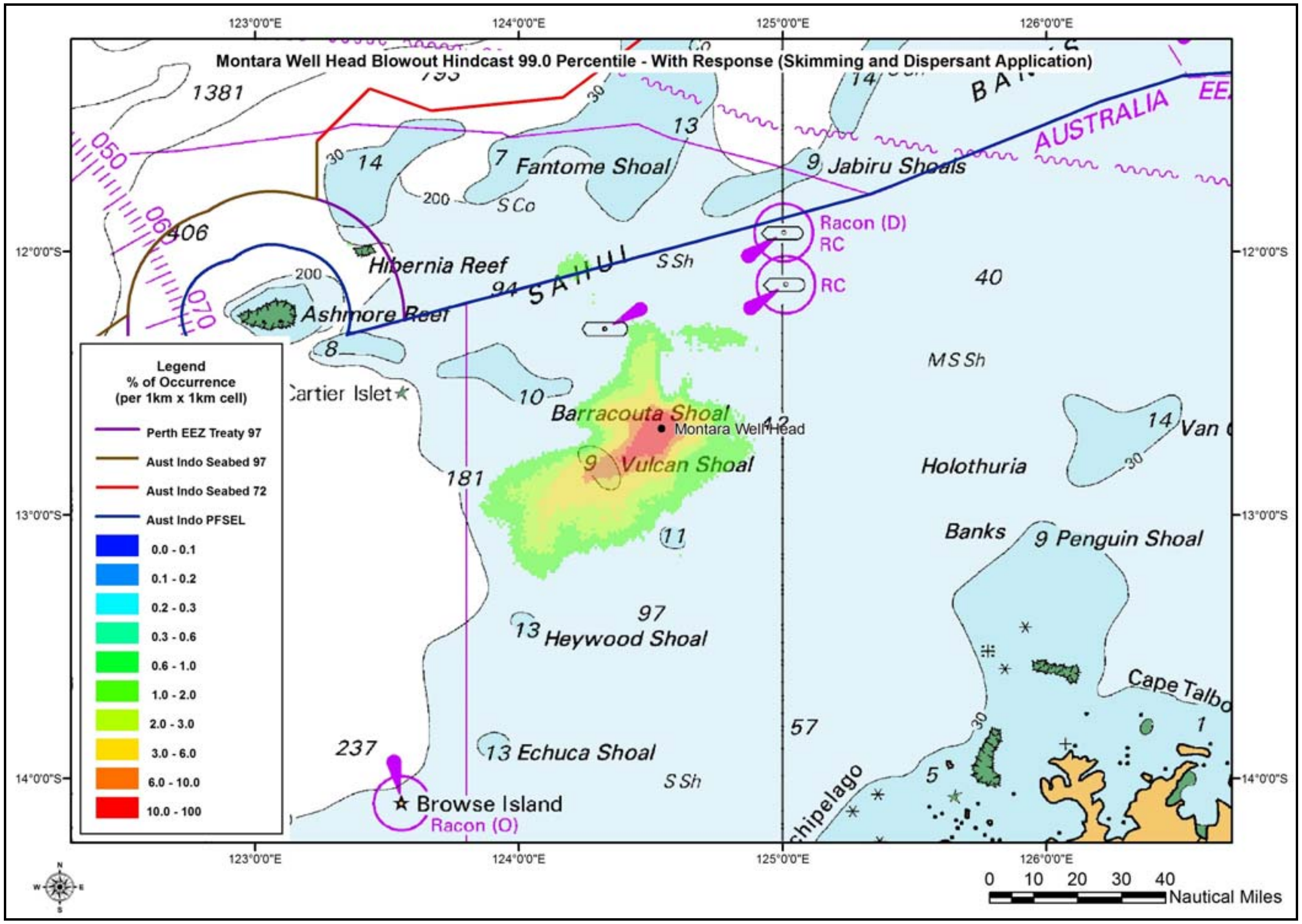

Figure 24c: Relative surface oil exposure map representing up to 99% of occurrences of visible surface oil associated with the Montara Incident. It is also important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling.

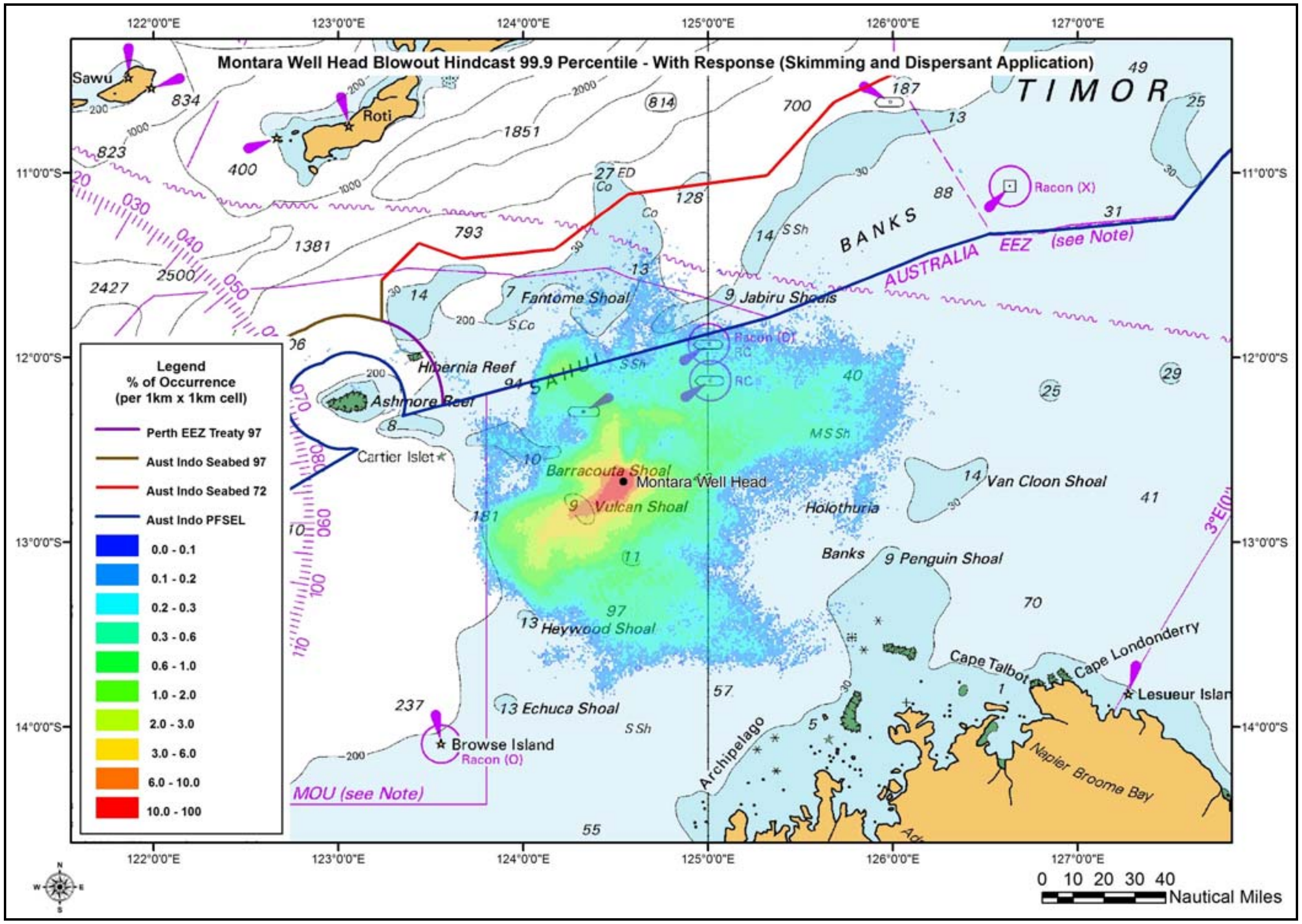

Figure 24d: Relative surface oil exposure map representing up to 99.9% of occurrences of visible surface oil associated with the Montara Incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling.

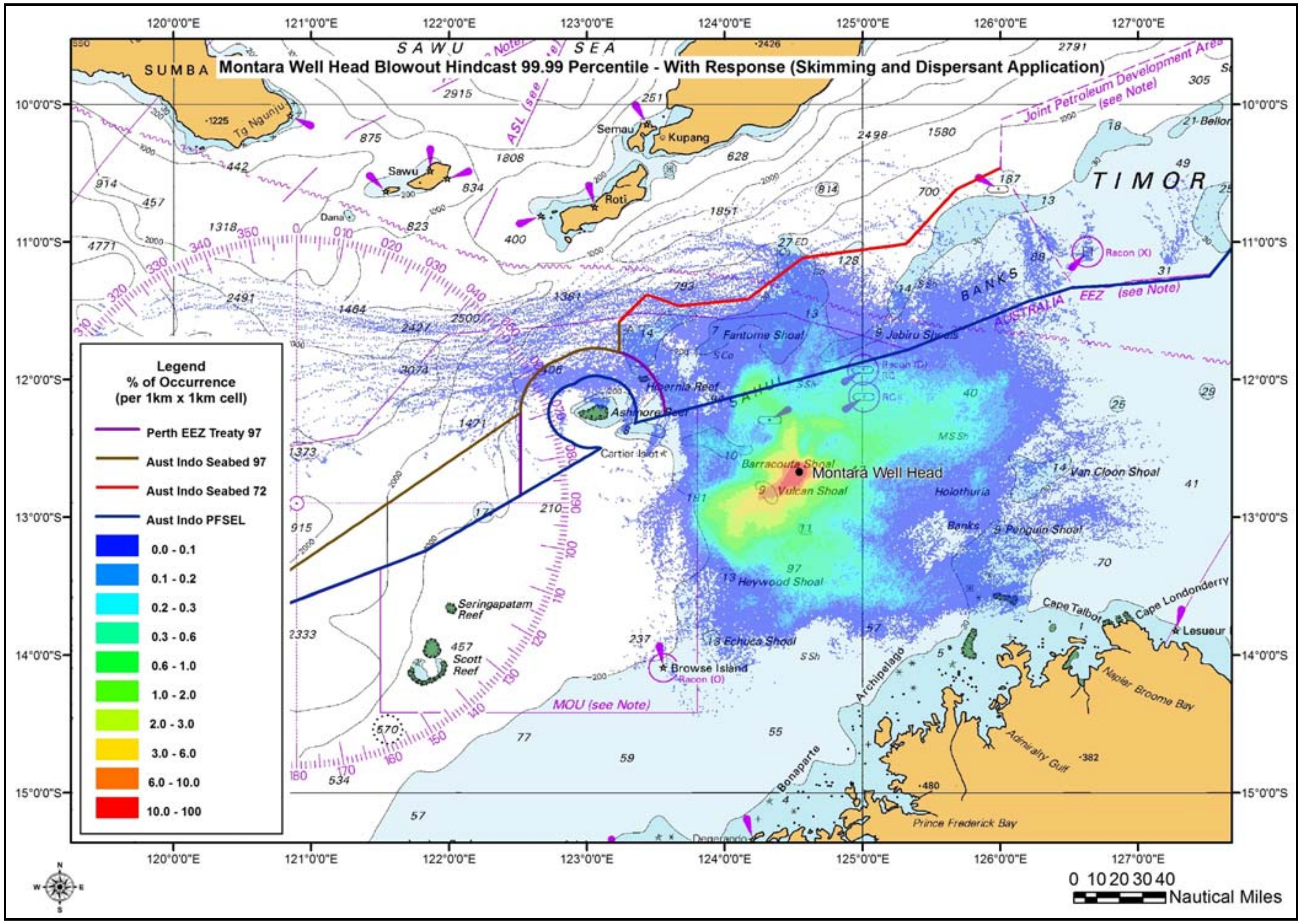

Figure 25: Relative surface oil exposure map representing all known and estimated occurrences of visible surface oil associated with the Montara Incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling. The dark blue extents are characterised by one off occurrences of highly weathered oil with durations of less than 2 hours in any one location, often associated with fast moving current regimes.

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