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On the dynamics of Oil spill dispersion off Timor Sea

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Abstract

The dynamical properties of the Montara oil spill in August 2009 in the Timor Sea is investigated. The two-dimensional numerical model of Oil Spill Analysis (SA) was used to simulate oil spill dispersion. The simulation showed that for daily period, the oil dispersion was dominated by advection processes due to tidal current. When South-East Monsoon (SEM) active the oil spill propagate into the eastern of the Timor sea until 300km long at the end of simulation. The high value of the exposure time lay on the Northern part of the Timor sea and the coast of the Roti island. The comparsion of the numerical results and SAR images was done by calculation of contaminant area show a good agreement.

Keywords: numerical model, oil spill, petroleum hydrocarbon, tidal current, timor sea

1. INTRODUCTION

On 21 August, 2009, a serious blow out caused the evacuation of the Montara oil platform and continual release of gas, condensate and crude oil over a ten week period. The Montara platform pollute the sea with oil 400-500 barrels per day during 74 days. After that, the spills and impact assessments of that have been conducted. For example the effect of oil spill to the phytoplankton community was investigate based on the time series of MODIS images of Chlorophyll a (Chl-a) at the surrounding area [1]. The existence of the phytoplankton bloom with a high concentration of 13.8mgm^{-3} occurred southeast of the platform at May 2010 namely nine months after oil spill.

The Montara oil platform incident occurred between August and November 2009 in the Timor Sea, within Australian waters. The location of Montara platform is depicted in Fig.(1). Approximately 400 barrels per days or 30, 000 barrels of light sweet crude oil was introduced into the marine environment over of period of 74 days. During the incident there were many environmental observations including regular satellite imagery and trajectory modelling was also assessed [2]. From the results of the simulation and observation that has been carried out show the dispersion was limited to an approximate radial distance of 82 kilometres from the spill site and typically small patches of highly weathered oil surrounded by wax sheets. It [2] was also supposed that the oil spill did not enter the coast of Timor due to the strong currents associated with the Indonesian Throughflow which carried weathered oil patches away distances.

The oil spill dispersion is very complicated object from dynamical system point of view. The gravitational, viscous, surface tension and weathering processes determine the spread of oil spill and transport of the spilled oil [8]. This problem can be handle by numerical modeling. Several oil spill models have been developed describe in detail the dispersion of oil spill under the effect of ocean currents and wind. Wind forcing is a very important factor when modelling the drift trajectories of marine pollutant spills. The aims of this research was to study the dynamics of oil dispersion due to oceanic effect and atmospheric as well. In this paper, we will show how the oil spill dispersion can be learned from a numerical modeling. The good result very depend on the input model such as wind forcing, tidal elevation etc. The paper is organized as follow, in the Sec.2, the nature of ocean dynamics of the Timor Sea is described briefly. The oil spill model with its boundary condition is given in Sec.3. The end of paper are discussion and conclusion.

2. THE ENVIRONMENT OF MONTARA OIL PLATFORM

The operation area of the Montara oil platform is located in the Timor Sea. The Timor sea is the primary inflow and outflow of the Indonesian throughflow (ITF) especially the Timor passage with 2000m depth [3]. The water mass from the North Pacific flow to the Timor sea through Celebes sea, Makassar strait, Flores sea and the Banda sea. Its estimate that 4.3 Sv (1Sv=10^6m^3/s) water mass from the North Pacific thermocline enter into the Tomor sea. The water mass of the Timor sea mimic to the southern part of Banda sea which is characterized by warmer temperature and higher salinity during the North-West Monsoon (NWM) and cooler temperature and lower salinity during the SEM as a response of local sea-air fluxes [4].

At the surface, the surface currents flow southwest for whole years where its dominant flow direction runs close to the Timor coast [5]. In SEM the current reaches the Australian coast with its velocity decreasing as it approaches the western Australian coast. In NWM a weak current in opposite direction flow from the Australian coast to the coast of Timor island. Based on as similation of ten years of sea-level measurements from the Topex/Poseidon satellite altimeter and nonlinear hydrodynamics model, the semidiurnal tide is clearly dominant in the Timor sea where the large tide observed in the southern part of Timor sea with shallower topography [6] with average depths of 80 to 100 m. The high tidal current (barotrophic M2) also observed in the southern path of Timor sea with the speed is about 100 cm/s. The velocity tend to weak in the northern part of Timor sea where the topography is deep. The direction of tidal currents tend to rotate anti-clockwise.

3. OIL SPILL MODELS

In the paper, the two-dimensional MIKE21 oil spill model [7] developed by the Danish Hydraulic Institute (DHI), Denmark was used to simulate oil spill dispersion. The simulation of oil spill dispersion required two basic model. First is the hydrodynamics model describing dynamic behaviour of ocean current. This is representation of advection proceses. The second is advection-dispersion model describing the fate of oil in the sea surface. We will describe two models as follow,

3.1. Hydrodynamics Model

The are two main physical processes describing the behavior of oilspill in the sea surface i.e advection and diffusion processes. The first processes cause by the dynamics of ocean environment such as current, wave and wave-current interaction. The second was caused by turbulence processes and molecular properties of the oil. There are two main module to studies the oil spill in this case. First is the hydrodynamics module and the second is spill analysis (SA) module. The hydrodynamics module describing advection processes have two main program that are continuity and momentum equation. The diffusion processes was caused by turbulence processes in the sea surface. This effect was simulated based on the Smagorinsky equation. By using vertically depth integrated the continuity and the momentum equation can be written as follows [7],

$$\frac{\partial h}{\partial t}+\frac{\partial(hU)}{\partial x}+\frac{\partial(hV)}{\partial y}=0 \tag{1}$$

$$\frac{\partial(hU)}{\partial t}+\frac{\partial(hU^2)}{\partial x}+\frac{\partial(hUV)}{\partial y}=fhV-gh\frac{\partial\eta}{\partial x}-\frac{\tau_{bed-x}}{\rho_0}+\frac{\tau_{wind-x}}{\rho_0} \tag{2}$$

$$\frac{\partial(hV)}{\partial t}+\frac{\partial(hUV)}{\partial x}+\frac{\partial(hV^2)}{\partial y}=-fhV-gh\frac{\partial\eta}{\partial y}-\frac{\tau_{bed-y}}{\rho_0}+\frac{\tau_{wind-y}}{\rho_0} \tag{3}$$

where x and y are zonal and meridional coordinate, U and V are zonal and meridional velocity respectively. $h = \eta + d$ is a sea level, η is wave amplitude, f is te Coriolis parameter, g is gravitation acceleration, ρ_0 is water density and d is the depth. The τ_{bed} is the botom stress and τ_{wind} is the wind stress. Solution is found by using numerical technique by alternating direction implicit (ADI) methods to integrate the equation of conservation mass and momentum in domain and the time scale used. Ther matrix calculation in each grid be resolved with the methods of double sweep alogaritms (DS).

3.2. Oil spill model

The SA module not only simulate advection processes due to hydrodynamics but also take care about the decaying processes such as evaporation, emulsification, dissolution and entrainment. The software have been used in many occurring of oil spill such as off the Eastern Arabian seas [8], Arabian Gulf [9] and Lach Huyen Port, Vietnam [10]. The most of sea states has random properties. The probability density function was used to describe the behavior of oil dispersion. This function $f(x, y, z, t) = hC(x, y, z, t)$ satisfy the Fokker-Planck equation as,

$$\frac{\partial f}{\partial t}+\frac{\partial(A_x f)}{\partial x}+\frac{\partial(A_y f)}{\partial y}=\tfrac{1}{2}\frac{\partial^2}{\partial x^2}\left[B_{xk}^2 f\right]+\tfrac{1}{2}\frac{\partial^2}{\partial x\partial y}\left[B_{xk}B_{yk}f\right]+\tfrac{1}{2}\frac{\partial^2}{\partial y\partial x}\left[B_{yk}B_{xk}f\right]+\tfrac{1}{2}\frac{\partial^2}{\partial y^2}\left[B_{yk}^2 f\right] \quad (4)$$

where A_x and A_y are advection coefficient in zonal and meridional direction respectively, B_{ij} are diffusion coefficient with ij are (x, y) index. In numerical scheme, MIKE 21 used the random walk model where the diffusion coefficient is given by

$$\Delta x=\left(\frac{D_{xx}}{h}\frac{\partial h}{\partial x}+\frac{\partial D_{xx}}{\partial x}+U\right)\Delta t+\sqrt{2D_{xx}\Delta t}Z_n \quad (5)$$

$$\Delta y=\left(\frac{D_{yy}}{h}\frac{\partial h}{\partial y}+\frac{\partial D_{yy}}{\partial y}+V\right)\Delta t+\sqrt{2D_{yy}\Delta t}Z_n \quad (6)$$

where D_{xx} and D_{yy} are dispersion coefficien in zonal and meridional direction respectivelyt, Z_n is a random function and $(U, V) = C_{da}(U, V)_{wind}+C_{dh}(U, V)_{current}$. The first step is define a parameters that causes oil spill dispersion physically, chemically or biologically. Not all parameter in detail been included in a numerical calculation modeling. Fist we describe emulsification paramater. Parameter which to be changed in the event of the emulsification process is the dispersion of sea water including the fine granules will enter to oil medium. The entry of droplets of sea cwater in the oil will cause an increasing of viscosity parameter and finally the oil volume will increase. The emulsification processes will decrease the evaporation dramatically. Parameter used in calculation of evaporation is oil temperature, the thickness of oil, sun radiation and the external force on oil including the wind and waves. The changing of the process of evaporation will result in a changing in the parameter of density and viscosity. Another importance parameter also taking into account are the dispersion coefficient and surface tension.

3.3. The sources and hydrodynamics forcing

The model was run by using the following information, the bathymetry source from Janhidros Indonesian Hydrography Office, CMap Norway and Gebco. The coordinate system used DD.WGS84 with the domain are minimum longitude 121.2 degree, maximum longitude 125.3 degree, minimum latitude-13.5 degree, and maximum latitude-9.3 degree with grid resolution is 1 × 1 km. The batimetry of research area is depicted in Fig.2. The simulation duration is about six month with stating date on August, 18 2009 and ending date on January, 8 2010 and the time step is one hour. The source of spill is located at 124.53333 longitude and −12.683333 latitude with the discharge 400 barrels/day, the spill velocity is about 5 m/s and emission type is assumed to be continue. The parameters used are albedo (0.14), emissivity of oil is

0.82, emissivity of water is 0.95, emissivity of air is 0.82 and evaporation is about 0.029. The emulsification including of crude oils are maximum water content 0.85, asphaltens content 3.6 (wt), wax content is 11.3 wt, K1 due to water uptake is about 5e − 007[kg/m3] and K2 due to water release is 1.2e – 005 [kg/s2]. Dissolution and entrainment mass transfer coefficient is 2.36e − 006 and oil in water interfacial tension is 17 [dyne/cm]. The oil properties type in volume fractions are C6-C12 (Paraffin) are 19.05, C13-C25 (Paraffin) are 0.00, C6-C12 (Cycloparaffin) are 22.55, C13-C23 (Cycloparaffin) are 0.00, C6-C11 (Aromatic) are 16.74 [C12-C18 (Aromatic) are 0.00, C9-C25 (Naphtheon) are 2.77, residual are 38.89, viscosity at refference temperature is about 3.7260 [cs], the refference temperature is set as 40.0 [C] and oil temperature is 30.0 [C]. Note that the unit of volume fraction in percent. In this case, we have open sea as a boundary condition where it was described by sea surface high (SSH). The SSH data was obtained from OSTM/Jason-2/1, Topex-Poseidon, Envisat, GFO, ERS1/2 and Geosat. The wind speed and direction was obtained from CERSAT Ifremer.

4. RESULT AND DISCUSSION

The batimetry of reasearch area is depicted in Fig.2. The platform within the depth relatively shallow which is about 200m. The topography of Timor sea have continental slopes type where the topography is depth at northern part close to the Roti island and tend to shallow in the southward close to the Australian mainland. The depth of 2000m is the narrow gaps where Indonesia troughflow (IT) flowing in this area. Topography conditions like this can usually conjures the presence of the internal waves. Observation with MODIS image shows the existence of large internal wave in these waters (www.internalwaveatlas.com) where the breaking of internal wave in the slope topography will generate the strong mixing processes. This is an importance factor in the contaminant dispersion in the area.

The first modul that should be run is hydrodynamics with input such as the surface wind velocity, water mass, sea surface high and tidal data. The main driving force is the wind depicted in Fig.(3). Wind speed on average $5ms^{-1}$ and began strengthen (more than $10ms^{-1}$) entering the Northwest monsoon namely in December. At the beginning of simulation, the wind have direction to the Northwest then alternating directions to the West and the East. Finally at the end of performs toward the Northeast. Another input is albedo and depicted in Fig.4. The Albedo (represented by air temperature and cloud cover) describes the fraction of the solar radiation, which is reflected, primarily depending on the colour of the oil. The emissivity of the oil, water and air are applied for the calculation of the heat balance for the oil slick. The evaporation constant is proportional to the amount of evaporated oil. Sea surface high data as an input for tidal elevation is expressed in Fig.5. The data source is merge between satellite data of Sea Level Height from OSTM/Jason-2, Jason-1, Topex/Poseidon, Envisat, GFO, and ERS. Geosat tidal prediction was simulated by using Mike21 Tidal Prediction including 172 tidal component, nearshore tidal correction with varying domain. The starting time = 12:00:00 AM and starting date =08-18-2009, with ending time = 12:00:00 AM and ending date at 08-18-2009.

The result of hydrodynamics model is depicted in Fig.6. It can be seen that ocean currents is dominated by tidal current where the current vector tend to rotate anti-clockwise ellipse. The result is similar with tidal currents derived from data assimilation [6]. The semidiurnal tide was observed with highest current speed 0.5-1 m/s occur at low tide (06.00 am and 11.00 pm) and high tide (11.00 am and 07.00 pm). The highest velocity occur at the southern part of the Timor sea to the Australian coast where the water are shalower. The currents speed tend to weak in the northern path due to the increased depth. The strong tidal current which came into shallower waters has also been observed by others[11]. On a daily time scale, the oil dispersion is dominated by advection processes due to tidal current which the oil disperse follow tidal pattern. The concentration disperse to the North at low tide (06.00 am) and then disperse to the Southwest at 11.00 am. Further, it disperse to the Northeast at low tide (07.00 pm) and flow to the Southeast at 11.00 pm. The strong currents act as a barrier so that the oil do not disperse into the Southern part of The Timor sea. The wind forcing is not significant for oils spill dispersion in daily period due to the wind data is averaged 24 hours.

The six month period simulation is depicted in Fig.7. It can be seen that the net dispersion of the oil spill dominated by the wind forcing and geostrophic current. In August to November where the SEM is active, the spill tend to disperse from Southeast to Northwest. From September to November the fate tend to constant and it was drift 10km long from the source. In this case the dispersion effect was weak and advection effect was dominant. Dispersion occurs in the opposite direction in December when SEM is weak, the wind flow to Southeast and its interaction with geostrophic current will drive the oil spill to move in the eastern part of the Timor sea. The oil fate disperse in very wide areas which implies that dispersion and advection processes were significant during this period. Indeed, wind speeds up to 10m/s were observed as a result of Huricane. In the cross section (blue line) showed that the dispersion was active from November. The end of simulation in the middle of January showed that the oil spill have moved 300km from the Montara rig.

The exposure area is an importance object which could act as a potential environmental monitoring control sites. The simulation result of exposure time is depicted in Fig.8. The pattern of exposure time is not the same form from the oil fate dispersion, especially at December when the oil supply stop. The location of the areas with the highest exposure about 3000 hours lay on the Northweastern part of the Timor sea and close to the coast of the Roti island. At the end of simulation the area exposed to oil extends about 30 km to the North and the Northwest of the Rig. The validation is done by comparison between model and satellite images. In this case, we used an envisat images on November, 9 2009 that it is depicted in Fig.9. Generally, we have a similar pattern between satellite images and simulation. Both of the images and the model showed that the oil disperse tend to the North part of Timor sea. Comparison exposure time of simulation result with MODIS image (see Fig. 10 show similar pattern. The oil spill basically move toward the northeast.

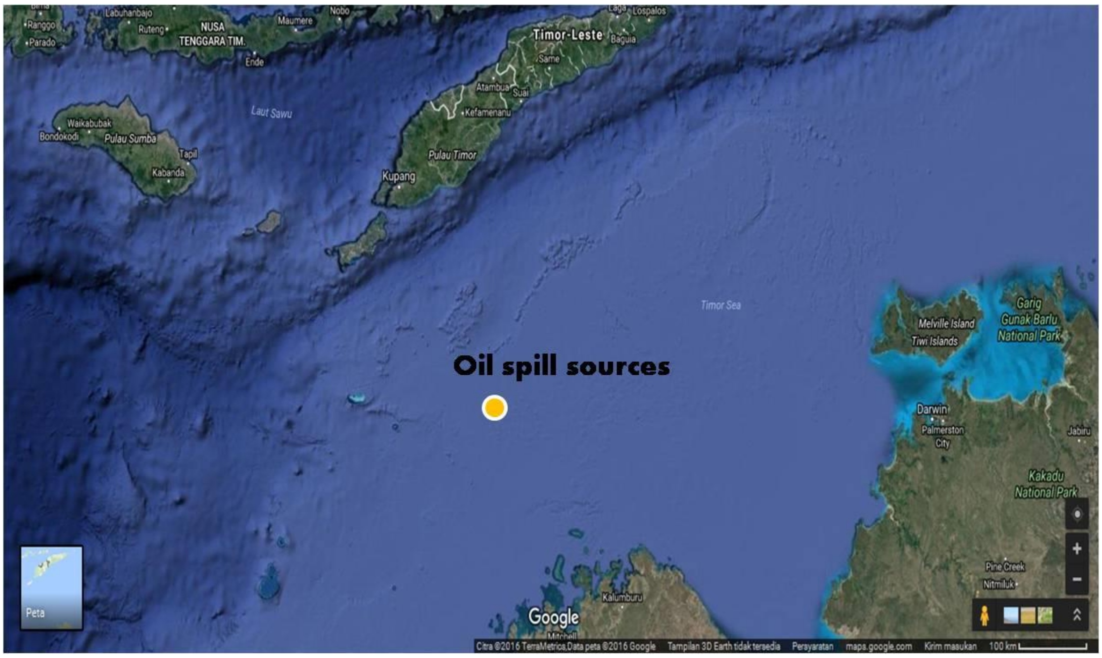

Figure 1: The location of Montara Platform. Most of oil spill disperse into the east and north part of platform. The oil spill pollute the large area over 74 days

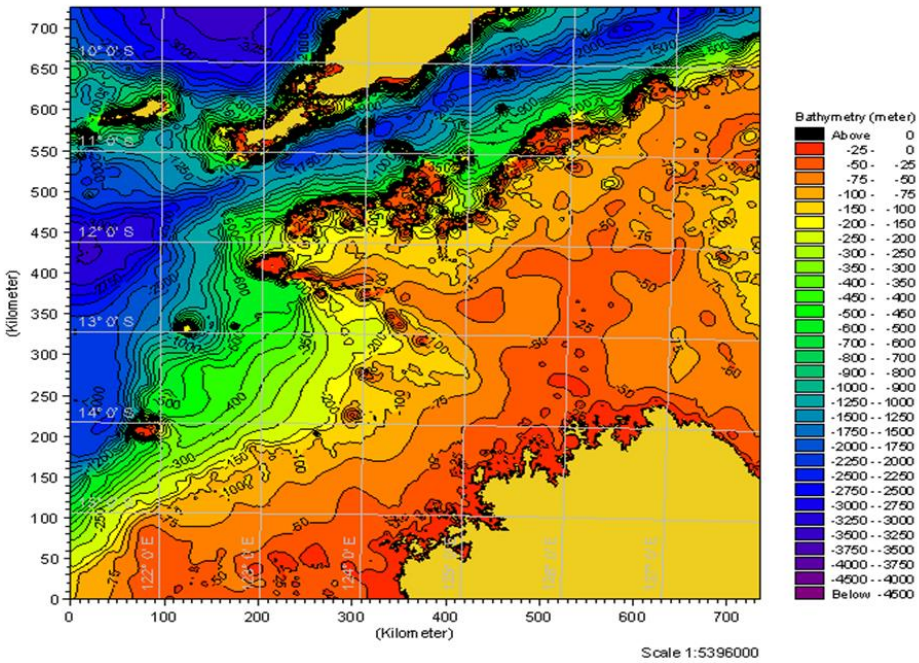

Figure 2: The seafloor topography of study area. The brown color to blue show degradation from shallow to deep. The platform in waters with the depth of relatively shallow with a depth is about 200m.

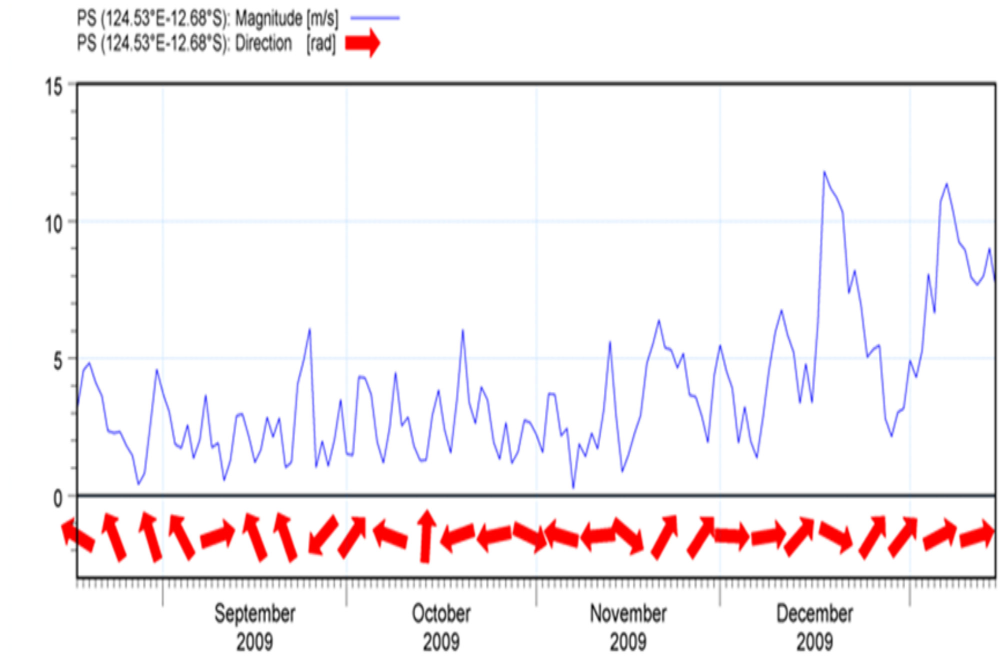

Figure 3: The main driving force is the wind obtained from NECP, NOAA and ECMWF that had been done by reanalysis. The simulation use six month time series with one hour interval.

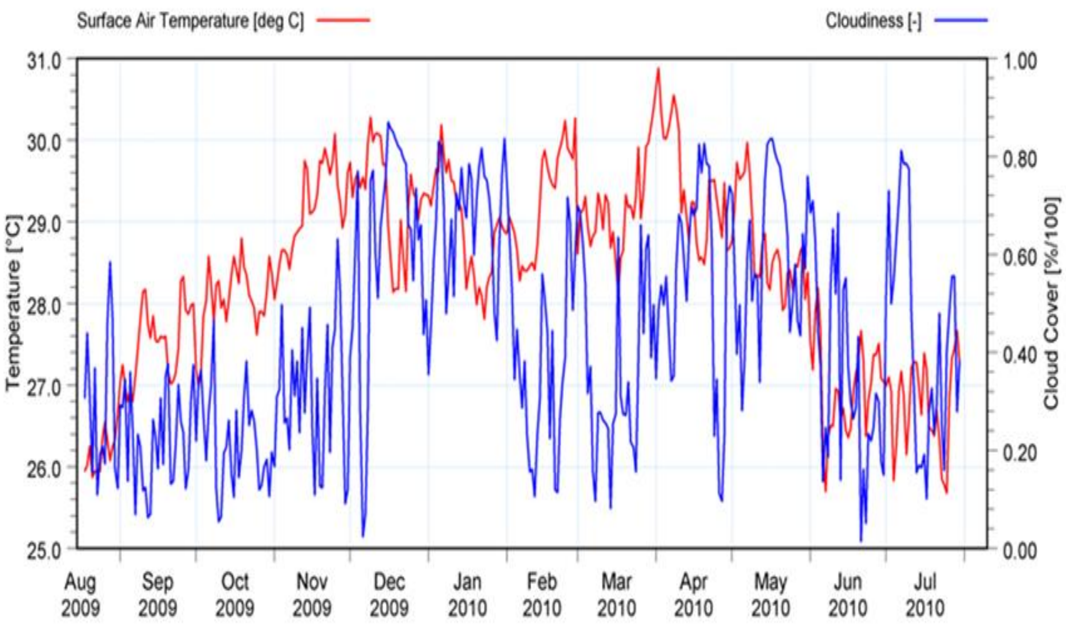

Figure 4: The Albedo describes the fraction of the solar radiation, which is reflected, primarily depending on the colour of the oil The red line is air temperature and the blue line is cloudiness. Data source: NCEP, NOAA and ECMWF

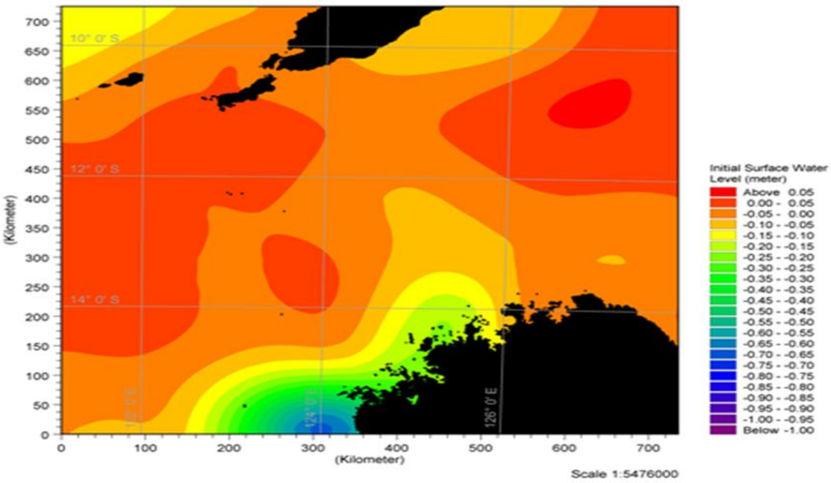

Figure 5: Sea surface high used in the simulation. The colour degradation from red to blue show the upper from mean sea level and below to mean sea level.

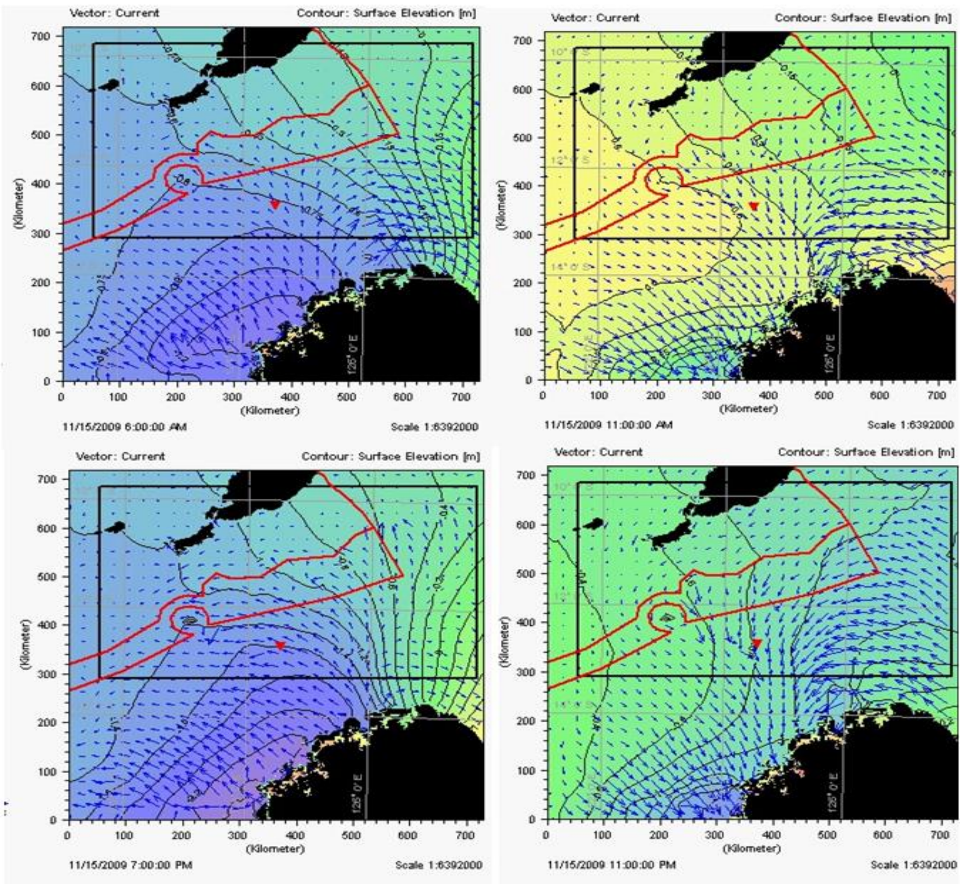

Figure 6: Hydrodymics simulation for 24 hours duration. Current vector at 06.00am, 11.00am, 07.00 pm and 11.00 pm in clockwise direction respectively. The red lines are Australian ZEE and Indonesian ZEE

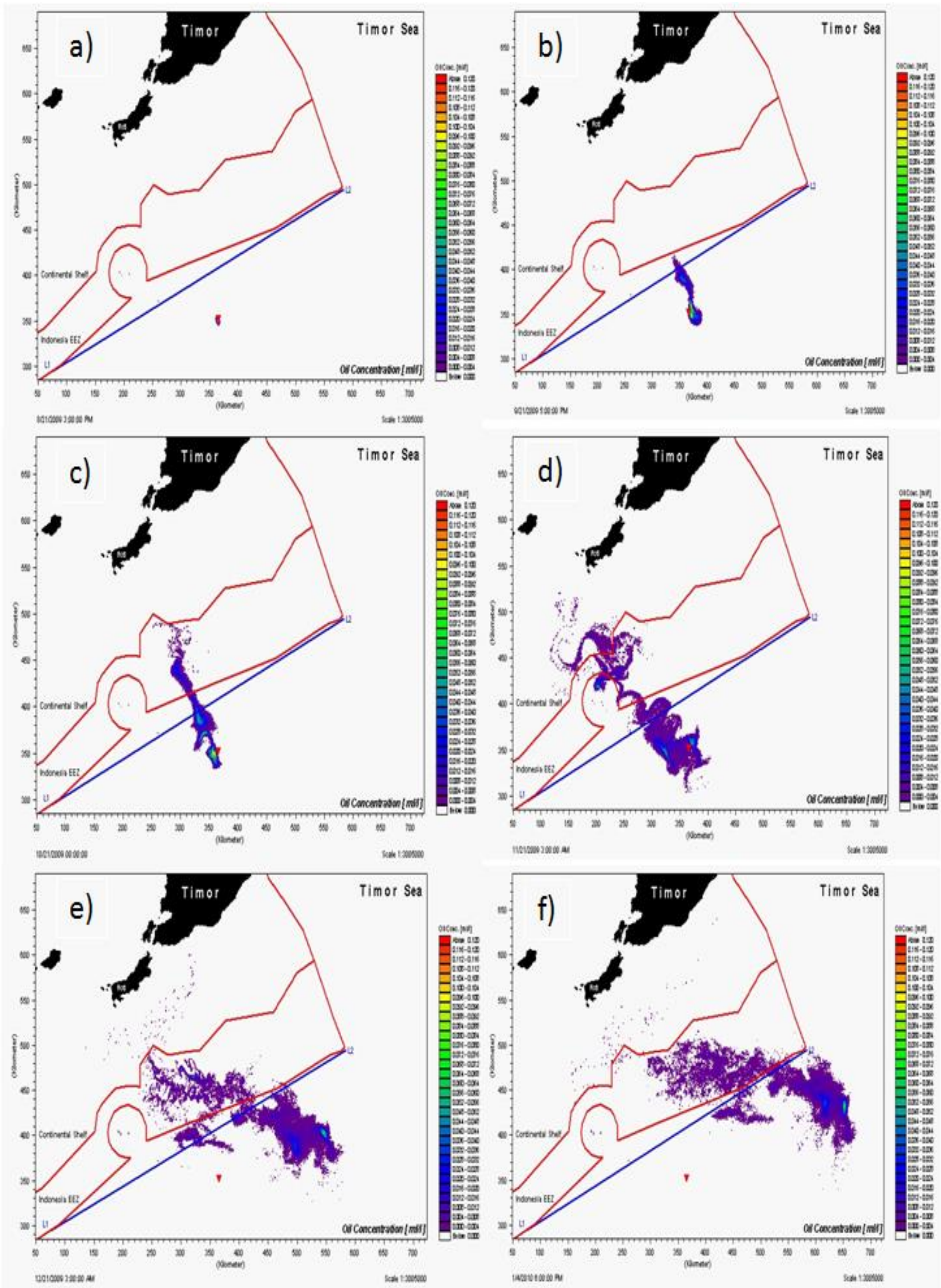

Figure 7: The oil dispersion simulated for six month duration. Red dot is the oil source location. a) August 2009, b) September 2009, c) October 2009, d) November 2009, e) December 2009 and f) January 2010. The red lines are Australian ZEE and Indonesian ZEE, The blue line is the cross section of region under consideration

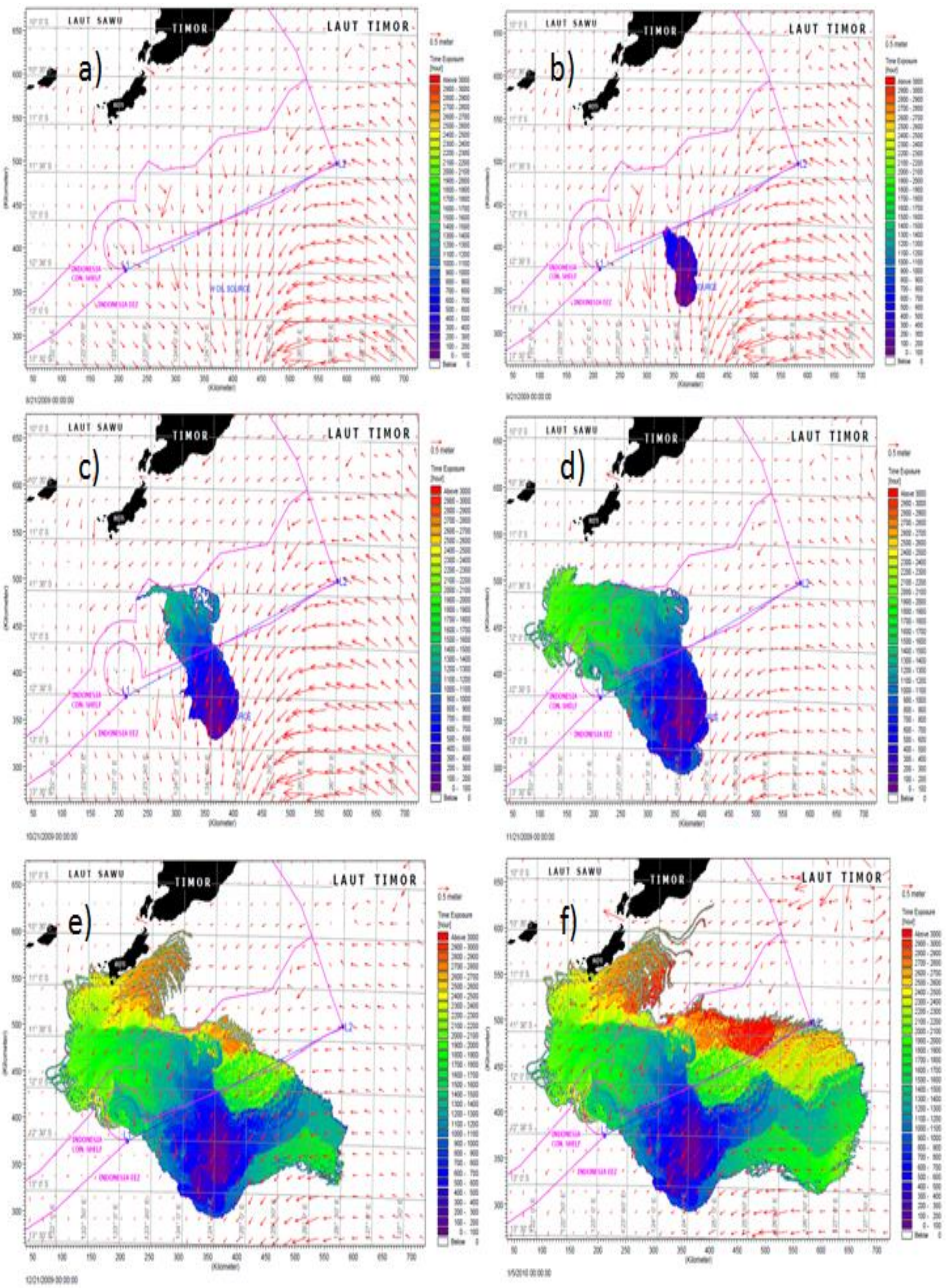

Figure 8: The oil time exposure simulated for six month duration. Red dot is the oil source location. a) August 2009, b) September 2009, c) October 2009, d) November 2009, e) December 2009 and f) January 2010. The red lines are Australian ZEE and Indonesian ZEE, The blue line is the cross section of region under consideration

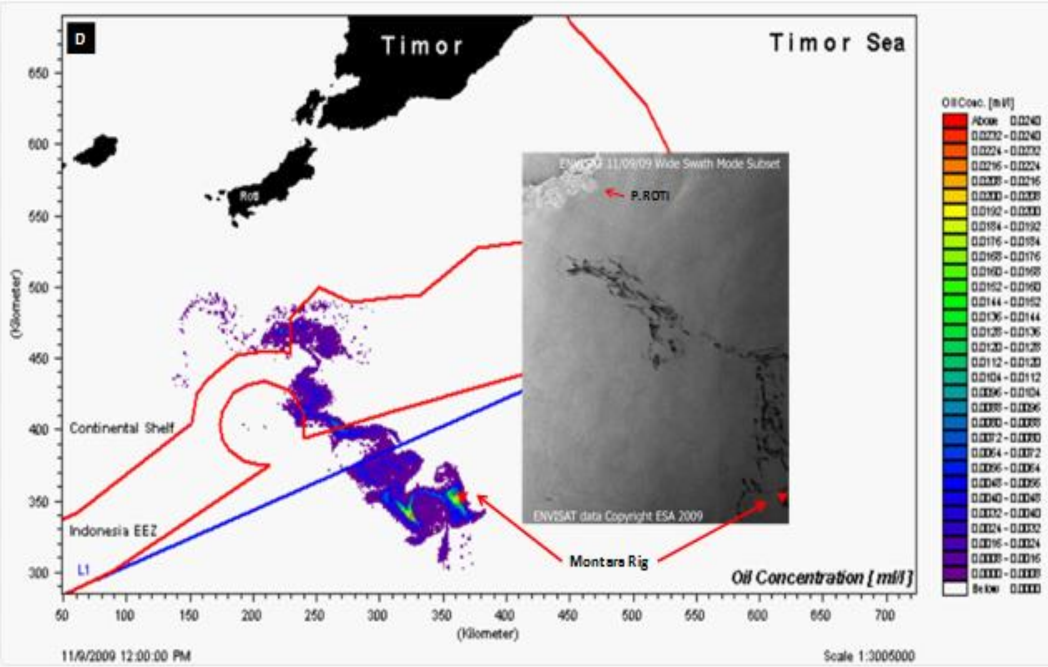

Figure 9: The comparison between the model of oil spill and enviast satelite images on November, 9 2009. The quick look images was obtained from www.crisp.nus.sg

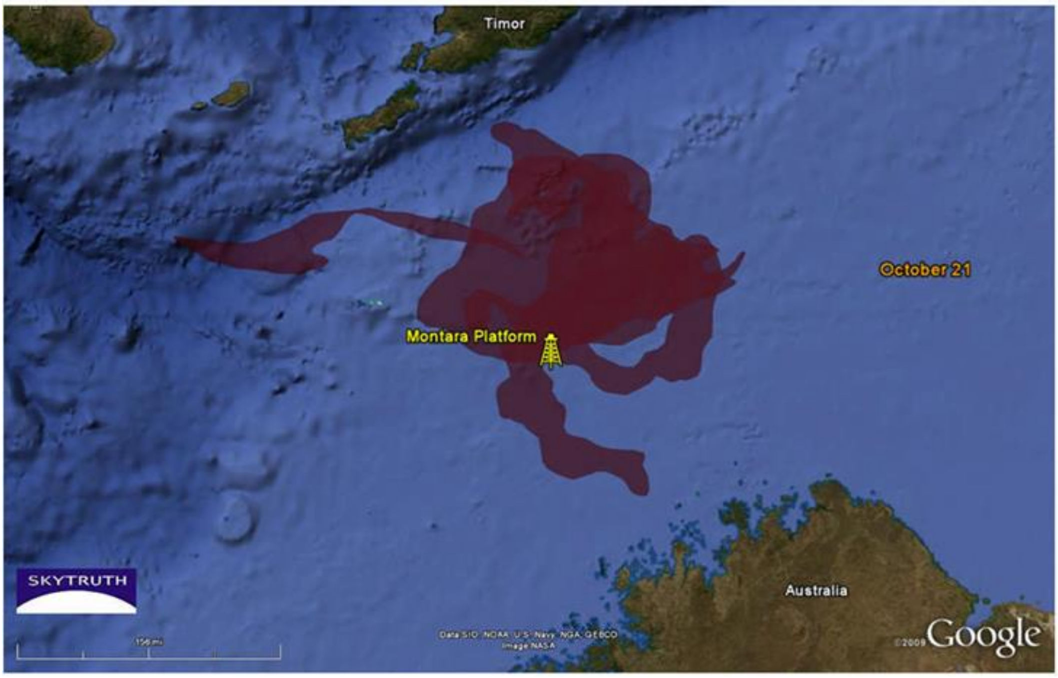

Figure 10: The cumulative oil slick footprint in the Timor sea as of October 21, 2009 based on SkyTruth analysis of MODIS imagery. The oil spill slightly over 22000 miles. (http://www.flickr.com/photos/skytruth)

5. SUMMARY

The simulation of the oils spill from the Montara oil platform located off the Timor sea based on the two-dimensional MIKE21 Spill Analysis (SA) model was investigated. The model was run by using Janhidros, Cmap and GEBCO batimetry data. The open boundary condition was calculated by sea surface high data. The synoptic wind data was obtained from CERSAT also used. The oil spill source type was a continue point with discharge 400 barrels/day. The hydrodynamics result showed that the tidal currents was dominant with semi-diurnal tidal type. This current was stronger in the Australian coast but tend to weak close to the Timor passage. The two month of simulation showed that the oil dispersion was strongly influenced by advection processes. When SEM active the oil spill propagate into the eastern of the Timor sea reaching 300 km long at the end of simulation. Areas with highest exposure times lie on the northern part of the Timor sea and close to the coast of the Roti island.

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