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Efficacy Evaluation of Data Assimilation for Simulation Method of Spilled Oil Drifting

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Abstract

In recent years, oil spill accidents in oil tanker and production facilities occur frequently. When spilled oil is drifted to the coast, natural environment and the ecosystem are destroyed and a big loss is given to the regional environment. In order to minimize the damage, we'll retrieve the oil on the sea and place the oil control equipment to the coast where spilled oil is predicted to drift ashore. To solve this problem, the forecast model of drifting oil has started to develop. In this study, we introduce data assimilation to the simulation of drifting oil and evaluate its efficacy.

In this study, Nakhodka oil spill accident is simulated as a test case and we evaluate the accuracy of data assimilation comparing simulation results to observed data. As a result, we find that the simulated result with data assimilation better than that of without data assimilation by comparing observed data.

Keywords: **Simulation, Spilled oil drifting, Data Assimilation, POM, WRF**

1 Introduction

Recently, the oil spill accidents occur frequently all over the world. When spilled oil drift to the coast, natural environment and the ecosystem are destroyed and a big loss is given to the regional environment.

In the case of Japan, Nakhodka oil spill accident occurred off the coast of Shimane prefecture in 1997, and severely damage to wide range of Japanese coast.

In order to minimize the damage, we retrieve the oil on the sea or place the oil control equipment on the coast where oil drift is expected.

To solve this problem, we started to develop a new spilled oil and gas tracking autonomous buoy system and application to marine disaster prevention system named SOTAB (Spilled oil Tracking Autonomous Buoy System) such as Fig.1.

The system is consisted by the buoy robot and oil spill simulation.

In measure 1, the underwater buoy robot called SOTAB-I autonomously tracks and monitors the plumes of oil and gas leaking from seabed.

In measure 2, the multiple floating buoy robots called SOTAB-II autonomously track the spilled oil on sea surface and transfer useful data to a land station through satellites in real time.

In measure 3, the simulation forecasts the oil drift incorporating the real time measured data obtained from these robots.

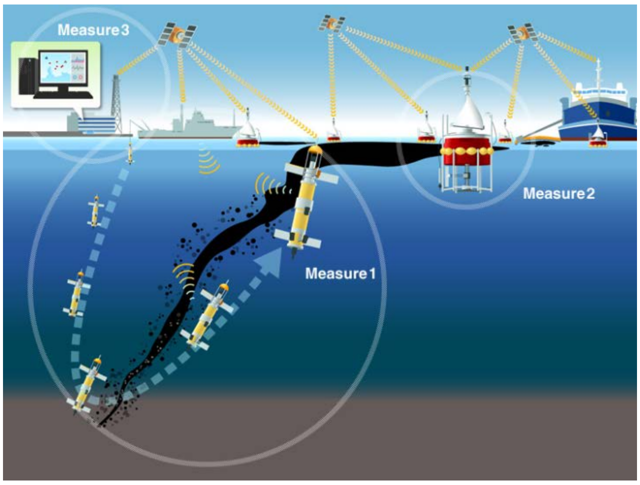

Fig.1 General view of SOTAB

In this study, we have tried to improve the accuracy of the oil drift prediction to minimize such severe damage. Mukumoto had carried out the simulation of Nakhodka oil spill accident using POM (Princeton Ocean Model) and WRF (Weather Research and Forecasting). As drift oil is susceptible to wind, we have used WRFDA (Weather Research and Forecasting Data Assimilation) that is applied data assimilation to WRF and evaluated its efficacy. In this paper, several parts of these results are presented.

2 Simulation of oil drift
2.1 Treatment of oil

The spilled oil on the sea absorbs water. Its volume peaks in first 12 hours. Its evaporative rate also rises quickly within the 24 hours, and becomes an oil mousse. Oil mousse is hard to change its form because of its high viscosity.
Accordingly, we consider oil mousse as a lump of oil in the simulation.
In this simulation, we substitute the oil for a circle oil spot until 24 hours and calculate the evaporative rate, emulsion and spreading width. 24 hours later, the particles of oil are arranged equally in the circle of that width. Then, they are affected by wind and sea current. The calculation flow of oil characteristics is shown in Fig.2.

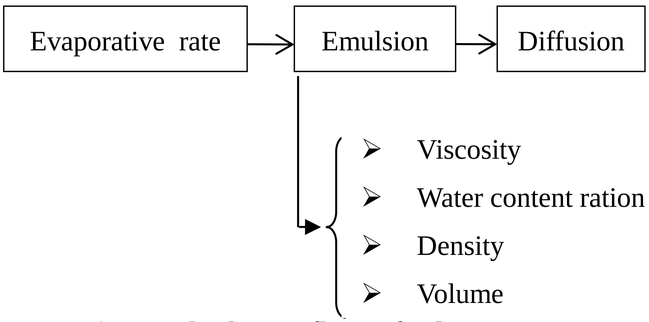

Fig.2 Calculation flow of oil property

In the case of Nakhodka oil spill accident, 6679 kiloliters of oil spilled when the accident occurred. Moreover, 1984 kiloliters of oil spilled while its bow was drifting on the sea. In this study, we set the trajectory of the bow to the simulation as Fig.3 (The report of Nakhodka oil spill accident 1997). 1984 kiloliters of oil spilled evenly according to the bow's trajectory.
In this simulation, 10 kiloliters of oil is treated as a particle. 676 particles are set to the place where the accident occurred and 4 particles are set every 3 hours according to the bow's trajectory. The sum of oil particles are 7766.
The velocity of oil particles is consisted from surface velocity calculated by POM and the wind velocity of altitude of 10 meter multiplied 3%. The wind velocity is calculated by WRF.

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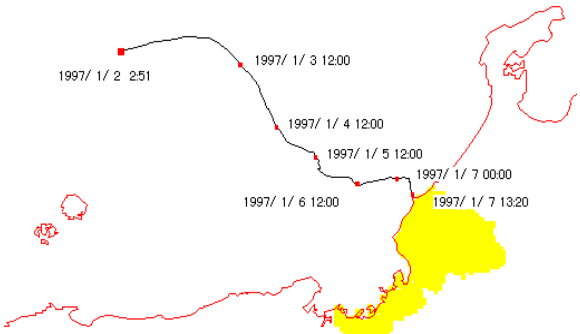

Fig.3 The trajectory of Nakhodka's bow

2.2 Construction of the numerical model

We used POM (Princeton Ocean Model) for the Ocean model and WRF (Weather Research and Forecasting) for the weather forecasting model. The ocean model has been modified to track the drifted oil in previous study (Mukumoto 2008).
In this study, Nakhodka oil spill accident is simulated as a test case as mentioned before. The simulation domain is as Fig.4. As for POM, the monthly mean flow rate, salinity, and seawater temperature are given at open boundary and the wind stress calculated by WRF is given at sea surface as external forces.

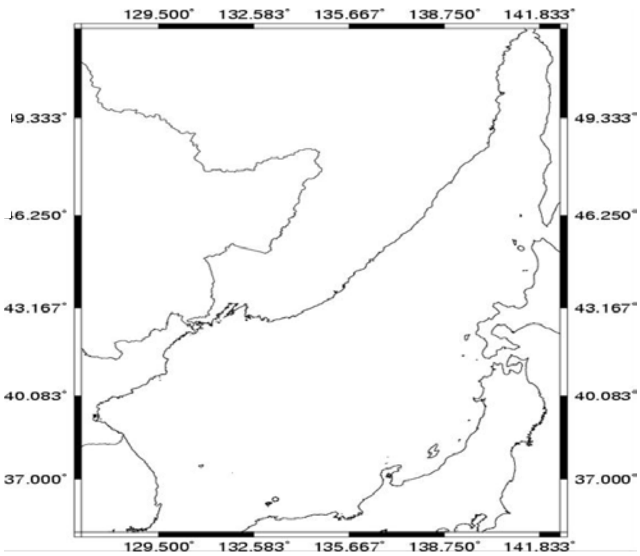

Fig.4 simulation domain

The conditions of the simulation are shown in table 1. If oil spill accidents occur, we have to forecast the oil drift as soon as possible.
To shorten the computational time, the grid size

is set to 18km. The calculation period is set to 30 days, the time the oil should have been drifted to the coast.

Table 1 The conditions of simulation

Model		POM	WRF
Domain	Latitude(deg.)	34- 53	34- 53
	Longitude(deg.)	127-142.5	127-142.5
Grid size		18km×18km	18km×18km
Time step		12s	60s
Period		1/1 ,1997~ 1/31,1997	1/1 ,1997~ 1/31,1997

The data assimilation (DA) methods we used are so-called four-dimensional variational method (4DVAR) and three-dimensional variational method (3DVAR) in WRFDA. The observed data for DA is "NCEP ADP Operational Global Surface Observations (SYNOP) and Upper Air Observations (SOUND)" which can be obtained from the website (http://ncar.ucar.edu/). The observation points are shown in Fig.5 and Fig.6. The observed variables are shown in table 2 and table 3.

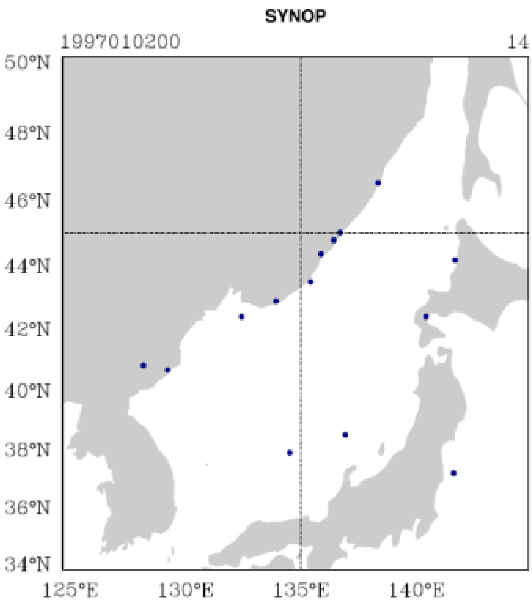

Fig.5 The observation points of SYNOP

Table 2 Variables of SYNOP

Air Temperature	Cloud Amount /Frequency	Cloud Base	Cloud Types
Dew Point Temperature	Precipitation Amount	Sea Level Pressure	Sea Surface Temperature
Snow	Station Height	Surface Pressure	Surface Winds
Swells	Visibility	Wave Height	Wave Period

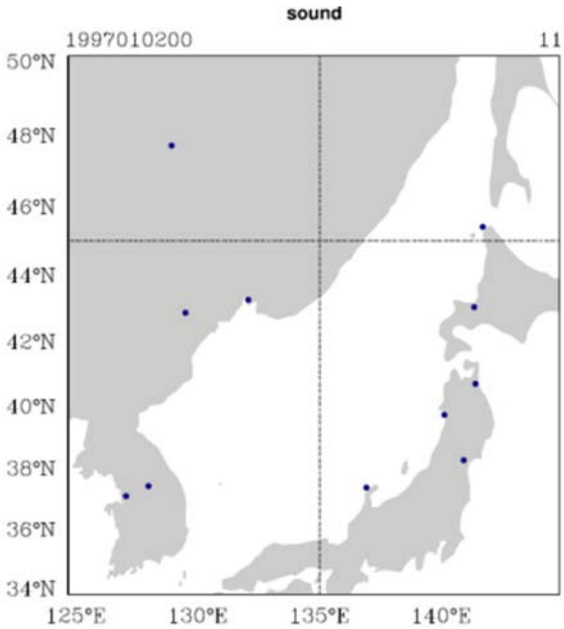

Fig.6 The observation points of SOUND

Table 3 Variables of SOUND

Air Temperature	Atmospheric Pressure Measurements	Barometric Altitude	Cloud Amount Frequency
Dew Point Temperature	Geopotential Height	Tropopause	Upper Level Winds

In this study, we used WRF and POM to compute the wind distribution and the current as mentioned before. Firstly, we carried out the computation of wind using WRF to get wind velocity. After that we gave the result of WRF to POM as wind stress on the sea surface.

To examine the efficacy of data assimilation, we carried out two patterns of simulations. One case is that initial values, boundary conditions and observed values are set to WRF and WRFDA every 6 hours for a period of one month (hereafter referred to as the simulation 1). The other case is that initial values, boundary conditions and observed values are not updated after setting these values for first few weeks. (hereafter referred to as the simulation 2).

3 Simulation results
3.1 Simulation 1

This simulation was performed to examine the efficacy of data assimilation by comparing with and without data assimilation.

Actually, in Fukui prefecture, the areas where a large amount of oil drifted ashore are marked by red points in Fig.7. However, other prefectures have not announced the amount of drifted oil of each region.

The computed distribution of oil drifted ashore without data assimilation is shown in Fig.8 and with data assimilation is shown in Figs.9-10.

Comparing Figs.7-9 to Fig.10, we found that data assimilation improves the accuracy of prediction of the area where much quantity of oil drifted ashore.

When oil accident occurs, we need to know where a large amount of oil will drift ashore to place the oil control equipment effectively. According to the result, it is proved that data assimilation is effective for this purpose.

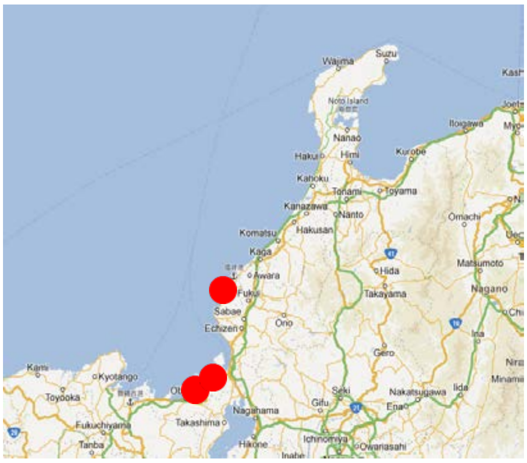

Fig.7 The area where a large amount of oil drifted ashore in Fukui prefecture

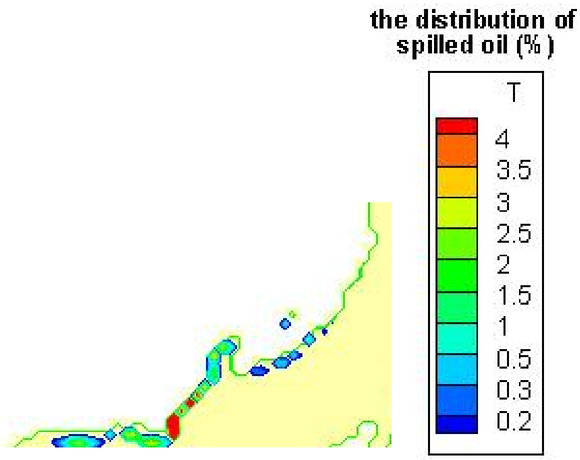

Fig.8 Distribution of oil drifted ashore (w/o DA)

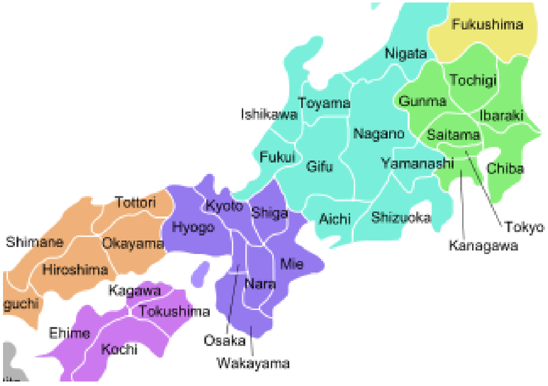

Fig.9 Distribution of oil drifted ashore (3DVAR)

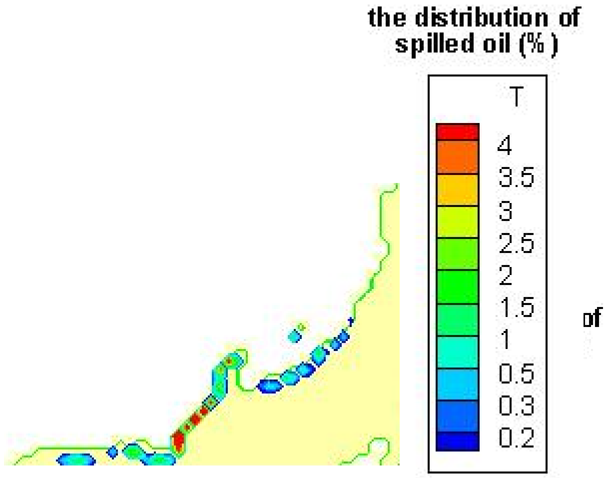

Fig.10 Distribution of oil drifted ashore (4DVAR)

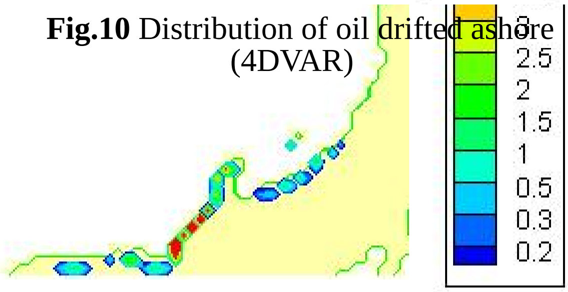

Fig.11 Location of prefecture

Just in case, we show the location of each prefecture in Fig.11.

Next, we evaluate the accuracy from the view point of the quantity of oil drifted ashore in each prefecture.

The simulation results are shown in table 4.

The ratio is defined by the oil particles drifted ashore and amount of oil particles (7766 particles) in each prefecture.

It should be noted that the observed values are defined by the quantity of oil.

The accuracy of computational results are evaluated by RMSE (Root Mean Square Error) defined as following equation.

$$\mathrm{RMSE} = \sqrt{\frac{(\mathrm{x}_0 - \mathrm{x}_\mathrm{i})^2}{\mathrm{N}}}$$

where
x_0:the ratio of observed values in the total
x_i: the ratio of calculated values in the total
N: the total number of oil particles

We found that the RMSE of simulated result with data assimilation better than that of without data assimilation by comparing observed data.

The area where the most oil drifted ashore was the coast of Ishikawa prefecture, but it is Fukui prefecture in the simulation. Moreover, there is little difference between the results of 4DVAR and 3DVAR. This may be resulting from less observed data in January 1997.

Table 4 Comparisons of drifted oil

	Observed value	w/o DA	3DVAR	4DVAR
Shimane / **Tottori**	0.60	9.19	4.98	5.49
Hyogo	2.90	2.16	1.37	1.24
Kyoto	7.30	9.26	5.11	5.49
Fukui	37.30	54.50	47.28	47.63
Ishikawa	44.30	21.08	30.60	29.86
Nigata	7.60	4.24	10.26	9.94
other		1.12	1.94	1.88
	RMSE	12.4	7.31	7.64

Unit: %

3.2 Simulation 2

When oil spill accident occurs, we have to forecast the area where spilled oil will drift ashore. In this simulation, we examine the accuracy of forecasting.

When we forecasted where spilled oil will drift ashore on January 31 1997 at 00:00 as at January 1 1997 at 00:00, the initial values, boundary conditions and observed values were set to WRF and WRFDA on January 1 1997 at 00:00. Since then, these values are not updated and the simulation was carried out until January 31 1997 at 00:00.

In case of forecasting that as at January 7 1997 at 00:00, the initial values, boundary conditions and observed values were set to WRF and WRFDA from January 1 1997 at 00:00 to January 7 1997 at 00:00 each 6 hours. Since then, these values were not updated and the simulation was carried out until January 31 1997 at 00:00.

Forecasting on January 13, 19 and 25 were carried out in the similar way.

The results are shown in tables 5-7. In the tables 5-7, forecasting day means when we forecast where spilled oil drifted ashore on January 31 1997 at 00:00 as of that day. The percentage is a ratio of drifted oil particles to all oil particles (7766 particles) in each prefecture on January 31 1997 at 00:00. For exception, observed values are a ratio of not particles but amount of oil which drifted down to coast.

w/o DA						
Forecast Day	Jan.1	Jan.7	Jan.13	Jan.19	Jan.25	Observed
Shimane	1.6	1.6	1.6	1.6	1.6	0.6
Tottori	2.3	21.0	7.7	7.7	7.7	
Hyogo	2.7	2.8	0.8	1.9	1.9	2.9
Kyoto	21.1	22.3	7.8	9.9	10.0	7.3
Fukui	25.2	42.8	46.5	53.5	54.1	37.3
Ishikawa	25.5	10.7	18.6	21.2	20.9	44.3
Niigata	15.6	0.2	17.2	4.9	4.6	7.6
other	7.5	0.2	1.5	0.8	0.8	
						(%)
RMSE	11.28	17.90	12.37	12.16	12.38	

Table 5 prediction of drifted oil (w/o DA)

According to table 5, we found that there are almost no differences in a period of forecasting in case of w/o DA.

3DVAR						
Forecast Day	Jan.1	Jan.7	Jan.13	Jan.19	Jan.25	Observed
Shimane	1.6	1.6	1.6	1.6	1.6	0.6
Tottori	40.1	18.8	3.5	3.4	3.4	
Hyogo	5.0	3.0	0.7	1.4	1.4	2.9
Kyoto	18.6	22.2	6.9	5.6	5.1	7.3
Fukui	20.0	44.2	40.7	44.9	47.3	37.3
Ishikawa	6.9	11.1	21.7	32.7	30.6	44.3
Niigata	6.6	0.3	24.8	10.2	10.2	7.6
other	2.7	0.3	1.8	1.8	2.0	
						(%)
RMSE	24.24	17.40	11.86	6.11	7.31	

Table 6 prediction of drifted oil (3DVAR)

According to table 6, the accuracy of the forecast of 3DVAR on January 1 is worse than that of w/o DA.

However the forecasting accuracy of 3DVAR on January 19 and 25 is better than that of w/o DA. We found that as the forecasting period becomes short, the forecasting accuracy improves.

Forecast Day	4DVAR Jan.1	Jan.7	Jan.13	Jan.19	Jan.25	Observed
Shimane	NOT AVAILABLE	1.6	1.5	1.5	1.5	0.6
Tottori		21.5	3.9	3.8	3.8	
Hyogo		3.1	0.6	1.3	1.3	2.9
Kyoto		21.6	7.7	6.1	5.4	7.3
Fukui		41.3	40.0	45.0	47.8	37.3
Ishikawa		12.2	21.5	32.3	30.0	44.3
Niigata		0.2	24.0	9.9	10.0	7.6
other		0.1	2.3	1.7	1.8	
						(%)
RMSE		17.37	11.72	6.27	7.63	

Table 7 prediction of drifted oil (4DVAR)

According to table 7, there is little difference between the results of 4DVAR and 3DVAR. The forecast on January 1 was unable to be carried out because of an error.

4 Conclusions

In present paper, we investigated efficacy of data assimilation for forecasting the phenomena of oil drift on sea surface.

From the result of simulation 1, applying data assimilation to the simulation of spilled oil drifting is efficient. However, the area where most oil drifted ashore is the coastal area of Fukui prefecture in the simulation, but it is Ishikawa prefecture actually.

The results of 4DVAR are approximately equal to that of 3DVAR. This may be because enough numbers of observed values is not set to the assimilation window in 4DVAR.

From the result of simulation 2, in case of data assimilation, we found that as the forecasting period becomes short, the forecasting accuracy improves.

However, the accuracy of all forecast are not high enough. To improve the accuracy, we must test the grid dependency carefully and introduce data assimilation to ocean model.

In the future, this simulation will be performed with incorporating real time measured data obtained from SOTAB2. However, in this study, we use observed data which is distributed by NCEP. We have to examine the simulation with SOTAB's observed data.

Acknowledgements

I would like to express my deep appreciation to Mr. Y. Mukumoto for his kind help.

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