Prediction of the alluvium transport and testing the results by remote sensing

Nga Duong Thi Thuy

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Duong Thi Thuy Nga
University of Science, VNU-HCM
Ho Chi Minh City, VIETNAM
ngadtt@gmail.com

ABSTRACT

To compute the alluvium transport, we use a current model based on a 2D finite-difference grid and a sediment transport model. The first one gives the velocity distribution on the surface of water body and in the case of transient analysis, the velocity distribution is computed at each computational time step. This velocity distribution will be taken as the input for the second model. The advanced experiment in this research is to test the results of computing with satellite data. The models were used to compute the alluvium transport in Ca Mau coastal zone. The reasonableness in the transport trend of alluvium shows that those models are confident.

KEYWORDS

Alluvium transport; current model; remote sensing.

1 Introduction

The alluvium transport at estuaries affects much to our economy, ecological environment. Alluviums make the ability of flood drainage decreases.

In the world, there are many research groups implemented this project. Most of them used Defant and Hansen methods [1, 7] at Atlantic, Pacific. Some of them used alternating direction implicit (ADI) method to solve the problem [2, 3, 4, 6, 9, 10]. The strength of those models is that they are easy to be applied to compute and predict the current as well as the sediment transport. Therefore, the main objectives for the development of these models are:

- Applying ADI finite different method to the current and alluvium models for the prediction of the current and alluvuim transport, and

- Testing the results by remote sensing.

The remainder of this paper is following, section 2 presents detailed expositions for the models. The experiment results are undertaken in section 3. Section 4 focuses on future developments of the models. Finally, section 5 gives conclusions of the study.

2 Methodology

2.1 Current model

The model solves the depth averaged 2D shallow water equations. They are equations of floods, ocean tides and storm surges. They are derived by using the hypotheses of vertically uniform horizontal velocity and negligible vertical acceleration (i.e. hydrostatic pressure distribution). The assumptions are valid where the wavelength is much greater than the depth of water. In the case of ocean tide the equations are applicable everywhere.

The 2D equations in the horizontal plane are describable by the following partial differential equations of mass continuity and momentum conservation in the X and Y directions for an in-plan Cartesian coordinate frame of reference.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv+g\frac{\partial \varepsilon}{\partial x}+gu\frac{\sqrt{u^2+v^2}}{(h+\varepsilon)C^2}-\frac{\tau_x}{h+\varepsilon}=f_x(t)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu+g\frac{\partial \varepsilon}{\partial y}+gv\frac{\sqrt{u^2+v^2}}{(h+\varepsilon)C^2}-\frac{\tau_y}{h+\varepsilon}=f_y(t)$$

$$\frac{\partial \varepsilon}{\partial t}+\frac{\partial}{\partial x}(h+\varepsilon)u+\frac{\partial}{\partial y}(h+\varepsilon)v=0$$

where:

u, v: depth averaged velocity components in X and Y directions [m/s]

ε : water surface elevation [m]

h+ ε : depth of water [m]

t: time [s]

x, y: distance in X and Y directions [m]

C: Chezy coefficient

f: Coriolis force coefficient

τ_x τ_y : horizontal diffusion of momentum coefficient in X and Y directions

$f_x(t)$, $f_y(t)$: sum of components of external forces in X and Y directions

2.2 Alluvium transport model

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=\frac{1}{H}\frac{\partial}{\partial x}\left(HK_X\frac{\partial C}{\partial x}\right)+\frac{1}{H}\frac{\partial}{\partial y}\left(HK_y\frac{\partial C}{\partial y}\right)+\frac{S}{H}$$

where:

C : depth averaged concentration [kg/m^3].

u, v : depth averaged velocity components in X and Y directions [m/s]

K_x, K_y: diffusion coefficients in the X and Y directions [m^2/s]

H : relative depth [m], $H = h + \zeta$

S : source of sediment particles [g/m^2.s]

To compute K_x, K_y, we use Elder formula:

$$K_x = 5.93\sqrt{g}h|u|C^{-1}$$

$$K_y = 5.93\sqrt{g}h|v|C^{-1}$$

where:

C : Chezy coefficient [m$^{0.5}$/s]

2.3 Algorithm

All of the models use an alternating direction implicit (ADI) finite different method to solve the problems. The method involves two stages. In each stage, a tri-diagonal matrix for the computational domain is built to solve the values:

$$\begin{bmatrix} B_1 & C_1 & & & & & \\ A_2 & B_2 & C_2 & & & & \\ & A_3 & B_3 & C_3 & & & \\ & & \cdots & & & & \\ & & A_i & B_i & C_i & & \\ & & & \cdots & & & \\ & & & & A_{I-1} & B_{I-1} & C_{I-1} \\ & & & & & A_I & B_I \end{bmatrix} * \begin{bmatrix} C_1^{t+1/2} \\ C_2^{t+1/2} \\ C_3^{t+1/2} \\ \vdots \\ C_i^{t+1/2} \\ \vdots \\ C_{I-1}^{t+1/2} \\ C_I^{t+1/2} \end{bmatrix} = \begin{bmatrix} D_1 \\ D_2 \\ D_3 \\ \vdots \\ D_i \\ \vdots \\ D_{I-1} \\ D_I \end{bmatrix}$$

There are millions of nodes to compute the values. There are also millions of equations to be solved. The tri-diagonal matrix method will increase the speed of computing because values out of the diagonals are 0.

- **Initial conditions**

At time t = 0:

u = 0, v = 0, ε = 0

C(x,y,0) = C_0(x,y) or C(x,y,0)= constant

- **Boundary conditions**

For the current model:

- Compute tidal components

$$\varsigma = \sum_{i=1}^{N} A_i \sin(\omega_i t + \varphi_i)$$

or

- Compute Q = U * W

Then, compute the velocities at the boundaries.

For the alluvium transport model:

- Solid boundary: $\frac{\partial C}{\partial n} = 0$

- Liquid boundary:

Water flow runs from outside to the domain: *C = C_b(t)*

Water flow runs out of the domain: $\frac{\partial^2 C}{\partial x^2} = 0$

- Algorithms

- Compute the current:

```
Initialize values at time t = 0 (v, ε : collected data)
t = 1;
while (t < Total time)
{
        row = 1;
        while (row <= Total rows)
        {
                Compute left boundary, right boundary;
                Solve 3 tri-diagonal equations to compute u;

                If (right boundary > Total columns)
                        row++;
        }
        Compute ε , v;
        column = 1;
        while (column <= Total columns)
        {
                Compute bottom boundary, top boundary;
                Solve 3 tri-diagonal equations to compute v;

                If (top boundary > Total rows)
                        column++;

        }
        Compute ε , u;
        t++;
}
```

- Compute the alluvium transport:

```
Initialize values at time t = 0 (v, u, ε : from current model)
t = 1;
while (t < Total time)
{
        row = 1;
        while (row <= Total rows)
        {
                Compute left boundary, right boundary;
                Solve 3 tri-diagonal equations to compute C;

                If (right boundary > Total columns)
                        row++;
        }

        column = 1;
        while (column <= Total columns)
        {
                Compute bottom boundary, top boundary;
                Solve 3 tri-diagonal equations to compute C;

                If (top boundary > Total rows)
                        column++;

        }
        t++;
}
```

3 Experimental results

3.1 Applying the models to Ca Mau coastal zone

The study area (W=61 km; L=88 km) is computed under the following conditions:

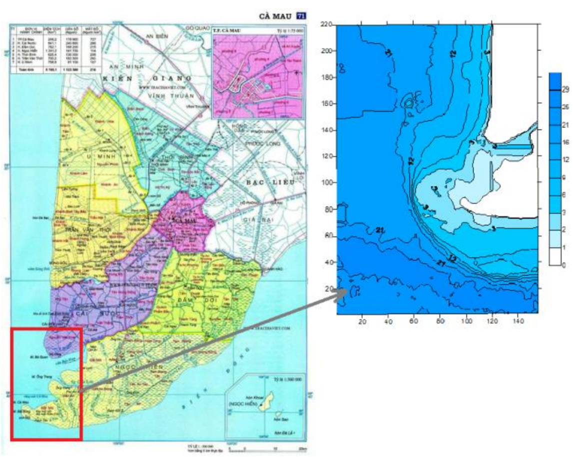

Figure 1: Map of the study area

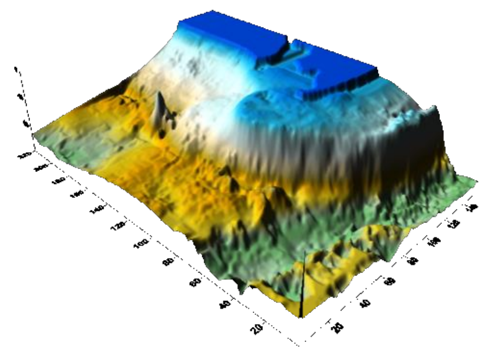

Figure 2: 3D Topography of Ca Mau coastal zone

- Boundary condition the for current model:

On the open boundary, the water levels are given by computing tidal components as shown in table 1 and 2. The parameters of these tidal components are from [11, 12, 13].

TABLE 1. TIDAL CHARACTERITICS AT EASTERN SEA

No.	Name of tidal components	Amplitude (m)	Phase (rad)
1	M_2	0.72	0.59
2	N_2	0.15	0.08
3	S_2	0.3	1.3
4	K_2	0.08	1.3
5	K_1	0.59	5.4
6	O_1	0.42	4.6
7	P_1	0.19	5.4
8	Q_1	0.01	4.2
9	M_4	0.01	4.8
10	MS_4	0.01	5.8
11	M_6	0.004	2.6

TABLE 2. TIDAL CHARACTERITICS AT THAI LAN BAY

No.	Name of tidal components	Amplitude (m)	Phase (rad)
1	M_2	0.15	1.35
2	N_2	0.15	0.08
3	S_2	0.12	1.35
4	K_2	0.08	1.3
5	K_1	0.38	0.18
6	O_1	0.25	1.8
7	P_1	0.49	5.4
8	Q_1	0.07	4.2
9	M_1	0.08	3.5

- Wind: Southern West direction, 4.2m/s.
- Alluvium concentration at boundaries: 0.0001g/ml

3.2 Prediction of the alluvium

We can see the graph of water surface areas in tidal rise and tidal fall:

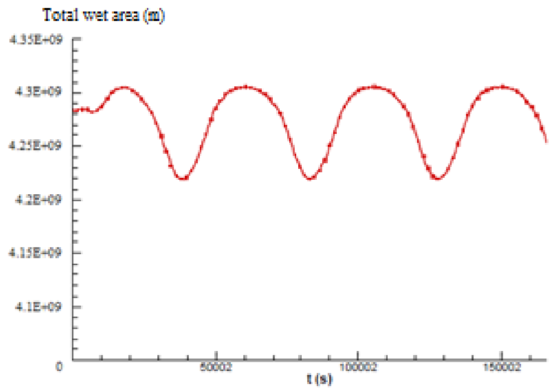

Figure 3: Water surface areas in tidal rise and tidal fall

When the tide changes, the boundary is also changed. Therefore, the total wet surface area is increased in tidal rise and decreased in tidal fall.

- ❖ Alluvium transportation

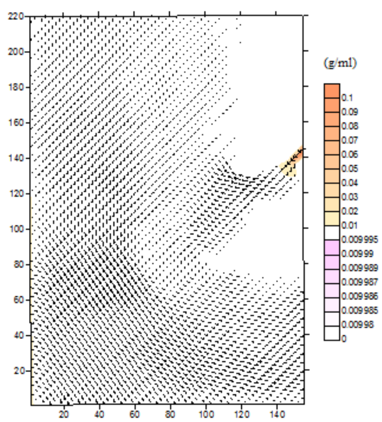

Figure 4: Alluvium transportation after 1 month and 15 days

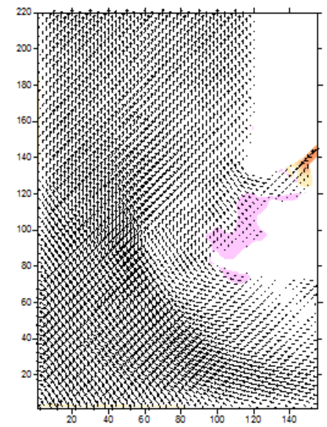

Figure 5: Alluvium transportation after 1 month, 15 days and 6 hours

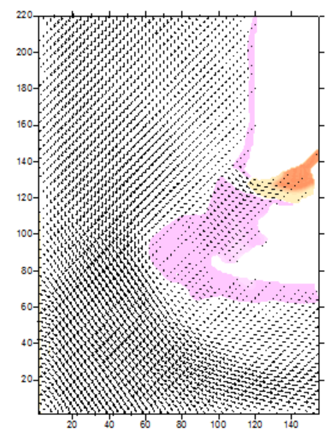

Figure 6: Alluvium transportation after 1 month, 15 days and 12 hours

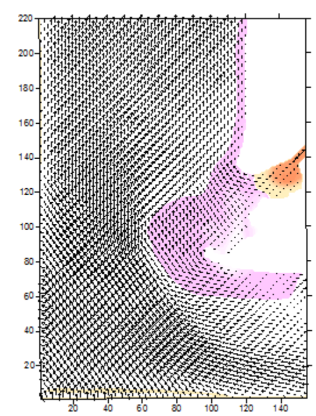

Figure 7: Alluvium transportation after 1 month, 15 days and 18 hours

- Evaluate:

At Bay Hap estuary, there is a heavy alluvium transportation. In tidal rise, the alluvium runs from the estuary to the ocean. In tidal fall, it runs following with the water flow to the reverse direction.

In reality, Bay Hap estuary is a place filled with a lot of alluvium. The models are suitable for this research.

3.3 Testing the models

Scientists often test the current model and then test the alluvium transport with the transport in reality.

One way to test the alluvium transport is to test the result by remote sensing. If the transport computed by the models and by remote sensing are similar, the models are reliable.

Figure 8, Figure 9, Figure 10 and Figure 11 show the alluvium transport computed by the models and by remote sensing.

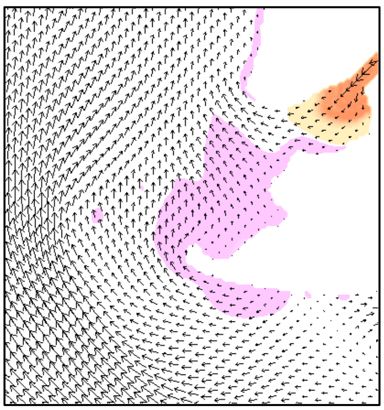

Figure 8: Alluvium transportation computed by the models in tidal rise

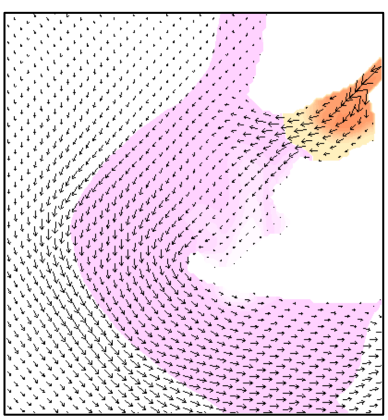

Figure 9: Alluvium transportation computed by the models in tidal fall

Figure 10: Alluvium transportation computed by remote sensing in tidal rise

Figure 11: Alluvium transportation computed by remote sensing in tidal fall

Figure 8 and Figure 9 show that in tidal rise, the direction of the alluvium transport is the same as that of the tide. In tidal fall, the direction is reverse. The alluvium transports in Figure 10 and Figure 11 are similar to those of the models. Therefore, the models are reliable.

3 Future developments

The alluvium transport may cause accretion or erosion. The next research will be studying the accretion, erosion at estuaries based on the alluvium transport.

4 Conclusions

This paper presents models to compute the current and the alluvium transport. In this study, we compute the changes of boundary in tidal rise and in tidal fall so that the accuracy will be increased. The models are tested by remote sensing and the results show that the alluvium transport trend is suitable with reality.

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