Chapter IV

Application of Hydrodynamic Model for Investigation of Oil Spill in the Sea

1. Theoretical of the oil spill trajectory model

When the oil is released on the sea surface, it will be caught by various physical, chemical, and biological processes. These processes will effect to oil properties such as evaporation, emulsification, dispersion, sinking, and biological degradation. Not only the changing in properties of oil is going on but also it will be transported as well. The physical forces concerned in transportation of oil come mainly from wind and current. However, if both oil properties changing and transportation of oil on the sea surface are included together in just one model, there will occur very much difficulty and get a long time in calculation. Thus, if only when and where the oil landing places or being transported are interesting, the properties of oil will not be included in the model. Moreover, calculation only the path of spilled oil on the sea is easier and saver the time. Such model is called the oil spill trajectory model.

The oil spill trajectory model is a numerical model to predict time and path of oil slick after spilling in the sea. The oil slick is considered as a piece of floating object that cannot spread or disperse. The basic concept of this model is that the motions of oil slick on the sea surface come from several forces, and it will move to the direction of the net force in that position and time.

Many contributors generating the oil drift that can be considered are: (Haung et al. 1989)

1) A current set up by the local wind (Ekman current)
2) Motion due to the wave propagation (Stokes drift)
3) Motion relative to the water caused by wind (Sailing effect)
4) Tidal currents
5) Permanent or semi-permanent current system on a large scale (Background current)
6) Any other more or less stochastic motion of the water.

Although, there may be a sailing effect of the oil assumed to be in the direction of the wind, its magnitude is not well known and assumed to be small.

And for stochastic motion, because it cannot be predicted systematically in the relation of parameters, this motion has to be cut off from the computational model. Thus, both sailing effect and stochastic motion are not included in the oil spill trajectory model.

The important forces included in the oil spill trajectory model and assumptions of the forces employed in the oil spill model that would be experimented which developed by Haung et al. (1989) are described as follow.

1) Ekman current

Ekman (1965) had solved the hydrodynamic equations considered the balancing between Coriolis acceleration and wind stress terms. He found that the effect of earth's rotation is accounted for the deflection of surface current at 45° to the right or left of the wind direction in the northern or southern hemisphere respectively. However, this theory is base on the assumption of infinitely deep water to avoid the bottom friction term. For the case of finite depth, the angle between wind and surface current direction is not 45°, but it depends on the depth of the sea and latitude. The formula to calculate this angle, α, is shown in equation (29).

$$\alpha = \tan^{-1}\left[\frac{\sinh\left(2\pi\frac{h}{d}\right)-\sin\left(2\pi\frac{h}{d}\right)}{\sinh\left(2\pi\frac{h}{d}\right)+\sin\left(2\pi\frac{h}{d}\right)}\right] \tag{29}$$

where

$d = \pi\sqrt{\frac{2A}{f}}$: Depth of frictional influence,

A : vertical eddy viscosity, h : water depth, ρ : water density,

f : Coriolis parameter ($=2\Omega\sin\phi$), Ω : angular rotation of earth,

ϕ : latitude.

In oil spill trajectory model, Ekman current is set equal to 1.3-1.4 % of the wind speed. The direction of the current depends on latitude. In area above 10° N and beneath 10° S, the current vector is deflected with a constant angle $\alpha_{10} = 33°$ to the right or left of the wind direction in northern or southern hemispheres respectively, while in area between 10° N and 10° S, the deflection angle (α) reduces linearly with latitude shown in equation (30).

$$\alpha = \alpha_{10} \frac{\varphi}{10} , \quad (30)$$

where α is latitude.

Equation (30) is used because the effect of the earth rotation near the equator will be reduced and becomes zero at the equator.

2) Stokes drift

Wave can generate current and mass transport in its direction. Such current generated from the motion of water particles that move in almost closed circle, resulting in a continuously increasing net particle displacement in the direction of wave propagation. However, in shallow water, the particle displacement becomes larger, because the water particles move in almost ellipse resulting from bottom friction. Although, Strokes drift is considered as a small speed (1-2 % of wind speed), it cannot be negligible in oil spill model. The mass transport velocity or Stokes drift for shallow sea can be calculated by equation (31).

$$U_S = \pi^2 \left(H/L\right)^2 C, \quad (31)$$

Where

U is velocity of oil drifted by wave, H/L is wave steepness,

and C is wave speed.

In oil spill trajectory model, this motion is set to be parallel to the wind with 1.7 % of wind magnitude.

3) Tidal current

Tidal current is considered not important in the open sea, because the net drift of water mass during a tidal cycle is very much small or zero if the completed tidal ellipse is occurred. But for shallow water, several effects such as the characteristic of sea bottom and shoreline, and Coriolis effect, will impact to the tidal ellipse that can not be occurred completely. This phenomenon will generate the net tidal drift larger than in the open sea. Thus, the tidal current are generally neglected in the oil drift model, when it is considered in the open sea, but for shallow sea, the tidal current becomes important and can not be removed from the calculation of oil slick on the sea surface.

4) Background current

In this study, background current means the very large current system that appears to be permanent or semi-permanent. Magnitude and direction of background current can not be calculated from the wind speed like Ekman current and Stokes drift. These are usually estimated by averaging over long time so as to remove the directly wind induced current and the tidal motion.

2. The operation and testing of the oil spill trajectory model

1) Model operation

In each operation of the oil spill trajectory model, background current, real-time measured wind, and the position and time of oil leaked, are read to compute the motion of the oil after spilling in the sea for every 3 hours.

The stored data of the background current derived by digitizing the available data as presented in "Oceanographic Features and Meteorological Phenomena of the East Asian Seas Region Relevant to Oil Pollution and Its Control", by Absornsuda Siripong are used. The data being available for 4 seasons only were interpolated to monthly value using yearly and half-yearly Fourier components. Furthermore, the data were interpolated from the available values for every degree latitude/longitude to grid point for 1/10 degree, and current vectors in grid point next to shore were adjusted to parallel along coast.

The oil spill trajectory model will read background current in the month that oil spill occurred from stored file. Because the whole of the operational area is from 9° S to 25° N and 99° E to 127° E, reading data from every grid point to calculate in oil spill model will spend so much time and use more computer memory in the process of calculation. To solve this problem, the oil spill model will read data only 101×101 grids around the center at the position that oil is spilled. The area of 101×101 grids is equal to 10×10 degrees in latitude and longitude which is widely enough to cover the area that oil slick can be moved. For the grid points defined as a land, the special data 999 will be read. Such data will be used to check in the computation whether the oil slick reaches a land or not.

The measured wind and the position of oil which it is spilled on the sea must be input by users by a small computer program. This wind data are used to calculate the Ekman current and Stokes drift in oil spill model. Then, Ekman and background current will be summed in vector form. However, if the component of these currents in north-south or east-west direction direct to the same sign, the stronger current will be selected as a component in that direction of the net current. The reason is that some parts of the Ekman current may be already be some parts of the background or residual current. Because this study area is located in the monsoon region, so the seasonal variations are considerable and will be represented in background current like Ekman current.

Then, the net current from Ekman and background current will be summed with Stokes drift. The new position of oil slick in the sea is calculated from this solution. The oil spill model will predict the position that the oil moving to for every 3 hours by using 6 hours measured wind data. This model still operating until the oil slick reaches a land or no input data are used.

2) Field experiment and model testing

The drift cards experiment was exercised near Ko Sichang at 6:00 on March 30, 1995. Approximately 200 pieces of laminated postcard were released at latitude 13°08' N and longitude 100°50' E. Wind speed and direction at the released time were measured. After that, the motion of drift cards on the sea surface were tracked down by fiber boat, and the positions of drift cards at every 3 hours after releasing were detected by Geographical Positioning System (GPS). The new wind data were measures in each time at the point where drift cards were detected, because it were used as input in the oil spill trajectory model. This field experiment finished at 15:00, because it is very hardly to trace the drift card for the next time-step (18:00). After all, the oil spill model would be run to predict the position of oil slick movement, and then the result of predicted and measured positions of spilled oil in the sea was compared and shown in table 4 and figure 81.

Table 4. Results from field experiment of oil slick movement on the sea surface and measured wind at Ko Sichang on March 30, 1995.

Time	Recorded Position		Computed Position		Measured wind	
	Latitude	Longitude	Latitude	Longitude	Speed (knot)	Direction (degree)
06:00	13° 08.0'	100° 50.0'	13° 08.0'	100° 50.0'	12	195
09:00	13° 07.0'	100° 49.0'	13° 09.0'	100° 50.0'	10	190
12:00	13° 07.5'	100° 49.3'	13° 10.0'	100° 50.0'	10	190
15:00	13° 09.5'	100° 50.0'	13° 11.0'	100° 50.0'	15	195

The result of the oil spill trajectory model prediction show that if the crude oil was leaked or spilled at the same position and time that drift cards were released, the oil slick would move to the north. But from measurement, the drift cards moved down to the southwest after releasing for 3 hours. Then, drift card moved up to the north, a little to the east. And finally, at 15:00, the measured and computed positions of drift cards were quite near as shown in figure 81.

The oil spill trajectory model was run again, but in this time the tidal current data from hydrodynamic model were included in computation. To see the tidal current at the time when drift cards were released, the current vector field every 3 hours from 6:00 to 15:00 on March 30, 1995 were shown in figure 82 to 85. The result of model prediction and measured positions were plotted and shown in figure 86. From computation, it clearly shows that after releasing drift cards for 3 hours, it will move down to the south near measured position, and still stop at this position until 12:00. After that, it will move to the north where the measured and computed positions are nearer.

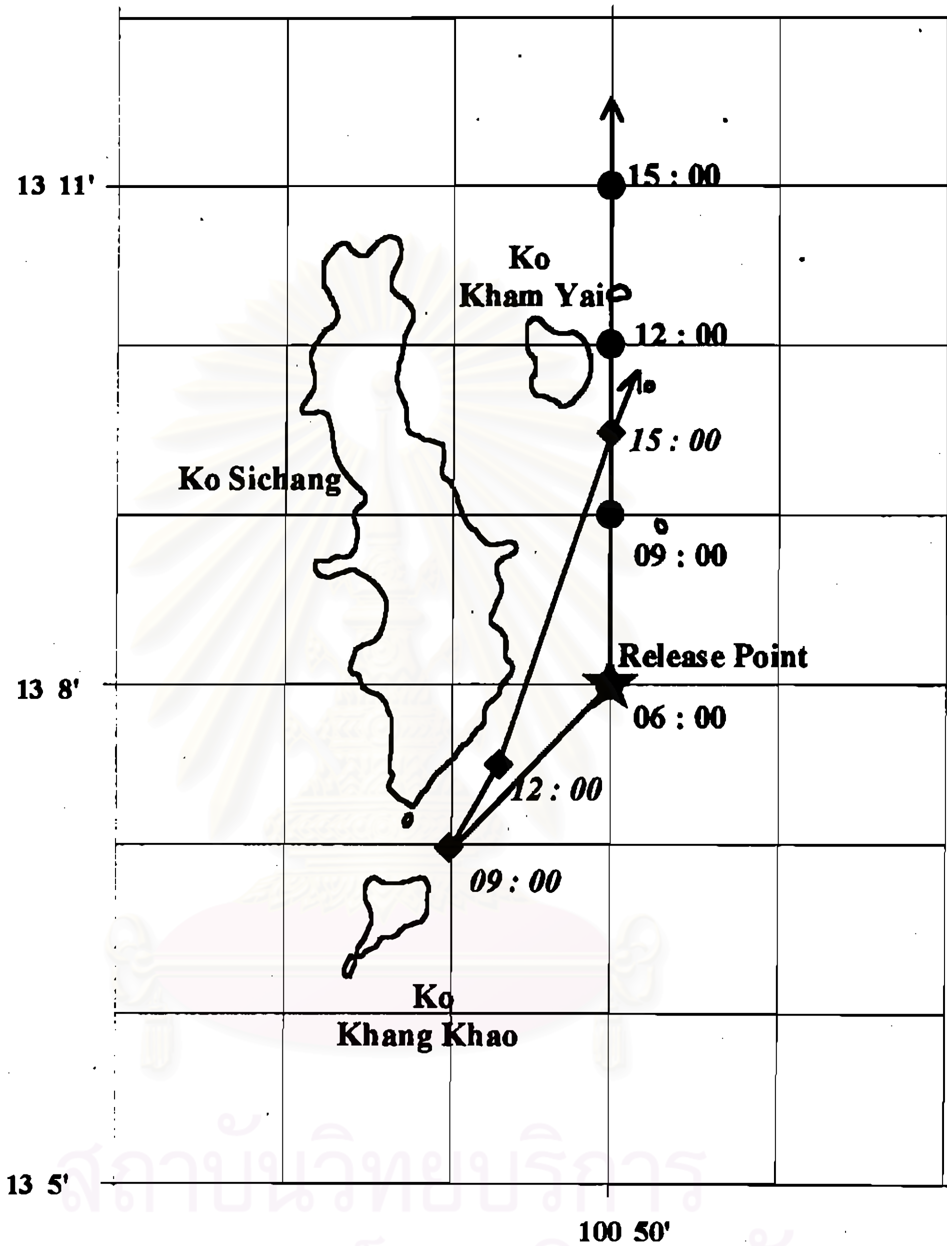

Figure 81. Computed (Solid circle) and recorded (Solid square) positions of drift cards on March 30, 1995

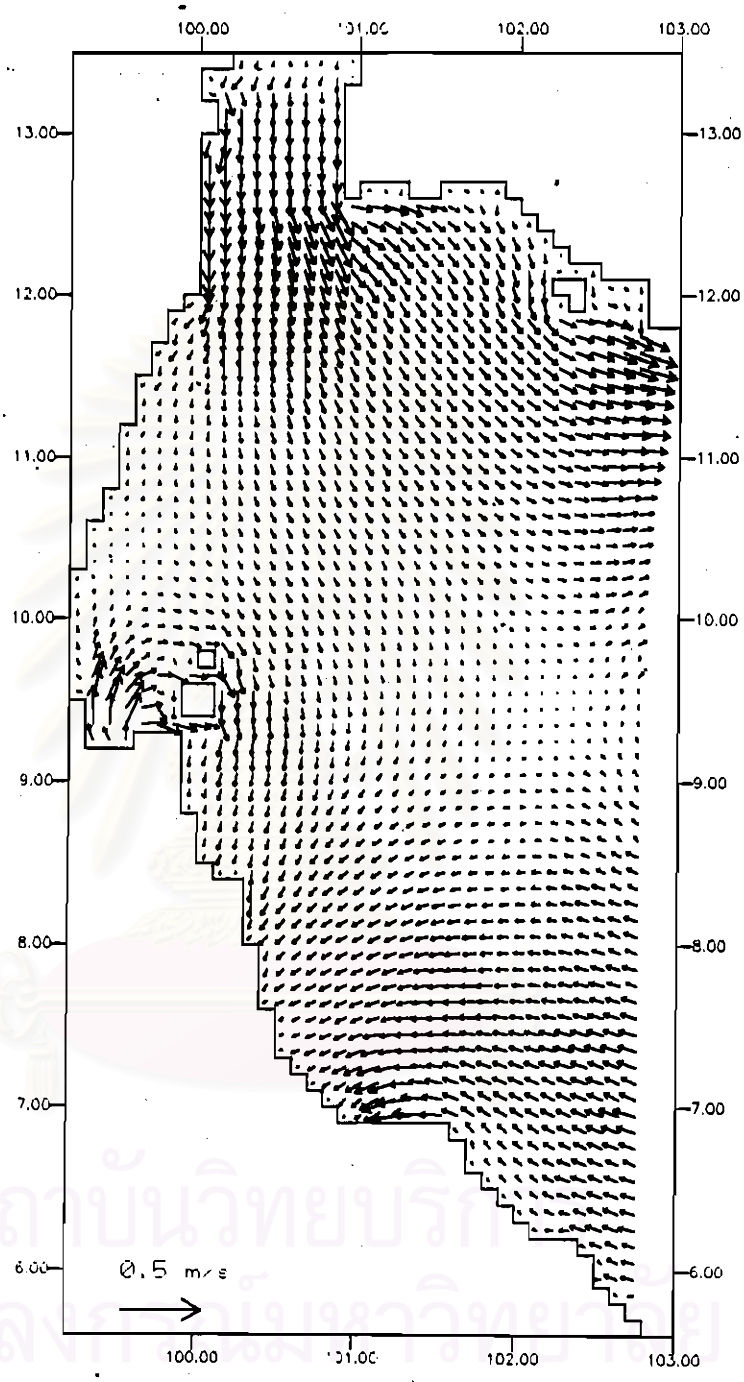

Figure 82. Tidal current vector field at 6:00 on March 30, 1995

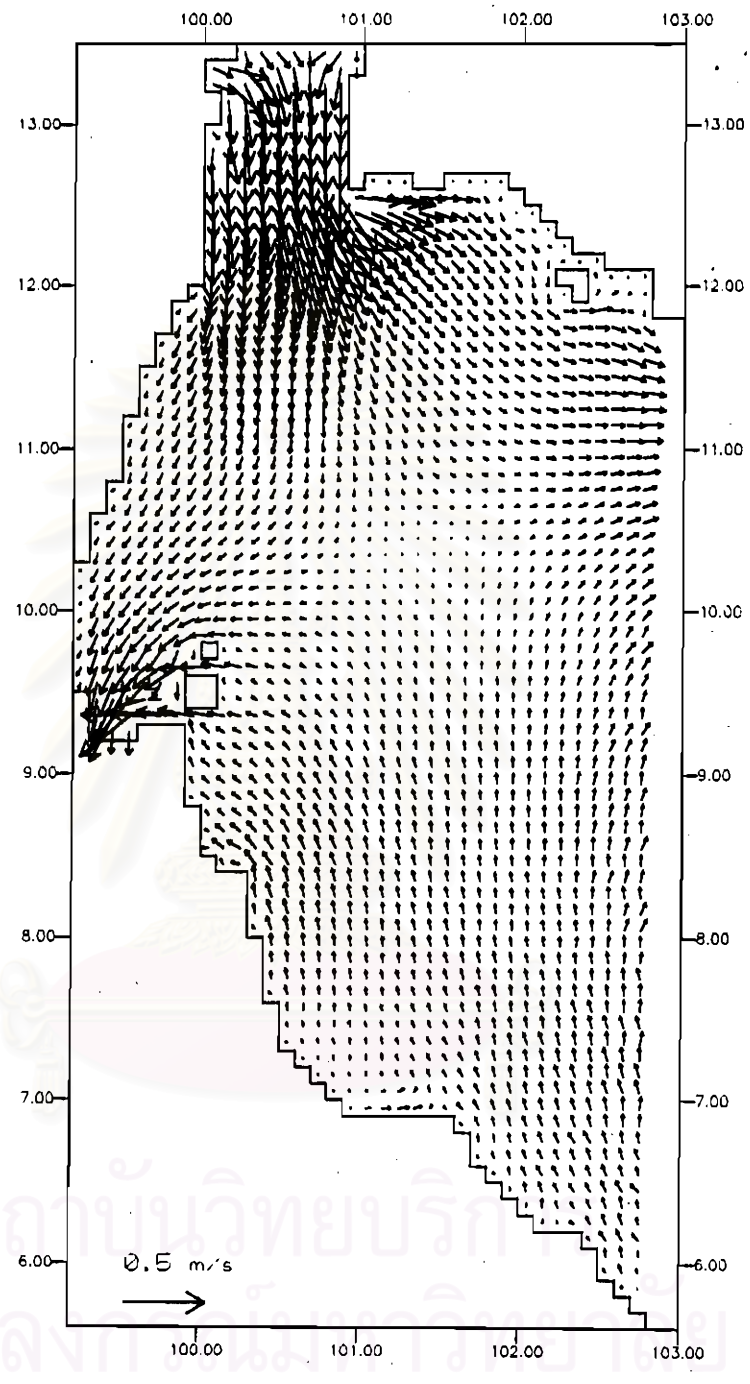

Figure 83. Tidal current vector field at 9:00 on March 30, 1995

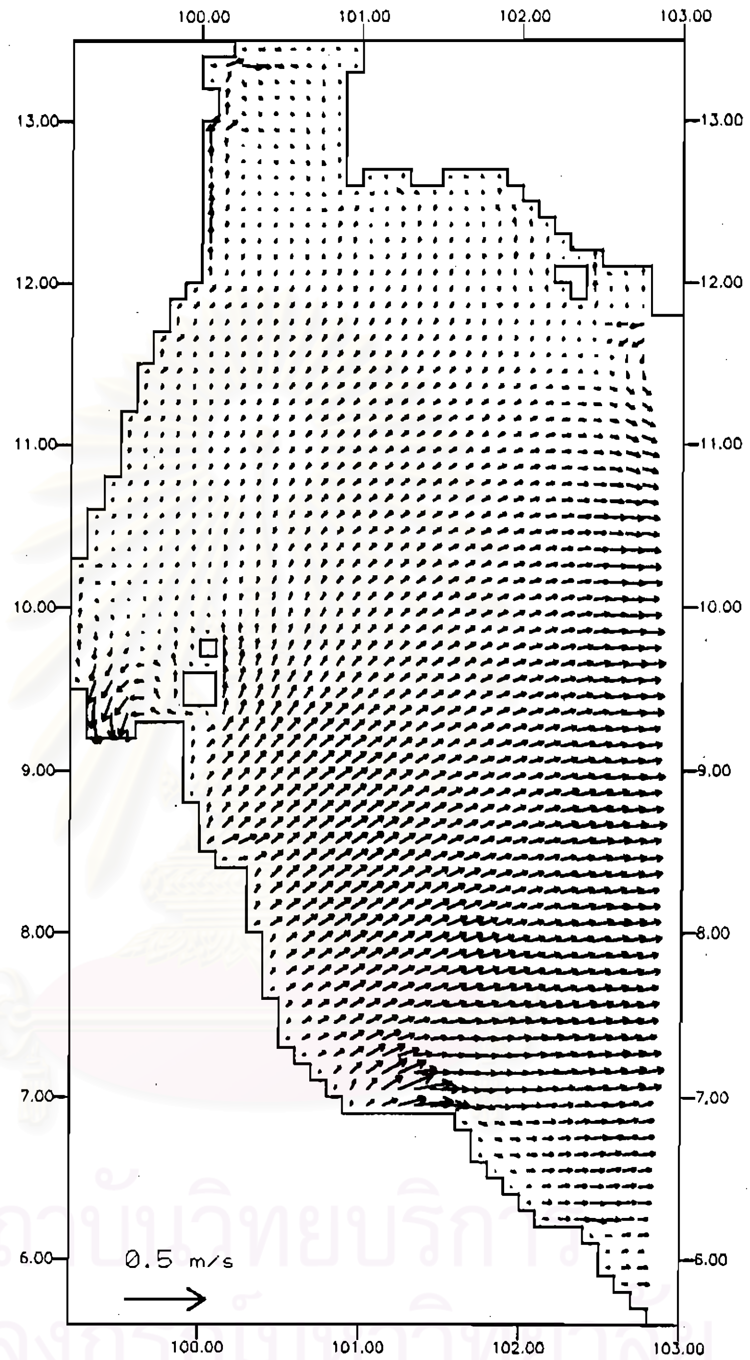

Figure 84. Tidal current vector field at 12:00 on March 30, 1995

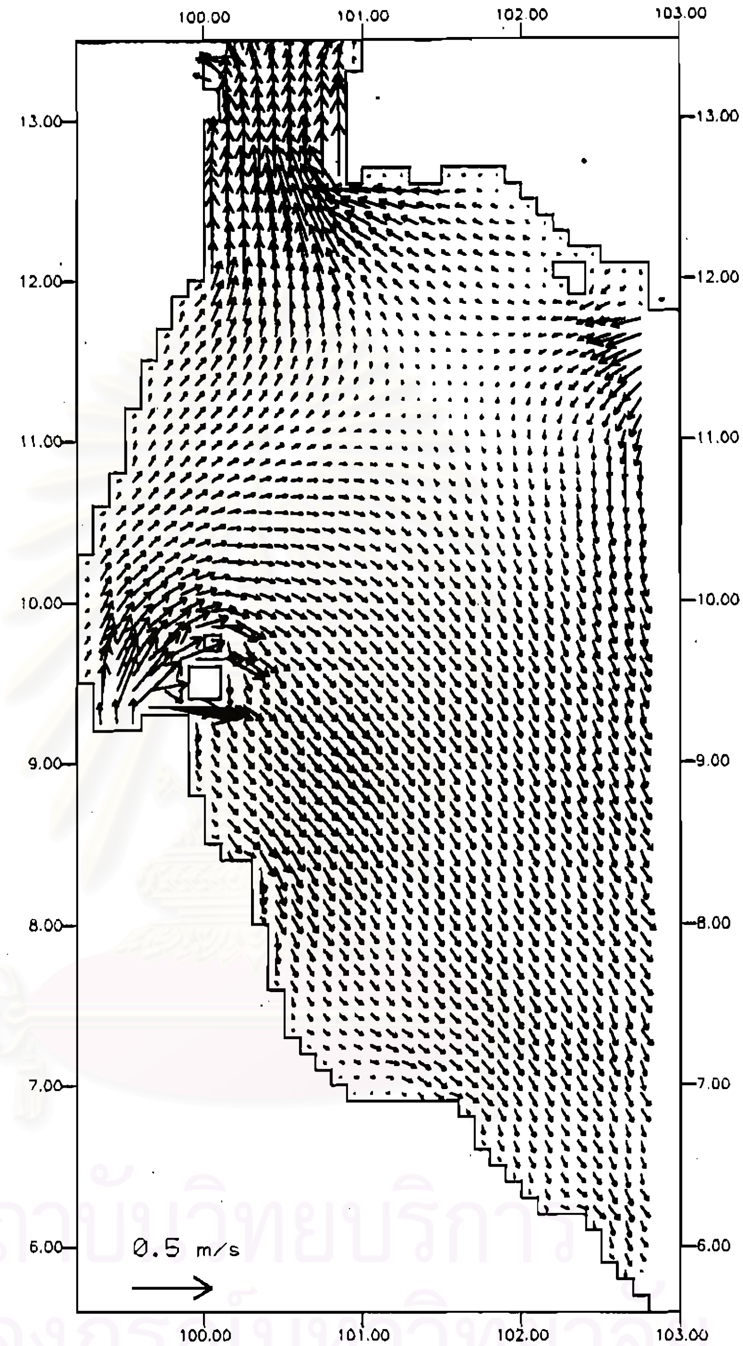

Figure 85. Tidal current vector field at 15:00 on March 30, 1995

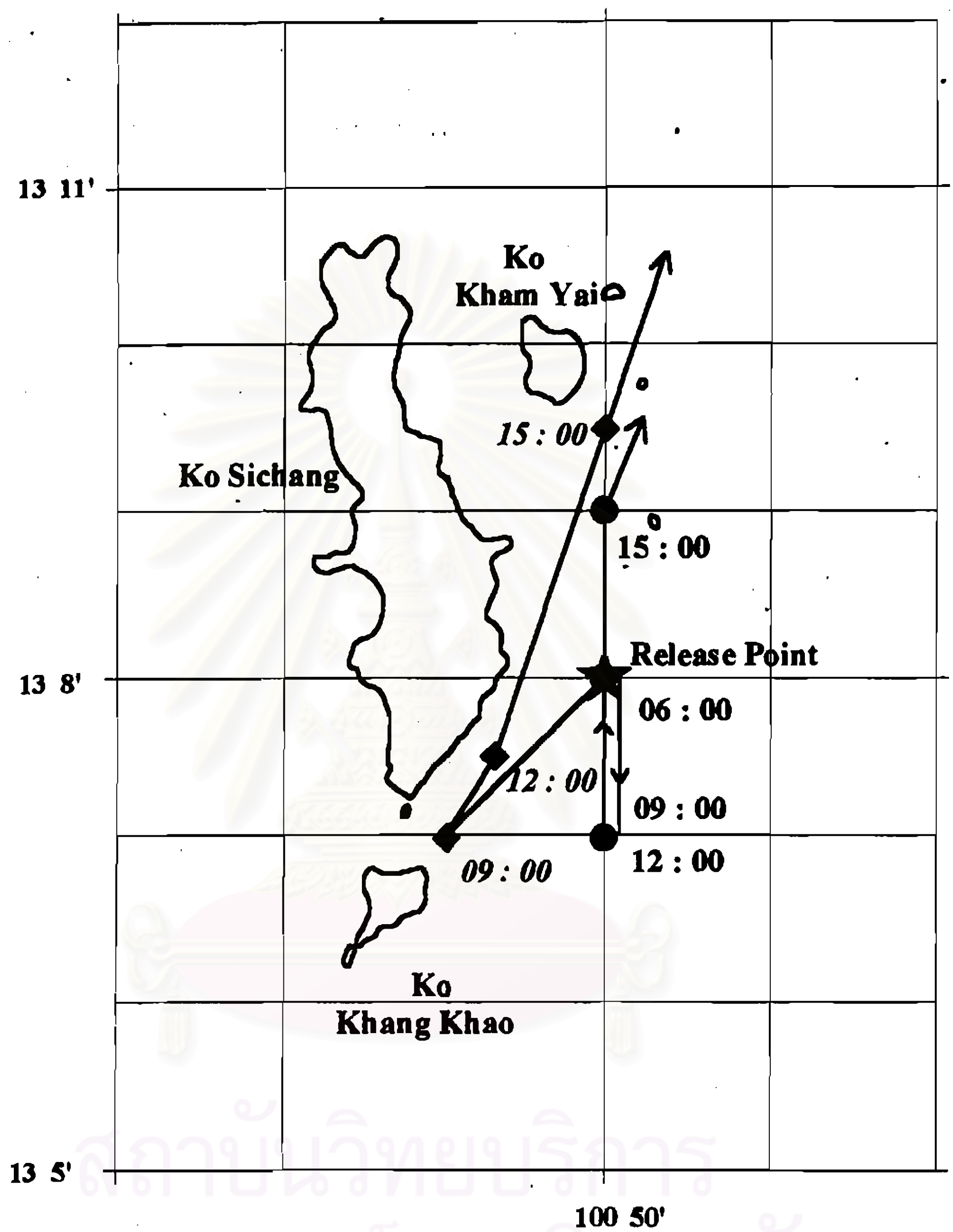

Figure 86. Computed (Solid circle) and recorded (Solid square) positions of drift cards on March 30, 1995, after including tidal current data in computation.