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Study on the Seawater Surface Elevation through Numerical Modeling Approach in Gulf of Manado

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Abstract. This paper presents the seawater surface elevation in Gulf of Manado with numerical approach. The RANS shallow water flow equation is used to obtain a numerical equation of seawater surface elevation with a semi-implicit approximation approach in which the pressure distribution in the vertical layer of seawater is assumed hydrostatic. The results found that the high seawater level is not more than 1.81 m upper seawater level and 1.30 m under seawater level respectively. The results can be used as a recommendation to predict the condition of sea waves in the Gulf of Manado.

1. Introduction

The horizontal and vertical motion of seawater occurs caused by the wind stress at the sea surface. If surface seawater is a divergence, water at the bottom will rise to surface and this situation will be happened upwelling; conversely, where it is a convergence and will happened downwelling. For condition where a system of cyclonic wind on surface seawaters where the average movement of the wind-driven layer is to the right of the wind which causing divergence of surface water and upwelling, and the sea-surface is lowered and the thermocline is raised, it is called Ekman pumping. In condition inverse correspond in anticyclone wind is convergence and sinking (downwelling), it causes the sea-surface to slope upwards the middle of the gyre [1]. It will produce a sea wave called seawater surface elevation. Transport at the position of Gulf of Manado is convergence.

A numerical modeling can predict seawater surface elevation. It conducted by [2-5] in the Straits of Bunaken and Bangka, North Sulawesi, Indonesia. The simulation seawater surface elevation from shallow water flows with a free surface correction method [6]. The distribution of seawater surface elevation with respect to a reference level (m) by study on modeling shallow water wakes using a hybrid turbulence model [7]. Calculating of seawater surface elevation by using the semi-lagrangian method and they compute the non-linear response of the full model due to a shear stress that comes from the action of the wind at the ocean surface [8]. Simulated seawater surface elevation in the variations of typical seasonal corresponding to the period 1956-1960 from the surface wind stress in the Aral Sea [9]. Also, Implemented fully-implicit time integration schemes in a version of parallel ocean program for calculation of seawater surface elevation by its simulation in the North Atlantic [10].

The objective of this study was to get distribution of seawater surface elevation by using numerical modeling in the Gulf of Manado, North Sulawesi, Indonesia.

2. The free surface navier-stokes equations

The conservation of energy equation, which would express the variations in temperature, particularly taking into account dissipation by friction, will be put aside and temperature will later appear as a tracer solely responsible for the effects of buoyancy. Let ρ be the density of the fluid, and the velocity vector, whose components are U, V, W. Conservative of the fluid mass contained in a domain is expressed as [11]

$$\frac{d}{dt}\left(\int_{\Omega}\rho d\Omega\right)=0 \qquad (1)$$

where Ω is the domain of study (see figure 1) and t is time.
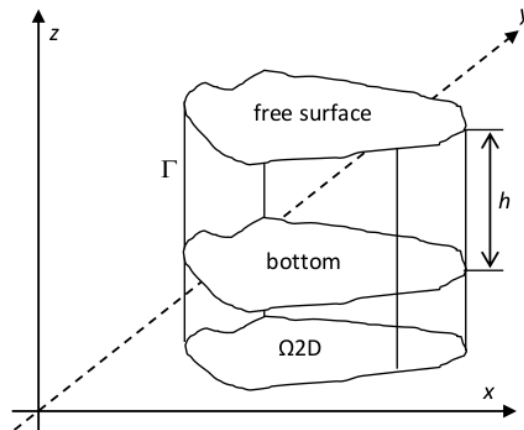

Figure 1. Modelling domain

If we assume hydrostatic pressure, and by using the decomposition of preceding Reynolds, the realized average Navier-Stokes equations are written [11, 12]:

Continuity equation

$$\frac{\partial \overline{u}}{\partial x}+\frac{\partial \overline{v}}{\partial y}+\frac{\partial \overline{w}}{\partial z}=0 \qquad (2)$$

Momentum equation

$$\frac{\partial \overline{u}}{\partial t}+\overline{u}\frac{\partial \overline{u}}{\partial x}+\overline{v}\frac{\partial \overline{u}}{\partial y}+\overline{w}\frac{\partial \overline{u}}{\partial z}=-g\frac{\partial \eta}{\partial x}+div\left(v_{eff}\,\overrightarrow{grad}\,(\overline{u})\right)+f_{cor}\overline{v} \qquad (3)$$

$$\frac{\partial \overline{v}}{\partial t}+\overline{u}\frac{\partial \overline{v}}{\partial x}+\overline{v}\frac{\partial \overline{v}}{\partial y}+\overline{w}\frac{\partial \overline{v}}{\partial z}=-g\frac{\partial \eta}{\partial y}+div\left(v_{eff}\,\overrightarrow{grad}\,(\overline{v})\right)-f_{cor}\overline{u} \qquad (4)$$

Free surface equation

$$\frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}\left(\int_{-h}^{\eta}\overline{u}dz\right)+\frac{\partial}{\partial y}\left(\int_{-h}^{\eta}\overline{v}dz\right)=0 \qquad (5)$$

where v_{eff} is an effective diffusion taking of account turbulent viscosity and dispersion, $v_{eff}=v+v_t$.

This effective diffusion is given by means of a model of turbulence adapted to the problem considers. Conservative of the fluid mass becomes Realized Average Navier-Stokes (RANS) shallow water flow equations (as in equations (2) to (5)) which were as a basic for the computation of numerical modeling.

3. Numerical modeling approach

The numerical modeling equations used diffusion step [11] with a general semi-implicit discretization of the momentum equations in equations (3) and (4) to get the velocities while the seawater surface elevation used equation (5). The velocities in x, y, and z directions, we can write in the more compact matrix form as in [2-5]. For determine the seawater surface elevation (as in equation (5)) in form numerical modeling, we can be written in the matrix notation form [2, 3]

$$\eta_{i,j}^{n+1} = \eta_{i,j}^n - \frac{\Delta t}{\Delta x}\left[\left(\Delta \mathbf{Z}_{i+1/2,j}\right)^{\mathbf{T}}\mathbf{U}_{i+1/2,j}^{n+1} - \left(\Delta \mathbf{Z}_{i-1/2,j}\right)^{\mathbf{T}}\mathbf{U}_{i-1/2,j}^{n+1}\right]$$
$$- \frac{\Delta t}{\Delta y}\left[\left(\Delta \mathbf{Z}_{i,j+1/2}\right)^{\mathbf{T}}\mathbf{V}_{i,j+1/2}^{n+1} - \left(\Delta \mathbf{Z}_{i,j-1/2}\right)^{\mathbf{T}}\mathbf{V}_{i,j-1/2}^{n+1}\right]$$

(6)

4. Methods

The Gulf of Manado is located between the Pacific Ocean and the Sulawesi Sea (Celebes Sea) whose area is approximately 300 km² (Figure 2), with an average width about 2.2 km and down to 79 meters deep (figure 3).

   The three-dimension current circulation in the Gulf of Manado is simulated using the present model with a 174 x 318 finite difference mesh of equal $\Delta x = \Delta y = 7$ m. The numerical solutions have been achieved using four vertical layers and an integration time $\Delta t = 0.4$ sec, and inlet volume transports at sections Singkil river, North, and South of Manado bay (figures 2 and 3) are 0.1 Sv (100000 m³/s). In addition, there are two of the current circulations in the Gulf of Manado i.e. low tide currents and high tide currents.

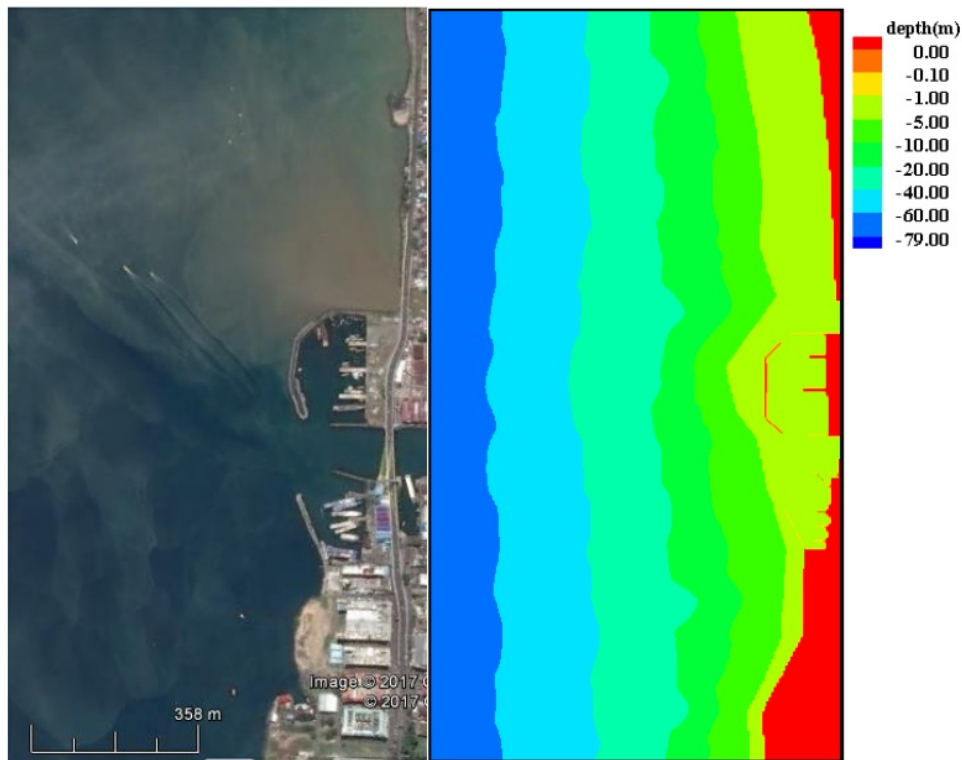**Figure 2.** Gulf of Manado, North Sulawesi, Indonesia

Figure 3. Bathymetry of Manado Gulf

The three-dimensional semi-implicit numerical method used in this study. The solution of a numerical model in calculating the velocities of $\bar{u}$, $\bar{v}$ and $\bar{w}$ respectively, we can explain step by step as follows:

- *start* is the beginning of numerical computation.
- *read data* is the process to read all data that using the all of parameters in equations 2 to 5 and table 1 which needed in calculation and also read data of variables: time of calculating maximum for doing iteration.
- *generation of the mesh* is the process to make the computational meshes which using Arakawa C-grid [13] and notations (spatial discretization).
- *generation of the index* is the process to make the index and generate the layers of vertical axis (depth) and generate index of boundary layers as denote calculating in the meshes.
- *initial conditions* are the process to make the initial conditions of velocities and seawater surface elevation, and also to make the coordinates for the result simulations in the Tec plot program.
- *the quantity of calculation* with iteration do-process until maximum iteration.
- *boundary conditions* are the process which give boundary conditions of calculation domain in the Gulf of Manado. Also, generation and determination about boundaries of velocities when enter and exit the Gulf of Manado bases data of investigation results.
- *calculate advections in $\bar{u}$ and $\bar{v}$* are the process for calculation advection of $\bar{u}$ and $\bar{v}$.
- *turbulence model* is the process calculating the turbulence of a mixing-length model [7] (for three-dimensional calculation). In this process also calculated diffusion step.

- *calculate components of velocities* ($\bar{u}$, $\bar{v}$ *and* $\bar{w}$) are the process for calculating of horizontal velocities $\bar{u}$ and $\bar{v}$ (equations 4 and 5) with a linear three-diagonal.
- *calculate seawater surface elevations* are the process for calculating equation 6 which is values of the seawater surface elevation with a linear five-diagonal system.
- *print results* are the process for print results calculation that we necessary.
- $T > T_{max}$ is the process to execute determination when the iteration has been greater than maximum iteration, if *no* then process will be go to the quantity of calculation for continue to calculate again, and if *yes* then it goes to "*finish*".
- *finish* is the process where the calculation is stop.

Table 1. Parameter value for 3D-numerical simulations

Parameter	Value	Parameter	Value
g	9.81 m s^{-2}	ρ_s	1024 kg/m^3
Cz	48	Δx	7 m
τ_o	2 days	Δy	7 m
τ_i	1 day	Δz	1 m
discharge	0.1 Sv	Δt	0.5 sec

Table 1 shows a discharge is 0.1 Sv (0.1 x 10^6 m^3/s). τ_o and τ_i are relaxation timescales at outflow and inflow conditions respectively [14]. Cz is Chezy coefficient and ρ_s is density of seawater. Δx, Δy, and Δt are space step in x direction, space step in y direction, and time step respectively.
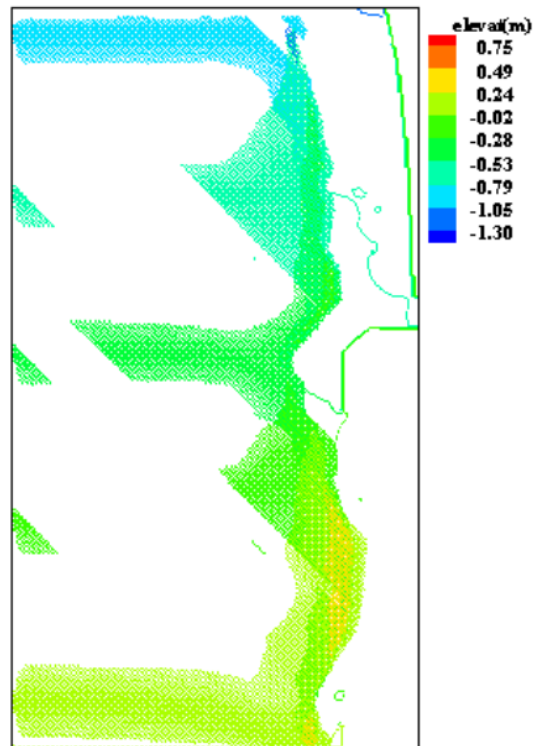

Figure 4. Simulations of seawater surface elevation distributions when low tide currents at discharge of 0.1 Sv

5. Results and discussion

The numerical modeling results we can see in figures 4 and 5 which are in the forms of simulations i.e. 3D-simulations (showed in 2D) when low tide currents and high tide currents. Figure 4 shows distributions of seawater surface elevation when low tide currents. High seawater level when low tide currents is biggest around Southside which the maximum of 75 cm and Northside locations of 130 cm under seawater level. Whereas when high tide currents, there is 181 cm of maximum high seawater level in Northside and the minimum of 117 cm under seawater level in Southside (figure 5). The distributions of seawater surface elevation when low tide currents in Eastside are 2 cm, Westside around 28-79 cm, and Center side around 28-53 cm respectively under seawater level. Whereas when high tide currents in Eastside same as Westside around 32-107 cm, and Center side around 70 cm respectively upper seawater level.
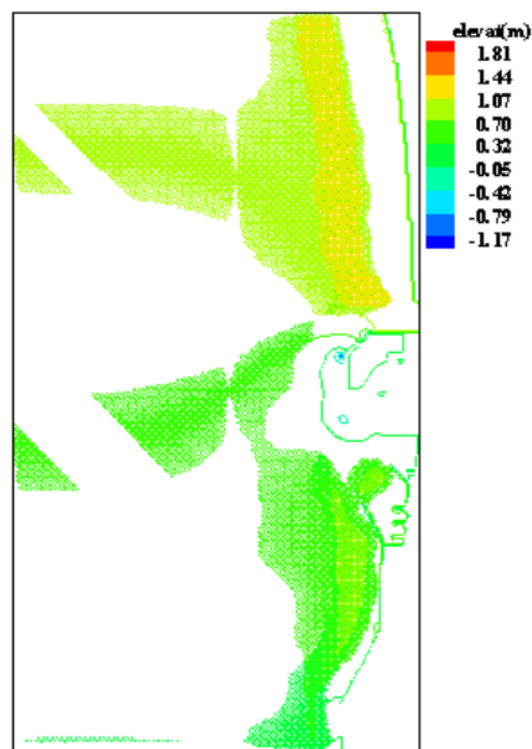

Figure 5. Simulations of seawater surface elevation distributions when high tide currents

The high seawater level occurs when high tide currents greater than low tide currents. It caused by the influence of velocities of seawater when high tide currents greater than when low tide currents [3]. The other effect is the horizontal and vertical movement of seawater results in the wind stress at the sea-surface when high tide currents greater than when low tide currents [1, 10].

6. Conclusion

The seawater surface elevation by numerical modeling approach in the Gulf of Manado, North Sulawesi, Indonesia has been investigation. The distributions of high seawater level were 1.81 m upper seawater level and 1.30 m under seawater level respectively. The results can be used as a recommendation to predict the condition of sea waves in the gulf of Manado.

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