THREE-DIMENSIONALSIMULATION OF TIDAL CURRENT IN LAMPUNGBAY: DIAGNOSTIC NUMERICAL EXPERLMENTS

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FAbstract

Princeion Ocean Model (POM) was used lo calculate the tidal current in Lampung Bay using diagnostic mode. The model was forced by tidal elevation, which was given along d* open boundary using a global ocean tide model-ORITIDE. The computed tidal efcvation at St. 1 and St. 2 are in a good agreement with the observed data, but the cempuled tidal current at St.I at depth 2 m is not good and moderate approximation is showed at depth 10 m. Probably, it was influenced by non-linicr effect of coastal geometry and bottom friction because of the position of current meter, mooring closed to the coasihne.

Generally, the calculated tidal currents in all layers show that the water flows into the bay during flood tide and goes out from the bay during ebb tide. The tidal current becomes strong when passing through the narrow passage of Pahawang Strait. The simulation of residual tidal current with particular emphasis on predominant constituent of M2 shows a strong inflow from the western part of the bay mouth, up to the central part of the bay, then ite strong residual current deflects to the southeast and flows out from the eastern part of the bay mouth. This flow pattern is apparent in the upper and lower layer. The other part flows to the bay head and forms an anticlockwise circulation in the "small basin' region of the bay bead. The anticlockwise circulations are showed in the upper layer and disappear Bithe layer near the bottom.

Kenvnb: POM, diagnostic mode, tidal current, residual current, Lampung Ba.

I. Introduction

Lampung Bay is a part of Sunda Strait, bcated at the southern part of Sumatra Isbnd, Indonesia (Figure 1). Lampung Bay has a shallow water depth, where the deepest part is less than 60 m, so that, seawater of this area Is vertically well mixed. The mean ctepth, bay length and width of the bay mouth are 25 m, 40 km and 49 km, respectively. Although there are 6 rivers flowing into the bay, Lampung Bay receives less freshwater due to the smaher rivers in the area (total mean discharge around 22.2 m3/s, Damar, 2003). Generally, Lampung Bay water is nfluenced by Sunda Strait water which is mostly coming from the Java Sea water, described in detail by Wyrtki (1961), and Birowo and Uktolscja (1981). Hendiartier *al.* (2002) investigated that during the southeast monsoon, Lampung Bay water is highly influenced by water masses from the Java Sea, characterized by high nutrient and chlorophyll-a. Meanwhile, during the northwest monsoon, Lampung Bay water is influenced by water masses from the Indian Ocean, which are relatively tow in nutrients and chlorophyll-a. Koropitan (2003) used the numerical area modeling and found that the ocean source (Sunda Strait) is an important supply of material to the region of Lampung Bay. Pariwono

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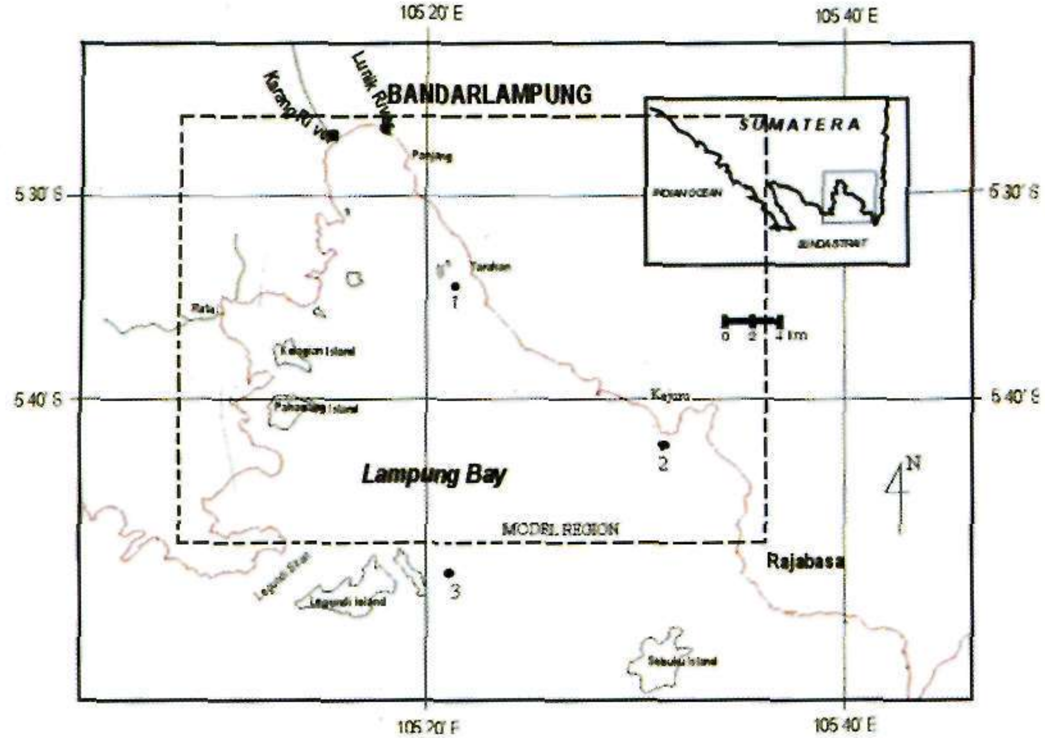

Figure 1. Model region (dot line) and observation stations in Lampung Bay.
(Source of base map: Damar, 2003)

(1985) reported that the tidal pattern in Lampung Bay is influenced by the Indian Ocean, resulting mixed tidal type with domination of semidiurnal constituents. Thus, as a part of Sunda Strait, Lampung Bay has a unique character and its ecosystem has to be managed precisely by Sunda Strait and Indian Ocean

Until now, many researchers have studied on the oceanic condition of Lampung Bay. Ecosystem studies, based on field observation and numerical modeling, have been done by Damar (2003) and Koropitan (2003), respectively. Mihardja *et al.* (1995) have carried out research on several aspects, i.e. meteorology, tidal, current observation and modeling of flow pattern and surface temperature distribution, waves and sediment transport estimation. Koropitan (2002) has also simulated the flow pattern in Lampung Bay. There were also several expeditions to collect oceanographic data in Lampung Bay which were done by several institutions from Indonesia and abroad. However, the previous studies were only on the general characteristics of oceanic conditions and the flow pattern simulations were restricted on two-dimensional circulation using depth-averaged approximation. There is no specific study on the three-dimensional simulation of water circulation in Lampung Bay.

It is well known that the tidal streams are generally weak and merely strengthen or reduce the currents due to the wind effect in open water. In coastal areas, off the mouth of rivers and in comparatively narrow passages, such as in the strait between the islands; the tidal streams are of considerable importance. In Lampung Bay, Mihardja *et al.* (1995) have reported that the non-tidal current contribution is distinctly same magnitude as the tidal current itself, having period of 2 to 3 days. Probably it might be the result of sea level resonance due to Lampung Bay coastal morphology. In this study, we try to simulate the three-dimensional circulation of Lampung Bay, restricted on the tide-induced current. Furthermore, we would like to calculate the residual current with particular emphasis on predominant constituent of M2. The three-dimensional model is Princeton Ocean Model (POM) and using diagnostic mode.

II. Numerical Model

a. POM Description

The Princeton ocean model was described in detail by Blumberg and Mellor (1987). It has been applied to coastal and estuarine bodies of water (Blumberg and Mellor, 1983), the Gulf Stream (Mellor and Ezer, 1991), and many other oceanic regions. A description of the model code can be found in Mellor (1998). It is a primitive equation model with a free surface, a split mode time step, and solves the equations for the ocean velocity component (u, v, w), potential temperature, and salinity. The vertical mixing is calculated using the Mellor and Yamada (1982) turbulence closure scheme, whereas the horizontal diffusion is calculated using a Smagorinsky horizontal diffusion formulation. The density calculation is based on the UNESCO equation of state. We ignore the Coriolis effect because of the lateral dimension of Lampung Bay (= 50000 m) is less than the Rossby Deformation Radius (A=54532768.4 m) (Pond and Pickard, 1985).

b. The Model Grid

The model uses a bottom-following, sigma-coordinate system. In this study, the model has 6 vertical sigma levels (0.0,-

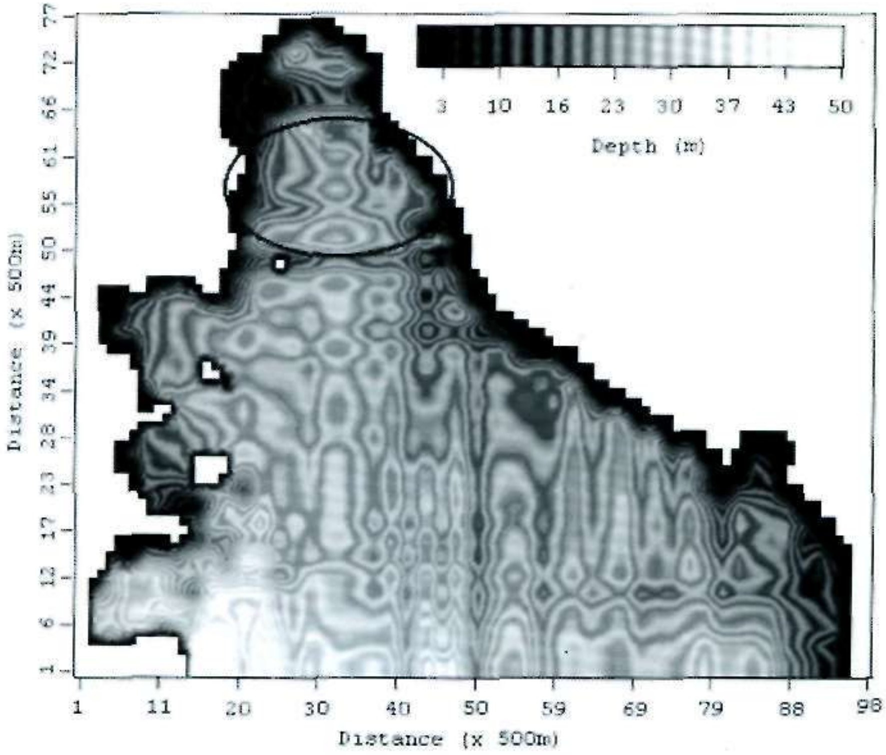

Figure 2. Bathymetric map of Lampung Bay and small basin in the bay head (ellips)

0.2,-0.40,-0.6,-0.8,-1.0). The horizontal grid is in the Cartesian coordinate system (Figure 2) and contains 98 x 77 grid points. The grid resolution is 500 m x 500 m. The external and internal time steps arc 3 seconds and 90 seconds, respectively, based on *Courani-Friedrichs-Levy* (CFL) stability.

C. Bathymetric and initial conditions

The bathymetric map was obtained from the Hydro-Oceanography Division, Indonesian-Navy (DISHIDROS TNI AL); bathymetric map no. 94 march, 1983 version. At the center of each grid cell, the water depth was read from the map to produce the bathymetric model (Figure 2). The bathymetric map shows that the water depth make shallower gradually from the bay mouth to the central part of the bay. There is a 'small basin' in the southern part of the bay head (circle) where the water depth forms a valley and rises again near the northern part of the bay head.

The model was initialized with only one observation point of CTD data, collected by the Faculty of Fisheries, Bogor Agricultural University (unpubl. data, 1996) at St.3, during Sebesi Expedition. The data were applied to the all ocean grid cell.

d. Boundary conditions

In lateral boundary conditions, zero flow normal was applied to solid boundaries, while along open boundary the Orlanski's radiation condition was applied for currents. Tidal elevation was given along open boundary using a tide global model-ORrriDE. We ignored the influenced of freshwater because of the smaller rivers. In bottom boundary condition, a quadratic equation was applied using an ordinary bottom-drag coefficient formulation (Mellor, 1998). We assumed that there was no salt flux and heat flux in the upper boundary conditions.

e. Residual Current

The tide-induced residual current is defined as the flow which is caused by the non-linearity of tidal current in relation to horizontal boundary geometry and bottom topography. Birowo and Uktolseja (1981) reported that the constituent of M2 has the highest amplitude in Lampung Bay based on admiralty method for 1 year observations, taken from "Zeemansgids voor Indonesia" Deel I at the bay head (05° 27" S - 105° 15 E). Mihardja *et at.* (1995) also found that the constituent of M2 has the highest amplitude in Lampung Bay, based on least-square method for 1 month observation at Tarahan. In this study, we have applied a velocity averaged over the M2 period to the residual current (M2-residual current).

III. RESULTS AND DISCUSSION

Firstly we calculate the tidal current forced by tidal elevation with 8 predominant (Ql, Ol, PI, Kl, N2, M2, S2, K2) constituents in Lampung Bay. The calculated tidal currents in the upper layer are shown in Figure 3. Generally, the calculated tidal currents in **all** layer show that the water column flows into the bay through flood tide and outflows from the bay through ebb tide. The tidal current becomes strong when passing through the narrow passage of Pahawang Strait.

In order to verify our calculated results, the comparison of calculated and observed tidal current is very important. The calculated and observed data arc shown in Figure 4. The current measurement was carried out at 2 m and 10 m below the sea surface at St, I during 26 March - 25 April 1988 (Mihardja *et aL,* 1995). The observation of tidal elevation was carried out at St. 1 during 26 March - 25 April 1988 (Mihardja *et* a/., 1995) and St.2 during 6 March - 3 April 1999 (DISHIDROS TNI AL, unpubl. data, 1999). The calculated tidal elevation at St. I and St. 2 arc in a good agreement with

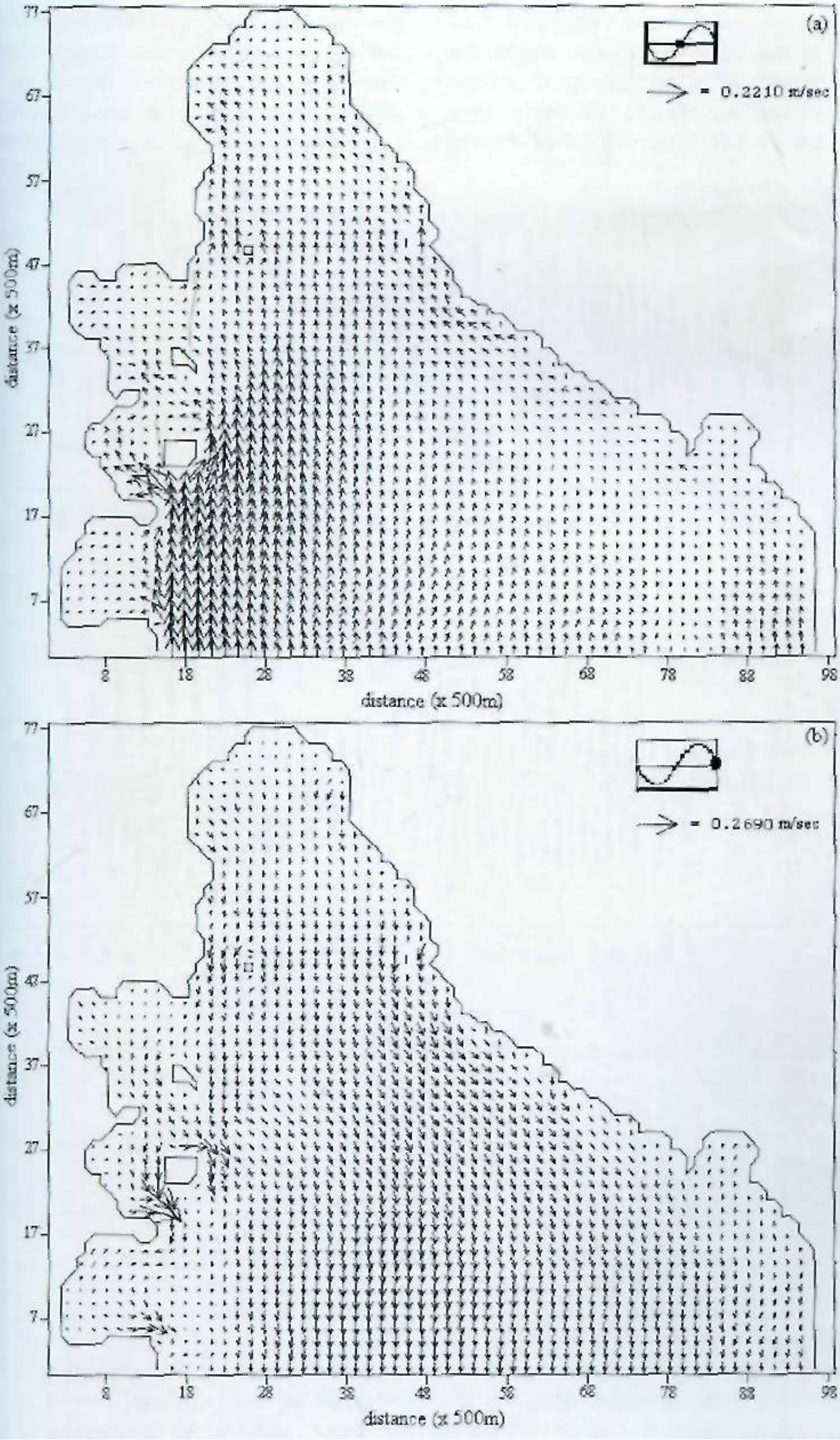

Figure 3. The calculated tidal current in the upper layer during (a) flood tide and (b) ebb tide

the observed data, but the calculated tidal current is not so good at 2 m below the surface water and moderately good at 10 m below the surface water. Probably, it is influenced by non-linier effect of coastal geometry and bottom friction because of the position of current meter mooring closed to the coastline. So, it is very difficult to simulate the current condition along the coastline using grid resolution of

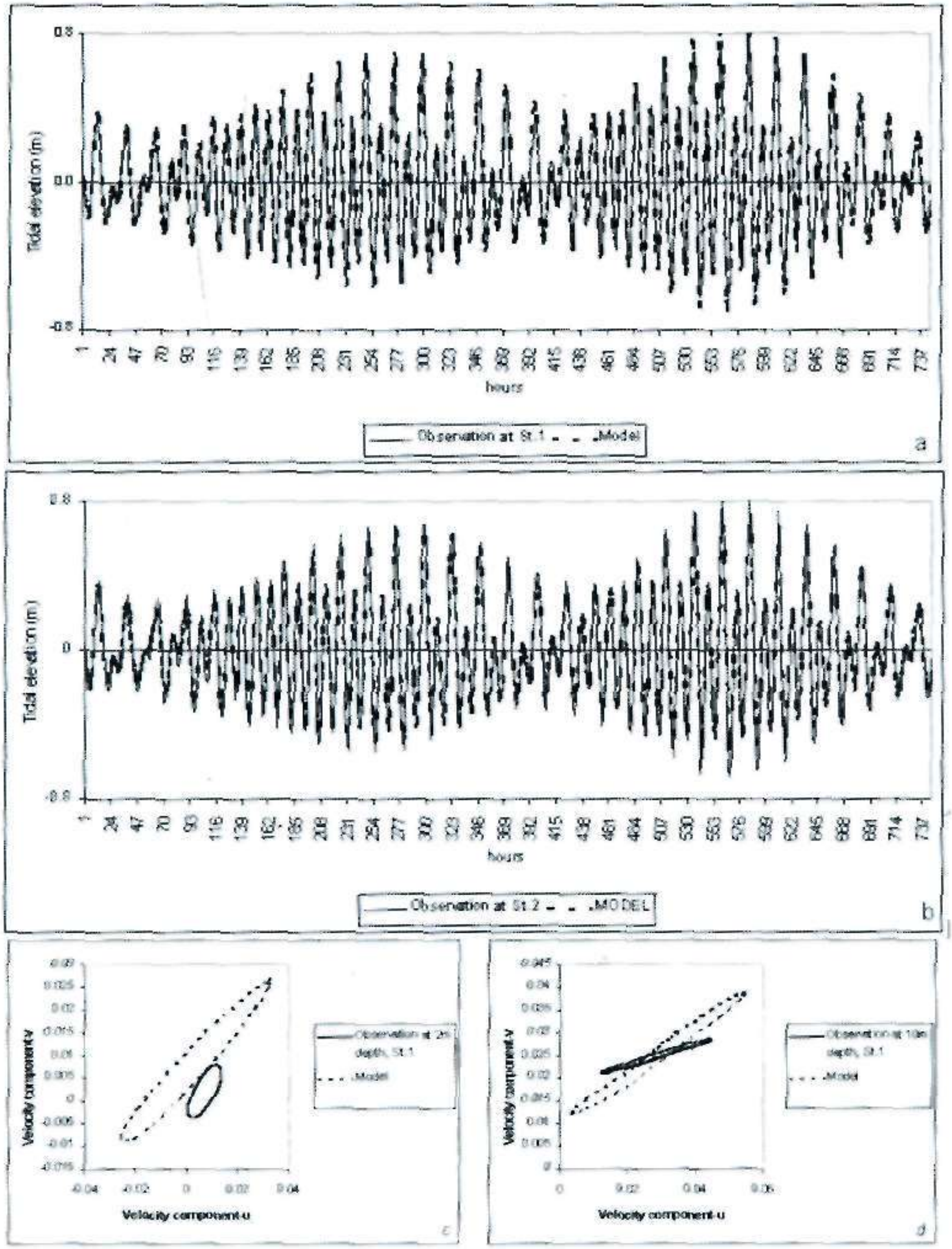

Figure 4. The comparison of model results and observation; (a) tidal elevation at St.l, (b) tidal elevation St.2, (c) the hodograph of tidal current, forced by M2 constituent at 2 m below the surface water, and (d) the hodograph of tidal current, forced by M2 constituent at 10 m below the surface water.

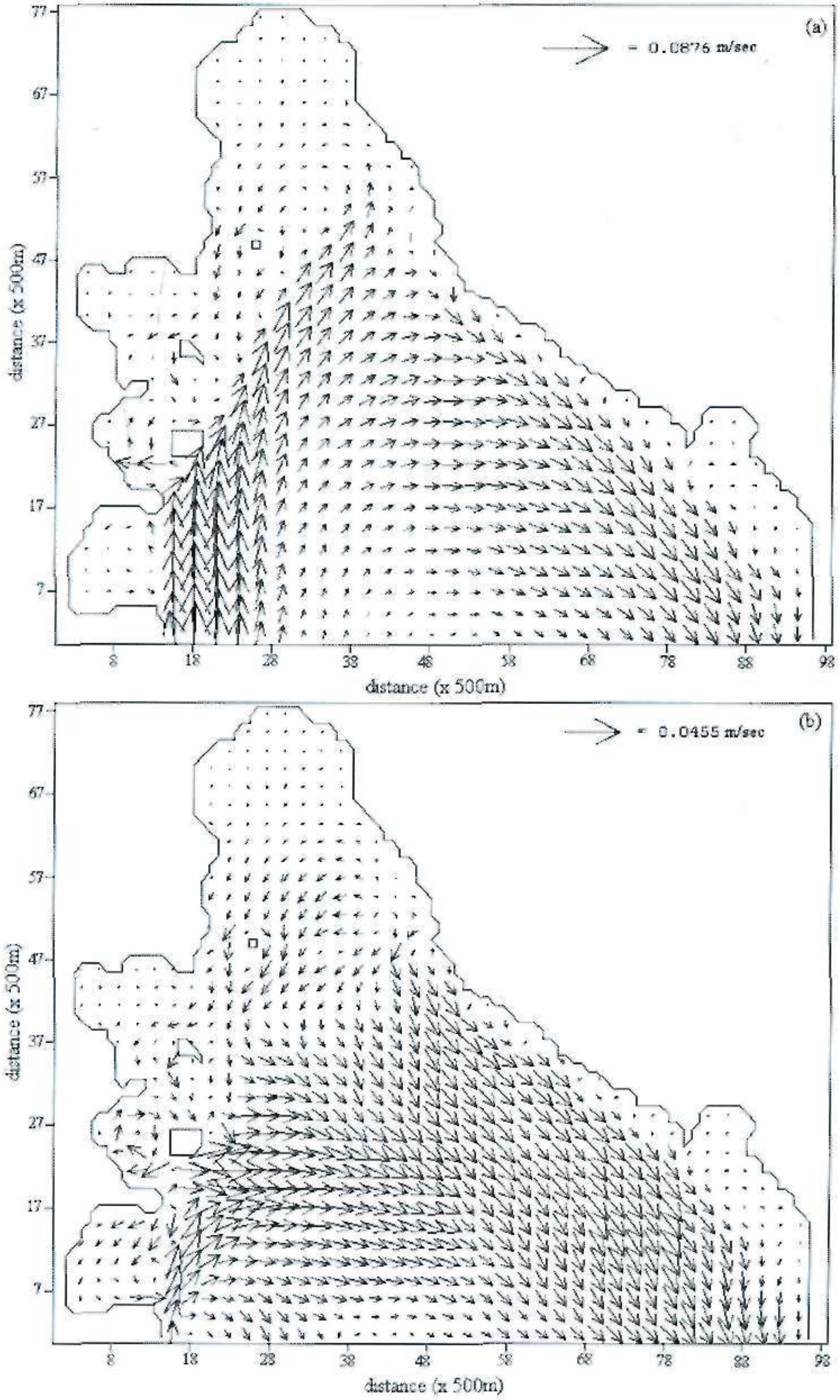

Figure 5. The calculated M2-residual current in (a) the upper layer and (b) the layer near the bottom

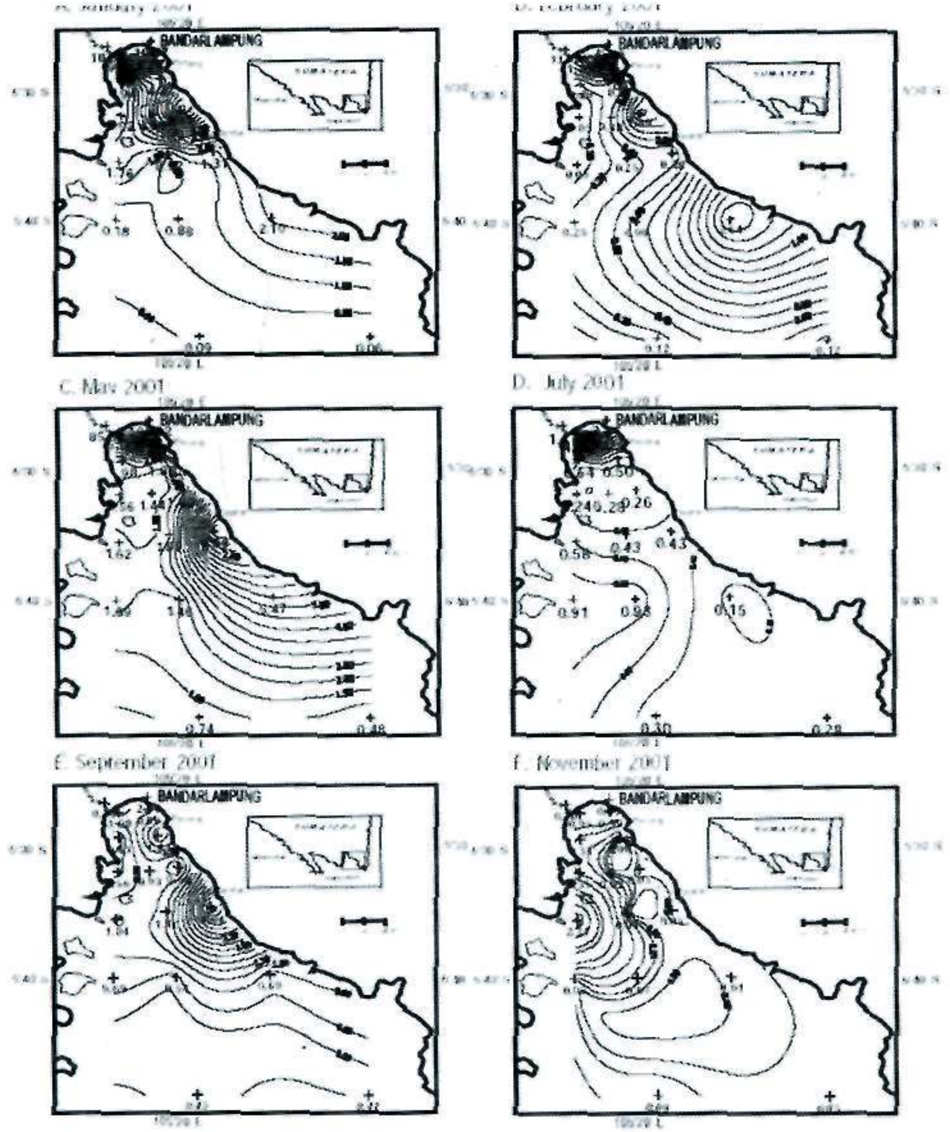

Figure 6. The observed dissolved inorganic nitrate (DIN) in the upper layer during January-November 2001 (Damar, 2003)

500 m x 500 m

The calculated M2-residual current is shown in Figure 5. There is a strong inflow from the western part of the bay mouth, until the central part of the bay, and then the current deflects to the southeast and flows out from the eastern part of the bay mouth. This flow pattern is apparent in the upper and lower layer. The other part flows to the bay head and forms an anticlockwise circulation in the 'small basin' region of the bay head. The anticlockwise circulations are appeared in the upper layer and disappear in the layer near bottom. The calculated residual current becomes smaller near the bay head. Probably, the anticlockwise circulation in the 'small basin' region of the bay head is influenced by residual vorticity component of the tidal stress and the bottom frictions. The explanation of the vorticity of tide-induced residual current is described in detail in Pond and Pickard (1985) and Yanagi (1999). When the tidal current reaches the bay head, the energy of tidal current reduced resulting in the smaller residual current.

The M2 residual current is very stable throughout the year because the tidal current is also stable. The flow pattern of M2 residual current has an important role in the material transport during a long period. The observed dissolved inorganic nitrate (DIN) in the upper layer was carried out by Damar (2003) during January - November 2001 (Figure 6). The distribution pattern of DIN is strongly related to the flow pattern of M2-residual current in the whole observation of the year. It is also shown an intensification of DIN concentrations in the bay head due to riverine inputs. The anticlockwise circulation occurred in the basin region of the head bay and the smaller residual current occurred in the head bay. Therefore, the intensification of DIN concentrations will be distributed gradually to the outer part of the bay head. We have calculated that the flushing time in Lampung Bay is 15 days, so it takes a half-month to distribute the material from riverine inputs. It is different with the other sources of nutrients scattered along the eastern part of the bay's coastline, such as shrimp pond and rice field culture activities, (Damar, 2003), where the DIN concentrations will be distributed rapidly to the eastern part of the bay mouth. However, the influence of water masses coming from the Sunda Strait might occur. Related to the M2 residual current, there is a material transport (included DIN) which inflows to the Lampung Bay from Sunda Strait.

Conclusion

The tidal currents and residual currents are calculated by POM using diagnostic mode and the calculated results reproduce the main characters of the 3-dimensional current system. The calculated tidal elevation at St. 1 and St. 2 are in a good agreement with the observed data, but the calculated tidal current is not so good at depth 2 m and moderately good at depth 10 m. The tidal current and residual current is very stable throughout the year and the flow pattern of M2 residual current has an important role in the material transport in Lampung Bay.

Future Works

The model described in this paper is the first attempt to simulate the 3-dimensional tidal current in Lampung Bay by using diagnostic mode of POM. We do not think that this model is complete enough to make many robust conclusions. We need more CTD observation points in Lampung Bay.

In further step, we will use a coupled POM and 3-dimensional ecosystem model in Lampung Bay to analyze the role of the nutrients from different sources, the material flux and the ecosystem structure. After that, we would like to extend the model region for Sunda Strait.

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