Combining ocean numerical model and SAR imagery to investigate the occurrence of oil pollution, a case study for the Java Sea

A Setiawan\textsuperscript{1*}, M R Putri\textsuperscript{2}, M Gade\textsuperscript{3}, T Pohlmann\textsuperscript{3} and B Mayer\textsuperscript{3}
\textsuperscript{1}Agency for Marine and Fisheries Research and Development, Ministry of Marine Affairs and Fisheries, Indonesia
\textsuperscript{2}Research Group of Oceanography, Institute of Technology Bandung, Indonesia
\textsuperscript{3}Institute of Oceanography, University of Hamburg, Germany

E-mail: setiawan.agus@gmail.com

Abstract. IndoNACE is an abbreviation of Indonesian Seas Numerical Assessment of the Coastal Environment, a pilot study between Indonesia and Germany that combining analysis of oil spills from SAR images and numerical tracer studies from 3-D numerical model. Aim of this study is to understand the observed seasonal variations in marine oil pollution. Within this study, a visual inspection of all available SAR images is performed in order to generate maps of oil pollution occurrence in the Java Sea. Afterward, a set of numerical models is applied to trace back the origin of oil pollution. Our results showed that by analysing 706 ENVISAT ASAR images, the highest number of oil spills occurrence in the Java Sea was found during the transition monsoons, i.e. March to May and September to November. Assuming Marine Protected Area (MPA) of Seribu Islands as the end position of oil trajectory, we found that the origins of oil pollutions in that area were mostly from north and east.

1. Introduction

The Java Sea is part of Sunda Shelf and has relatively shallow water with mean depth of 50 meters. The area is located between Kalimantan and Java Islands and has significant role on water mass exchange between the South China Sea and Indonesian seas. Moreover, Java Sea is also a major fishing ground within the Fishing Management Area (FMA) 712 that contributes to about 18\% of total Indonesian capture fisheries production in 2014 [1]. Beside its potential in capture fisheries, some areas in the Java Sea are also potential for tourism and, moreover, have been declared as Marine Protected Area (MPA) such as Seribu Islands (approx. 1075 km\textsuperscript{2}) and Karimun Jawa (approx. 1100 km\textsuperscript{2}). There is also some oil and gas fields located in the Java Sea, particularly in the areas north of Cirebon in West Java to Seribu Islands in Jakarta (known as Offshore North West Java Block or ONWJ) and east of Sumatra Island (known as Offshore South East Sumatra Block), covered areas of approx. 8,284 km\textsuperscript{2} and 5,852 km\textsuperscript{2}, respectively (see figure 1) [2]. In general, around 530 oil and gas platforms exist in the offshore Indonesian waters, where around 141 platforms are located in the ONWJ block and 82 of them still active. Pertamina Hulu Energy Offshore North West Java Ltd. (PHE) currently operates this block with average daily crude oil output reached 40,000 barrel per day in 2015 [3].

The Java Sea is prone to oil spills due to offshore oil exploration and production activities as well as ship traffic through the sea-lanes of the Indonesian archipelago (known as Alur Laut Kepulauan...
Indonesia or ALKI). Based on historical data, about 2-4 oil spills occurred per year around Seribu Islands, where the main source of these spills is offshore oil production [4]. Moreover, these oil spills have also polluting the MPA in Seribu Islands. According to the local authority of Seribu Islands Regency, in 2003 and 2004 around 78 and 37 of 87 islands were polluted by the oil spills, respectively. Table 1 shows some occurrence of oil spills around Seribu Islands since 2003.

![Figure 1. Offshore oil and gas fields at Java Sea (Source: www.energy-pedia.com)](image)

| Time                 | Records of events                                                                 |
|----------------------|----------------------------------------------------------------------------------|
| December 2003        | Around 78 of 87 islands of Seribu Islands were polluted by crude oil spill, including islands in the Marine Protected Area (MPA) |
| April 2004           | Around 37 islands were polluted by crude oil spill                                |
| May 2004             | Oil spills were detected eastward of Pramuka Island until Peniki as well as Kelapa Islands |
| October 2004         | Clumps of tar ball of 4-5 cm thick detected 1-2 km around Kotok Island            |
| February 2006        | Oil spill was detected in the MPA of Seribu Islands                               |
| October 2008         | Waters in the southern part of Seribu Islands, i.e. around Pari, Tikus, Burung, and Payung Islands were covered by oil spill with thickness of 1-20 cm |
| February, March, and August 2011 | Four islands, namely Putri, Payung, Tidung Kecil, and Tidung Besar were polluted by crude oil spill |

Synthetic Aperture Radar (SAR) deployed in the satellite currently becomes an important tool that can be used to monitor the oil spill [5]. In the ocean oil spills appear as slicks that generally could be distinguished by SAR imagery as dark patches [5][6][7]. Even though SAR imagery does not have any capabilities on estimating oil spill thickness and recognizing oil types, its ability on detecting oil spills is still the most efficient and superior due to its wide area of coverage and capabilities to capture images in all weather condition day and night [5].

Since the MPA of Seribu Islands is located close to offshore oil exploration and production and for several times have already polluted by oil spills, continuous monitoring is a key of importance for this
area. Based on this reason, a pilot study called Indonesian Seas Numerical Assessment of the Coastal Environment (IndoNACE) is proposed by combining the advantage of remote sensing technology and numerical model techniques to meet the needs. The objective of this joint Indonesia-German cooperation is to improve the information on the state of marine environment gained from satellite data, particularly SAR, in order to produce oil pollution density map and hydrodynamics and trajectory models in order to trace back the source of oil spills. This study has two regions of interest (ROIs) namely western Java Sea and Makassar Strait, and this paper will focus the discussion on results obtained for the western Java Sea region.

2. Materials and Methods

The IndoNACE pilot study will utilize historical and actual data from ESA’s ENVISAT archive and Sentinel 1A Rolling Archive to generate map of occurrence of all detected oil pollution, binned on 0.05°x0.05° grids. Approximately, 706 ENVISAT ASAR images acquired over the study area were used in this study. Afterwards, in order to identify the source areas for oil, which was detected via satellites, as well as to confirm their pathways, a tracer model was applied in backward mode, making use of daily average surface current velocity obtained by the hydrodynamics model.

2.1. Regions of Interest

Based on its potential to oil spills occurrence, particularly due to offshore oil exploration and high density of MPAs as well as mangroves and coral reef ecosystem, western Java Sea (105°-111° E and 3°-7° S) has been chosen as region of interest (ROI) for this pilot study. The area is given in figure 2 as a hatched area.

![Figure 2](image.png)

**Figure 2.** One of the regions of interest (ROI) for the pilot study of IndoNACE

2.2. Detection of Oil Spill from SAR Images

The detection of oil spills from SAR images was performed using visual inspection. All of SAR images that are available for the ROI were processed, along with manual registration, including geo-information (latitude, longitude, size, etc.) on the detected spills [6][7]. Special emphasis has been put on the discrimination between anthropogenic (mineral oil) spills and biogenic slicks, since both species tend to cause similar feature on SAR imagery [8][9]. Figure 3 shows the monthly coverage (October 2002 to April 2012) of ENVISAT ASAR of both IndoNACE ROI.

In general, the detection of oil spill consists of four operations, i.e. pre-processing (calibration and speckle filtering to source images), land-sea masking (in order to focus the detection only on area of interest), dark spot detection, and clustering and discrimination (clustering and then eliminating pixels
that detected as part of dark spot based on dimension of the cluster and user selected minimum cluster size) [10]. All of these processes could be performed making use of Next ESA SAR Toolbox (NEST), an open source toolbox that available to read, post-process, analyse, and visualize the large archive data from ESA SAR missions.

2.3. Hydrodynamics and Tracer Models
Long-term simulation of meso-scale (approximately 11 km horizontal resolution) Hamburg Shelf Ocean Model (HAMSOM) covering the entire region of Indonesian waters has been carried out to produce velocity data used in tracer model. Results from Max Planck Institute-Ocean Model (MPI-OM) were used for open boundary values. Atmospheric data from National Centers for Environmental Prediction (NCEP) as well rivers discharge from Research Center for Water Resources (RCWR) was used as external forcing in order to obtain adequate results [11]. The tracer model used in this study was based on Lagrangian approach. Similar resolution was applied to the tracer model, where velocity data obtained by the HAMSOM were used to estimate the oil spills pathways in backward mode.

Figure 3. Monthly coverage of ENVISAT ASAR for both IndoNACE ROIs (Oct. 2002-Apr. 2012), unit for the color bar is number of coverage.
3. Result and Discussion

Figure 4 shows an example shows oil slicks around Seribu Islands after image processing. Meanwhile, figure 5 shows the map of pollution occurrence that includes all detected oil pollution generated from visual inspection over 706 ENVISAT ASAR images. From this figure, which is indicating the number of oil spills per 0.05°x0.05° cells, higher number of oil spills mostly detected in the area around offshore oil exploration, particularly Arjuna and Cinta fields, and Port of Tanjung Priok. These results clearly show that oil production and ship traffic putting the western Java Sea (including MPA of Seribu Islands) under severe threat. By calculating the ratio of the total number of oil spills detected in each month of the year and monthly distribution of the approximately 706 ENVISAT ASAR images, monthly distribution of oil spills was estimated and shown in figure 6. From this estimation, in general the highest number of oil spills was occurred during March to May and September to November, respectively.

Based on results of one-week simulation of backward tracer model, making use of daily average velocity data of years 2003-2011, during the northwest monsoon (represented by result in February) the MPA of Seribu Islands was most likely hit by oil spills originating in the area around Offshore Southeast Sumatera Block and ALKI I that passing through Sunda Strait-Karimata Strait-Natuna Sea-South China Sea (figure 7 top left panel, diamond marks indicate the position of oil spills a week before reach the MPA). In general, there is an eastward transport in the Java Sea during the northwest monsoon (December to February). Water mass from the South China Sea (SCS) enters the Karimata Strait and flows eastward to the Java Sea. However, water mass in the western Java Sea flows also south-westward to the Indian Ocean through Sunda Strait. On the other hand, during southeast monsoon (represented by result in August), the MPA of Seribu Islands mostly hit by oil spills originating in the area around ONWJ Block (figure 7 bottom left panel). During this period (southeast
monsoon - June to August), main flow in the Java Sea is in opposite direction to northwest monsoon. Water mass from Makassar Strait flows westward into the Java Sea and then north-westward to the Karimata Strait. In the western Java Sea, water mass flows also south-westward to the Indian Ocean through Sunda Strait.

![Figure 5](image)

**Figure 5.** Number of oil spills per 0.05°x0.05° cells generated from visual inspection over 706 ENVISAT ASAR images

Interesting results were obtained during both monsoon transitions, where statistically the number of oil spills detected by satellite was higher than that during northwest and southeast monsoons (see figure 6). Comparing the condition with northwest and southeast monsoons periods, surface current velocity and residence time in the Java Sea during transition periods is weaker [4] and longer [11], while the sea surface current direction is varied without any dominant direction. Consequently, oil spills tends to accumulate in this region and this condition can be seen clearly in the results of backward trajectories in April and October as shown in figure 7 top and bottom left panels. Sources of oil spills reach the MPA of Seribu Islands during these periods were vary with year, but mostly dominated by spills originated from offshore oil exploration of ONWJ.

![Figure 6](image)

**Figure 6.** Monthly distribution of the average numbers of oil spills per SAR image
4. Conclusion

In the case of oil spills in Java Sea, the number of spills during monsoon transition periods is higher than during northwest and southeast monsoons and the residence time in the Java Sea plays very important role to this condition. From the simulation of backward trajectories model, we found that the origin of spills is mostly from offshore oil exploration in ONWJ block. However, during northwest monsoon source from ALKI I have also detected.

In general, the pilot study of IndoNACE has successfully demonstrated how to manage data from SAR satellites and combine them with ocean numerical models in order to assess the incidence of oil spills and estimate the origin of spills that taking into account the seasonal aspect. However, since SAR imagery does not have any capabilities to recognize oil types, further laboratory analysis on oil spills sample is needed to improve the assessment, especially when dealing with trajectory model, since different type of oil needs different parameterization. Moreover, further information on weather conditions, particularly wind speed as the limiting factor for the visibility of oil pollution on SAR imagery, is also needed in order to improve the results of oil spills detection.
Acknowledgements
The pilot study Indonesean seas Numerical Assessment of the Coastal Environment (IndoNACE) receives funding from the European Space Agency (ESA) under contract ITT AO 1-8176/14/F/MOS. ENVISAT ASAR imagery was kindly made available by ESA’s EO Grid Processing On-Demand (EO0GPOD) Team.

References
[1] Ministry of Marine Affairs and Fisheries 2015 Keragaan Perikanan Tangkap
[2] Energy-pedia News Website 2010 http://www.energy-pedia.com/news/indonesia/inpex-sells-offshore-northwest-java-and-offshore-southeast-sumatra-interests-to-pertamina, accessed August 4th 2016
[3] Petro Energy Website 2016 http://www.petroenergy.id/article/---2015-phe-onwj-penuhi-target-produksi-minyak-40-ribu-bopd, accessed 4 August 2016
[4] Putri M R, Setiawan, T. Pohlmann, B. Mayer, M. Gade 2016 The assessment of oil pollution in Seribu Islands abased on remote sensing and numerical models Proc. ESA Living Planet Symp (Prague, Czech Republic)
[5] Brekke C and Solberg A H S 2005 Oil spill detection by satellite remote sensing Remote Sensing of Environment 95 1-13
[6] Gade M, Mayer B, Pohlmann T, Putri M R, Setiawan A 2016 Using SAR data for a numerical assessment of the Indonesian coastal environment Proc. ESA Living Planet Symp 2016 (Prague, Czech Republic)
[7] Gade M, Mayer B, Pohlmann T, Putri M R, and Setiawan A 2016 An assessment of the Indonesian coastal environment based on SAR imagery Proc. Int. Geosci. Remote Sens. Symp. (IGARSS) 2016 (Beijing, China)
[8] Gade M, Alpers W, Hühnerfuss H, Masuko H, Kobayashi T 1998 The imaging of biogenic and anthropogenic surface films by a multi-frequency multi-polarization synthetic aperture radar measured during the SIR-C/X-SAR missions J. Geophys. Res. 103 18851-18866
[9] Gade M, Byfield V, Ermakov S, Lavrova O, Mitnik L 2013 Slicks as indicators for marine processes Oceanography 26 138-149
[10] Solberg A S, Brekke C, Solberg R 2004 Algorithm for oil spill detection in Radarsat and ENVISAT SAR images Geoscience and Remote Sensing Symposium IGARSS Proc. IEEE International 7 p 4909-4912
[11] Mayer B, Stacke T, Stottemeister I, Pohlmann T 2015 Sunda shelf seas: flushing rates and residence times Ocean Sci. Discuss. 12 863-895