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Study of the Current and Divergence Fields in Meiliang Bay, Taihu Lake, China with the Air-Water Model*

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Abstract: *Research is conducted on the distribution features of flow and divergence fields under the stress of ununiform and unsteady wind at Meiliang Bay on Lake Taihu by using a 3D atmospheric boundary layer model and a 2D hydrodynamic model for the area of the lake. Some meaningful results were achieved.*
Keywords: *Ununiform wind, flow and divergence fields, mathematical model, Taihu Lake*

I. Introduction

Taihu Lake is one of the largest fresh water lakes in China. In relation with rapid increase of population, development of industry and agriculture in the lake region, both the aquatic prodoction and water quality are decreasing obviously in the lake, especially in Meiliang Bay of Taihu Lake. Meiliang Bay is located at the north part of Taihu Lake, where there are many famous scenic spots and drink water plants. It is important to know the distribution of the current and divergence field in order to do some useful work to improve the environment in the bay. As we know, the current in Taihu Lake is mainly induced by wind, so it is significant to use air-water coupling model to study thc current and divergence field in the bay.

2. The equations of the air-water model

2.1 The equations of a three dimensional atmospheric model

A topography coordinate of $z^*= s(z-z_0)/(z-z_0)$ and the following equation system was used:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w^*\frac{\partial u}{\partial z^*} + f(v - v_s) - \theta\frac{\partial \Pi}{\partial x} + g\frac{z^* - \bar{s}}{\bar{s}}\frac{\partial z_G}{\partial x} - g\frac{z^*}{\bar{s}}\frac{\partial s}{\partial x} +$$

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$$(\frac{\bar{s}}{s-z_G})^2\frac{\partial}{\partial z^*}(K_z\frac{\partial u}{\partial z^*})+\frac{\partial}{\partial x}(K_H\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(K_H\frac{\partial u}{\partial y});$$

$$\frac{\partial v}{\partial t}=-u\frac{\partial v}{\partial x}-v\frac{\partial v}{\partial y}-w^*\frac{\partial v}{\partial z^*}+f(u_g-u)-\theta\frac{\partial \Pi}{\partial y}+g\frac{z^*-\bar{s}}{\bar{s}}\frac{\partial z_G}{\partial y}-g\frac{z^*}{\bar{s}}\frac{\partial s}{\partial y}+ \\ (\frac{\bar{s}}{s-z_G})^2\frac{\partial}{\partial z^*}(K_z\frac{\partial v}{\partial z^*})+\frac{\partial}{\partial x}(K_H\frac{\partial v}{\partial x})+\frac{\partial}{\partial y}(K_H\frac{\partial v}{\partial y});$$

$$\frac{\partial \Theta}{\partial t}=-u\frac{\partial \Theta}{\partial x}-v\frac{\partial \Theta}{\partial y}-w^*\frac{\partial \Theta}{\partial z^*}+(\frac{\bar{s}}{s-z_G})^2\frac{\partial}{\partial z^*}(K_z\frac{\partial \Theta}{\partial z^*})+\frac{\partial}{\partial x}(K_H\frac{\partial \Theta}{\partial x})+\frac{\partial}{\partial y}(K_H\frac{\partial \Theta}{\partial y});$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w^*}{\partial z^*}-\frac{1}{s-z_G}(u\frac{\partial z_G}{\partial x}+v\frac{\partial z_G}{\partial y})+\frac{1}{s-z_G}(\frac{\partial s}{\partial t}+u\frac{\partial s}{\partial x}+v\frac{\partial s}{\partial y})=0;$$

$$\frac{\partial \Pi}{\partial z^*}=-\frac{s-z_G}{\bar{s}}\frac{g}{\Theta};$$

$$w^*=\frac{\bar{s}}{s-z_G}w-\frac{z^*}{s-z_G}(\frac{\partial s}{\partial t}+u\frac{\partial s}{\partial x}+v\frac{\partial s}{\partial y})+\frac{z^*-\bar{s}}{s-z_G}(u\frac{\partial z_G}{\partial x}+v\frac{\partial z_G}{\partial y});$$

where u, v, w are the components along the directions of x, y, z respectively; w^* is the vertical wind speed in transformed vertical coordinate z^*; u_g, v_g are the components of geostraphic wind; f is the Coriolis parameter; s is the top of the modal; Θ is the potential temperature.

2.2 The equations of a depth-averaged water model

The two-dimensional depth averaged water model are as follows (Wang. 1989):

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-g\frac{\partial \eta}{\partial x}+fv+F_x+K_h\nabla^2 u$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-g\frac{\partial \eta}{\partial x}-fu+F_y+K_h\nabla^2 v$$

$$\frac{\partial \eta}{\partial t}+\frac{\partial}{\partial x}[(\eta+h)u]+\frac{\partial}{\partial y}[(\eta+h)v]=0;$$

where ∇^2 is defined as the $\nabla^2=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}$, $\eta+h$ is the thickness of the water column;

K_h is the horizontal coefficient of turbulent viscosity; F_x, F_y are the friction components in *x*, *y* directions:

$$F_x = \frac{1}{\rho_w(\eta+h)}(\rho_a C_D{}^a u_a \sqrt{u_a^2+v_a^2} - \rho_w C_D{}^b u_b \sqrt{u_b^2+v_b^2});$$

$$F_y = \frac{1}{\rho_w(\eta+h)}(\rho_a C_D{}^a v_a \sqrt{u_a^2+v_a^2} - \rho_w C_D{}^b v_b \sqrt{u_b^2+v_b^2});$$

where $C_D{}^a$, $C_D{}^b$ are the surface and bottom shear stress, ρ_a, ρ_w are the densities of air and water, respectively; u_a, v_a are the wind above 10 m above the water surface; u_b, v_b are the components of mean water currents.

3. The computed wind field

In calculation, the horizontal grid size of 6 km and the vertical grid size of 0, 5, 10, 100, 300, 500, 700, 900, 1 200, 1 500, 2 000, 3 000, 4 000, 5 000, 6 000 m were used in the model. The specific calculating method can be seen in reference (Pang Yong, *et al*, 1995). Fig. 1 is the computed results in the conditions of u_g=5.0 m·s^{-1}, v_g=9.0 m·s^{-1}. From fig. 1, we see that the computed wind blew along the pressure gradient direction after simulating for 2 hr, because the wind and pressure fields are not in geostrophic balance at this time. After simulating for 24 hr, the wind direction paralleled to the isobaric line in that the geostrophic balance was reached at this time. Fig 2 is the results computed in the conditions of u_g= -5.0 m·s^{-1}, v_g= -9.0 m·s^{-1}. From Fig. 1, and 2, we see that wind velocity will be speed up when it enters the lake area, which was caused by the different roughness of land and water.

4. The computed current and divergence field

4.1 The conditions in the computation

There are two boundaries which around Meifiang Bay, one is open boundary which is in the south part of Meiliang Bay connected to Taihu lake else, the others are solid boundary. In calculation, the lake current in all Taihu Lake was computed firstly, then it was interpolated to the fine grid in the open boundary of Meiliang Bay. The horizontal grid size of 2 km (for Taihu Lake) and 0.5 km (for Meiliang Bay) were used in the model. The specific calculating method can be seen in reference (Pang, Y., *et al*, 1994).

.2 The analysis of the current

The initial conditions were u=v=0, η=0, and the wind field was taken from the computed

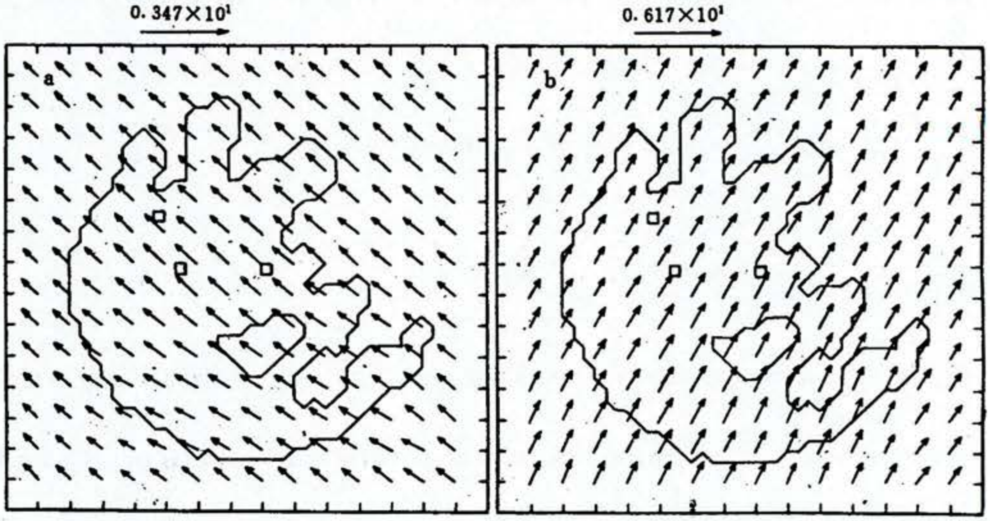

Fig. 1 Simulated lake current field; 10 m horizontal wind with u_g=5.0 m·s^{-1} and v_g=9.0 m·s^{-1}; integrated with the 3D- boundary-layer model for 2 hr(a) and 24 hr (b)

results of atmospheric model in the conditions of u_g=-5.0 m·s^{-1}, v_g=9.0 m·s^{-1}. The computed current field was shown in fig. 3. From Fig. 3, we see that the water was poured into the bay from Taihu Lake else after simulating for 2 hr. After simulating for 12 hr, the counter-clockwise circulation field was formed. After simulating for 24 hr, the circulation field disappeared, the water was poured out to Taihu Lake else from the bay.

Some author (Liu Qilun, 1996) have studied the current characteristics of Meiliang Bay driven by the steady and uniform wind, it showed that there were a stable circulation fields in Meiliang Bay after simulating for about 4 hr. We know there are many pollution sources around the bay. Because the circulation field can prevent water exchange from the bay to Taihu lake else, the water quality in Meihang Bay may be worsen heavily than Taihu Lake else, if the stable circulation field existed. But the real situation was not so.

Fig. 2 Simulated lake current field; 10 m horizontal wind with u_g=-5.0 m·s^{-1} and v_g=- 9.0 m·s^{-1}, integrated with the 3D-boundary-layer model for 24 hr

4.3 The analysis of the divergence field

Fig. 4 is the computed divergence field. From Fig. 4, we can see that:

(1) The distribution of the divergence field changed with the wind field sensitively.

(2) The centers of divergence fields are almost near the bank of the bay, so irregular shape of the bank is the main cause of divergence field and the different wind can result in different distribution of divergence fields.

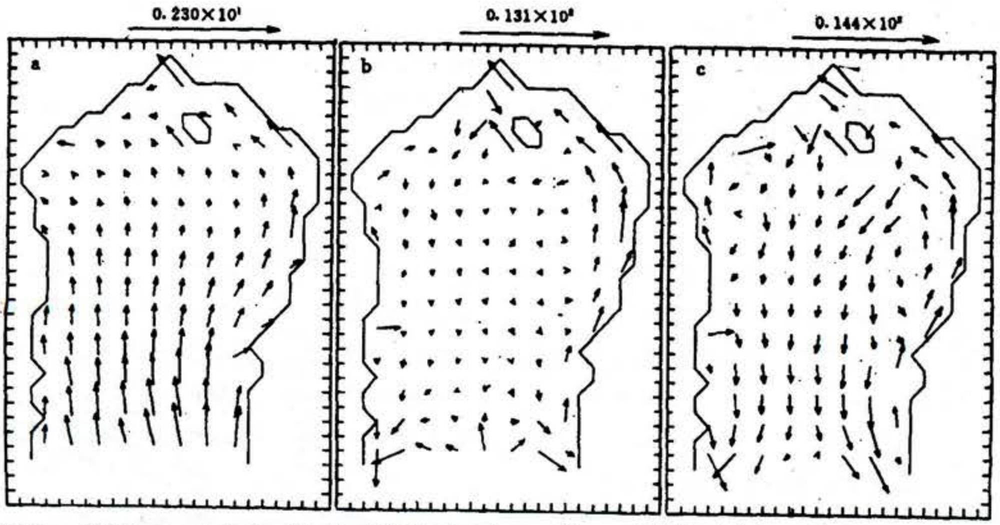

Fig. 3 Flow field simulated with the 2D hydrodynamic model for 2 (a), 12 (b) and 24 hr (c) when u_g=5.0 m·s^{-1} and v_g=9.0 m·s^{-1}

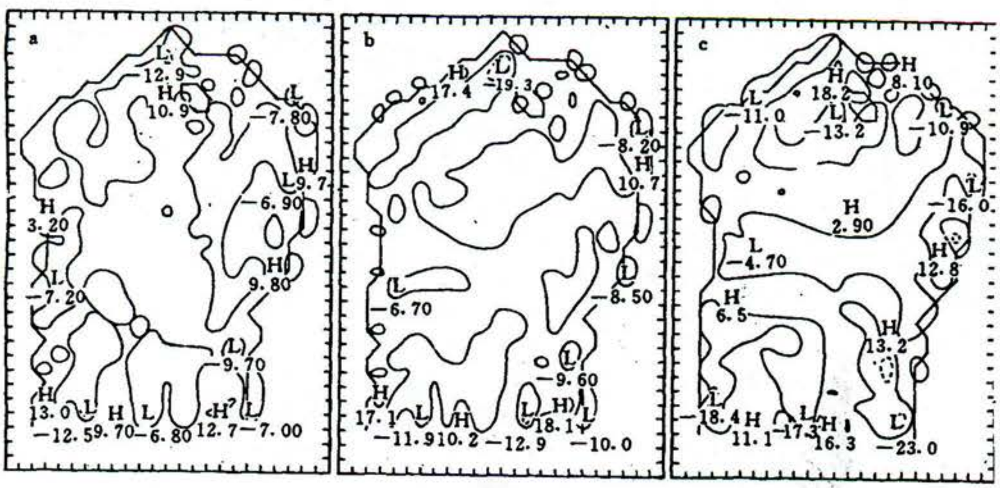

Fig. 4 Divergence field coming from the hydrodynamic model

a. 12 hr integration for u_g=5.0 m·s^{-1} and v_g=9.0 m·s^{-1}

b. 24 hr integration for u_g=5.0 m·s^{-1} and v_g=9.0 m·s^{-1}

c. 24 hr integration for u_g=-5.0 m·s^{-1}and v_g =-9.0 m·s^{-1}

5. Conclusions

(1) The wind field distribution changed obviously with time and space in Taihu Lake, so the ununiform and unsteady wind should be considered in order to study the current and divergence field in Taihu Lake.

(2) In contrast with the action of the steady and uniform wind, the circulation field in Meiliang Bay would not be maintained longer under the action of unsteady and ununiform wind field. This result seems to be reasonable.

(3) The main factors in influencing the distribution of divergence field are wind field and the irregular bank shape in Meiliang Bay, so it is important to consider the two factors in controlling eutrophication problems in Meiliang Bay.

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