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Abstract

This paper describes the dynamic initialization procedures of a two-dimensional lake breeze model, based on radiosonde data at one site. Three approaches of initialization have been tested. The results prove that dynamical balance between mass and momentum fields can be obtained from unbalanced, inexact first guesses, but there is an obvious difference between results calculated with each initialization procedure. In comparison, we found that the approach, one-dimensional dynamic initialization with nudging, probably is preferable to the others.

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initialization
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CONTENTS

1. INTRODUCTION

The process of numerical simulation is classically viewed as an initial value problem whereby the governing equations are integrated forward from the initial values of meteorological fields. The baroclinic primitive equation models admit undesirable high-frequency gravity waves. The gravity waves frequently are excited by initial imbalance between wind and temperature (or rather mass) fields and by inconsistencies between model and atmosphere. Therefore, we must pay attention to the "initialization problem".

In sea breeze model simulations, however the access to extensive measurements, especially of the vertical structure is an exception. In many case only one radiosonde site with soundings is available in the area of interest. In this paper we attempt mainly to discuss the methods of determining the initial value of the wind field and the large scale, boundary values of the wind field based on one radiosonde site.

The present model is based on two-dimensional primitive equations and with turbulent energy closure, in which the dependent variables are decomposed into a large scale part and a mesoscale part. Furthermore it is assumed that the large scale part is stationary. In this case the procedure of determining the large scale values is equivalent to the initialization approach, since it is assumed that initially there is no meso-scale circulation.

A lake breeze case at Lake Vättern, Sweden, on May 7 1980, is simulated with three approaches of initialization, based on the data of GOTEX II experiment (Bergström and Alexandersson, 1981; Ericson, 1982). The calculated results are analysed and discussed in detail.

2. NUMERICAL MODEL

A detailed derivation and description of the model equations is presented in Wu Zengmao (1986 a), thus only a short version is presented here.

In the model, the dependent variables are decomposed as

$$A = \overline{A} + a + a'$$

where A represents any one of the dependent variables (U, V, Θ, W and Π). The barred component denotes the large (or synoptic) scale value, the primed component represents the value on a scale that is too small to be resolved explicitly by the model grid and whose effect must be parameterized. The value denoted by a lower case letter represents the mesoscale variable which is our primary interest.

2.1 Governing equations

$$\frac{\partial u}{\partial t} + (\bar{U} + u)\frac{\partial u}{\partial x} + w\left(\frac{\partial \bar{U}}{\partial z} + \frac{\partial u}{\partial z}\right) = f\,(\bar{V} + v - \bar{V}_{gR}) - \frac{\partial \pi}{\partial x} + \frac{\partial}{\partial z}\left(K_m\left(\frac{\partial \bar{U}}{\partial z} + \frac{\partial u}{\partial z}\right)\right)$$

$$\frac{\partial v}{\partial t} + (\bar{U} + u)\frac{\partial v}{\partial x} + w\left(\frac{\partial \bar{V}}{\partial z} + \frac{\partial v}{\partial z}\right) = -f\,(\bar{U} + u - \bar{U}_{gR}) + \frac{\partial}{\partial z}\left(K_m\left(\frac{\partial \bar{V}}{\partial z} + \frac{\partial v}{\partial z}\right)\right)$$

$$\frac{\partial \Theta}{\partial z} + (\bar{U} + u)\frac{\partial \Theta}{\partial z} + w\left(\frac{\partial \bar{\Theta}}{\partial z} + \frac{\partial \Theta}{\partial z}\right) = \frac{\partial}{\partial z}\left(K_H\left(\frac{\partial \bar{\Theta}}{\partial z} + \frac{\partial \Theta}{\partial z} - \gamma_{cg}\right)\right)$$

$$\frac{\partial w}{\partial z} + \frac{\partial u}{\partial x} = 0$$

$$\Pi = \Theta\, C_p\,(P/P_0)^{R/C_p} \qquad P_0 = 1000 \text{ mb}$$

$$\frac{\partial \pi}{\partial z} = g\,\theta/\bar{\Theta}$$

$$\bar{V}_{gR} = \frac{1}{f}\frac{\partial \bar{\Pi}}{\partial x} = \frac{1}{f}\frac{\partial \bar{\Pi}}{\partial x}\Big|_H = \text{constant}$$

$$\bar{U}_{gR} = -\frac{1}{f}\frac{\partial \bar{\Pi}}{\partial y} = -\frac{1}{f}\frac{\partial \bar{\Pi}}{\partial y}\Big|_H = \text{constant}$$

Where Π is the Exner function and γ_{cg} the counter-gradient heat flux correction term. The rest of the symbols have their standard meaning in meteorological parlance.

K_m and K_H are the turbulent diffusivities for momentum and heat respectively. It is specified

$$K_m = l \cdot (\alpha_1 E)^{\frac{1}{2}}$$

and the approximation $\alpha_H = K_H/K_m = 1.35$ is utilized; l is the mixing length. The turbulent energy E is defined as

$$E = \frac{1}{2}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$$

and the turbulent energy equation is expressed (Bodin, S., 1979) as:

$$\frac{\partial E}{\partial t} + (\bar{U} + u)\frac{\partial E}{\partial x} + w\frac{\partial E}{\partial z} = K_m \left(S_v^2 - \alpha_H \frac{g}{\bar{\Theta}}\left(\frac{\partial \bar{\Theta}}{\partial z} + \frac{\partial \theta}{\partial z} - \gamma_{cg}\right)\right) + \alpha_2 \frac{\partial}{\partial z}\left(K_m \frac{\partial E}{\partial z}\right) - \varepsilon$$

where ε is turbulent kinetic energy dissipation,

$$\varepsilon = (\alpha_3 E)^{3/2}/l_\varepsilon, \ \alpha_1 = \alpha_3 = 0.2, \ \alpha_2 = 1.2,$$

$$S_v^2 = \left(\frac{\partial \bar{U}}{\partial z} + \frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial \bar{V}}{\partial z} + \frac{\partial v}{\partial z}\right)^2$$

and l_ε is the dissipation mixing length. l and l_ε are formulated according to Therry, G. (1983).

2.2 Boundary conditions

It is assumed that at $z = z_0$, $u = v = w = 0$. In the meantime since a staggered grid is used at the bottom level, $\frac{\partial E}{\partial z} = 0$ and temperature holds a constant 8.1°C at the lake surface and a prescribed diurnal temperature wave $F_s(x,t)$ is imposed at the land surface. $F_s(x,t)$ is obtained from the hourly screen observation (at Klockrike) and shown in Figure 1; meanwhile an advective temperature correction is added to the gridpoints near the coastlines.

The top of the model domain H is taken as 3000 m, and at $z = H$, $\frac{\partial u}{\partial z} = \frac{\partial v}{\partial z} = \frac{\partial E}{\partial z} = \Theta = \pi = 0$. L is the horizontal extent of the model domain; at $x = 0$ and $x = L$, $\frac{\partial \Theta}{\partial x} = 0$ and the so-called "constant inflow and gradient outflow" conditions are utilized for equations of u, v and E; while an implicit filter enhanced near the lateral boundaries is employed to prevent contamination of the inner domain.

The surface roughness parameter is simply set as 0.15, 0.10 and 0.0001 m for the western and eastern coast area and water surface respectively.

2.3 Initial conditions and initialization procedures

The large scale potential temperature profile is obtained by averaging four radiosonde ascents at 0200, 0800, 1400 and 2000 hours on May 7, 1980 (at Klockrike), and with a slight modification at low levels where the atmosphere is set in neutral condition. Using the assumption that at t = 0 there is no mesoscale flow, we have t = 0 (corresponding to 07 am. local time) $u = v = w = \Theta = \pi = 0$. The large scale wind is initialized by three approaches, as shown in Figure 2:

a) *Approach A:* Static initialization
Here we have used the Ekman solution with the turbulent exchange coefficient given as a constant.

b) *Approach B:* One-dimensional dynamic initialization
The large scale wind can be calculated with a one-dimensional dynamic model

$$\frac{\partial \bar{U}}{\partial t} = \frac{\partial}{\partial z}(\bar{K}_m \frac{\partial \bar{U}}{\partial z}) + f(\bar{V} - \bar{V}_{gR})$$

$$\frac{\partial \bar{V}}{\partial t} = \frac{\partial}{\partial z}(\bar{K}_m \frac{\partial \bar{V}}{\partial z}) - f(\bar{U} - \bar{U}_{gR})$$

The geostrophic wind is taken as the first guess. The boundary condition is assumed at $z = 0$ $\bar{U} = \bar{V} = 0$, and at $z = H$ $\bar{U} = \bar{U}_{gR}$ and $\bar{V} = \bar{V}_{gR}$. $\bar{K}_m$ is the turbulent diffusive coefficient corresponding to the large scale flow. After integrating the equations for about six inertial periods, steady solutions are obtained.

c) *Approach C:* One-dimensional dynamic model with nudging (Hoke, 1976)
It is almost the same as approach B, but nudging terms have been added.

$$\frac{\partial \bar{U}}{\partial t} = \frac{\partial}{\partial z}(\bar{K}_m \frac{\partial \bar{U}}{\partial z}) + f(\bar{V} - \bar{V}_{gR}) + G_u(U_{obs} - \bar{U})$$

$$\frac{\partial \bar{V}}{\partial t} = \frac{\partial}{\partial z}(\bar{K}_m \frac{\partial \bar{V}}{\partial z}) - f(\bar{U} - \bar{U}_{gR}) + G_v(V_{obs} - \bar{V})$$

where subscript "obs" denotes the observed value; G_u and G_v are refered to as the nudging coefficients. The value of G_u and G_v, genereally, depend upon the observed data and typical magnitudes of the other terms in the predictive equations. In this experiment we have used $G_u = G_v = 0.0003$.

3. ANALYSES OF RESULTS

In Figures 4, 5 and 6, diagram (a), (b), (c) respectively corresponds to approach A, B, C. In Figures 3 and 4 the wind components are the combination of the large scale value and the mesoscale value. In the contour diagrams of Figures 3-6, mark '*' denotes the site of GOTEX II experiment, 'I - - - - I' indicates the lake area.

3.1 Onset of the lake breeze

As shown in Figure 3, the lake breeze starts at about 1000 local time. The branch corresponding to the western coastline is weaker and the location of its center is higher than one corresponding to the eastern shore. The onset time simulated with three initialization approaches are consistent with each other and confirmed by the the fact observed at the synoptic station Karlsborg which is located at the western shore.

3.2 Fully developed stage of the lake breeze

The results in the three experiments show that the lake breeze gets in its fully developed stage at about 1530 hours. We can find from Figure 4 that the intensity ratio of two branches of the breeze, respectively located at the western and eastern shore, is different in three cases. The ratio of the eastern branch to the western branch is 7/4 for approach A, 8/3 for approach B, and 7/3 for approach C. From Figure 5 we can see that the vertical speed and temperature fields simulated by approach A and B are quite similar, but Figure 5 (c) presents some interesting features, especially of the upward vertical speed much stronger above the eastern shore.

3.3 Inland advance rate of the lake breeze

TABLE 1. Inland penetrating distance of the eastern branch of the lake breeze.

		local time					
	approach	1100	1230	1400	1530	1700	1830
x (km)	A	7.0	11.0	14.5	16.2	18.0	20.4
	B	8.4	12.0	16.2	20.3	22.3	25.0
	C	5.5	5.5	6.5	8.0	11.0	17.4

note: x is the distance from the eastern shore

It is seen from the Table 1 that the leading edge simulated by approach C progresses slowly during the developing process of the lake breeze and accelerates in the late afternoon; whereas the one of approach B appeares to move in an uniform speed and its penetrating distance is far larger than approach C. It is worth noticing that the hourly observed data fo GOTEX II point out that the lake breeze didn't arrive at the observational site Klockrike located at about 22 km from the eastern coastline.

3.4 Collapse of the lake breeze and variation of the v component

The results in the three experiments show that the lake breeze begins to disappear near the ground shortly after 2000 hours and extends upwards rapidly. Due to the effect of turbulent friction, the increasing period of the mesoscale component v is shortened. The strongest stage of v appears before the collapse of the lake breeze begins. With reference to Figure 6 the strongest stage of v for approach A occurs at about 1830 hours, and for B and C much later even just before the beginning of the collapse. In addition, we can see from Figure 6 that the intensity and extension of the v component are very different in each diagram.

4. CONCLUDING COMMENTS

In mesoscale meteorological numerical modeling, frequently there is only one radiosonde station with soundings in the area of interest. In this situation, how to minimize the inconsistencies between the initial values and the true atmospheric state as well as with the model is a primary but rather difficult procedure. In order to obtain the representative initial values for the integration, the following measures should be adopted: first, to choose a reasonable starting time for the simulation; second, to separate the meteorological noice (namely, high frequency gravity waves) from the data.

Usually in the early afternoon, due to strong turbulent mixing over land, the atmosphere within the planetary boundary layer presents the characteristics of guasi-neutral stratification, therefore it is advisable for some mesoscale meteorological simulations to begin in the early afternoon. However, for sea or lake breeze study, since the temperature contrast between the land and the water surfaces is the predominant factor in generating sea or lake breeze circulation, it should be preferable to choose a starting time when the land temperature nearly equals that of the water surface. Generally, in this case it is more reasonable to choose a time in the late afternoon than in the early morning.

In this paper we have discussed three initialization approaches which can be utilized when only one radiosonde site is presented in the area of interest. The results from the three initialization approaches illustrate that the onset, maturity and collapse of the lake breeze is mainly controlled by the temperature contrast between the land and the lake surfaces, thus the simulated times of occurence of the above three stages, respectively, agree with each other. However, the extension and the intensity of the lake breeze are different in the three experiments, although almost all the conditions are the same, except for the synoptic scale wind at low levels. We can conclude that the result of the initialization procedure strongly affects the simulation. In a comparison, we find that for a two-dimensional, primitive equation model the initialization procedure the one-dimensional dynamic model with nudging, probably is more advisable than the others. The values seem to be more realistic in this case since they take into account the actually observed values at the site. As a consequence the simulation will be more realistic.

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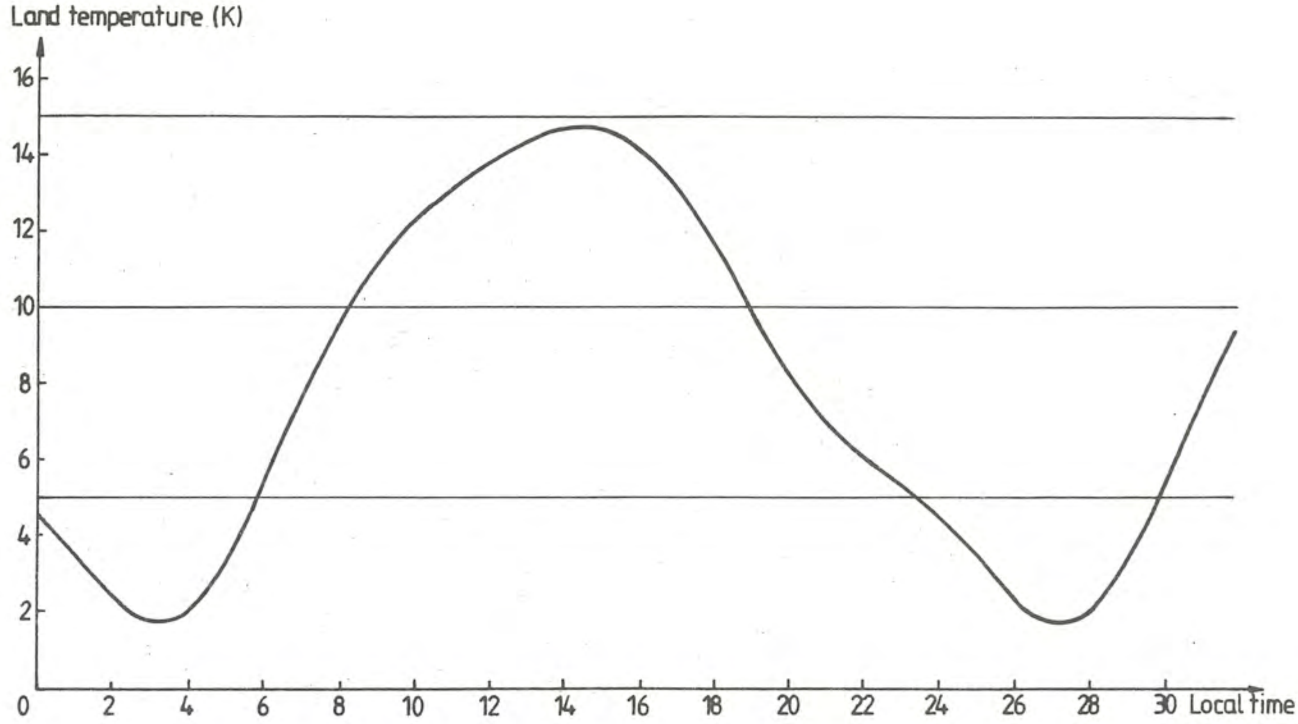

FIGURE 1. Diurnal variation of land surface temperature.

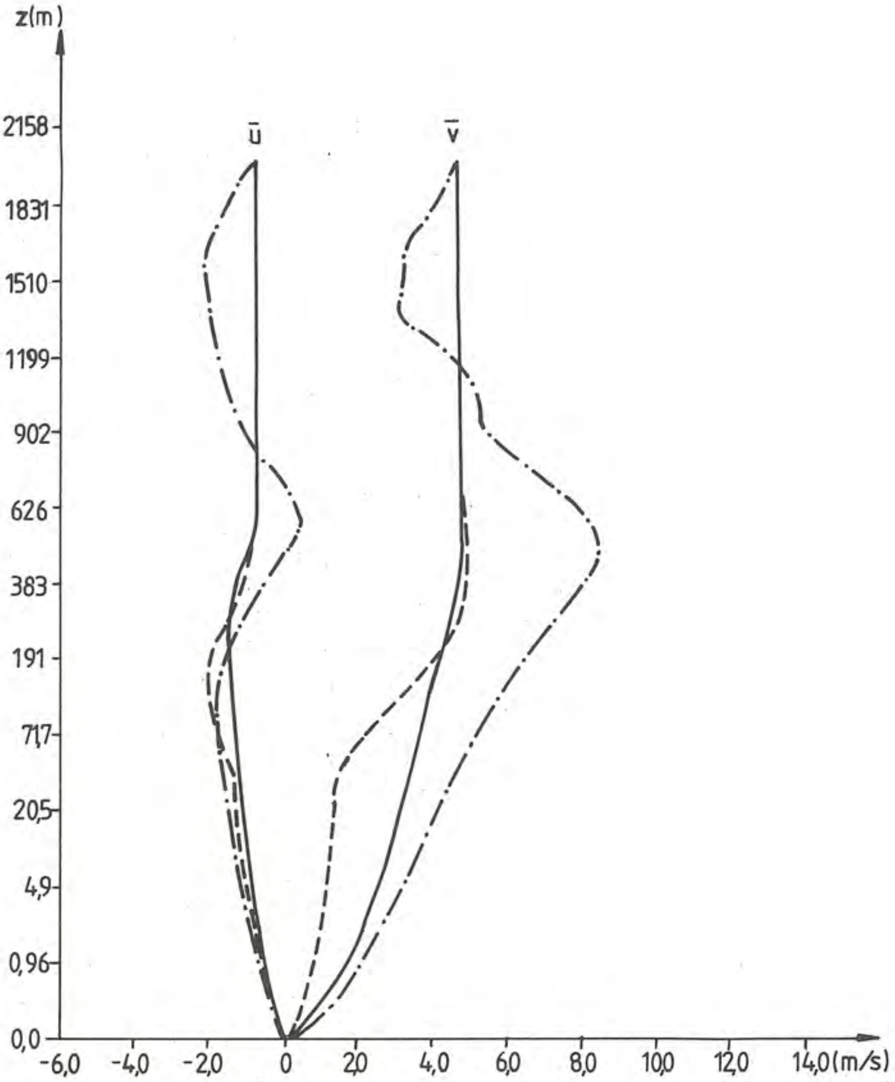

FIGURE 2. Large scale wind components given, respectively by initialization approach A, B, C; the full line corresponds to approach B, the dashed to A and the dashed-dotted to C.

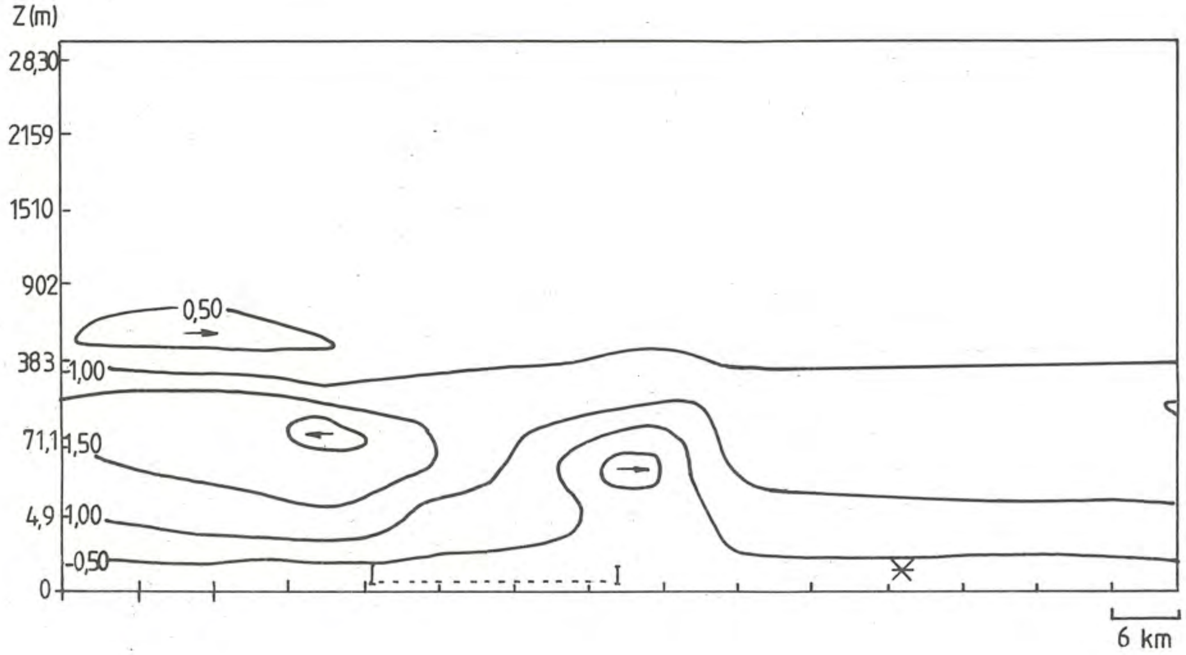

FIGURE 3. Field of wind component U when the lake breeze starts at about 1000 local time.

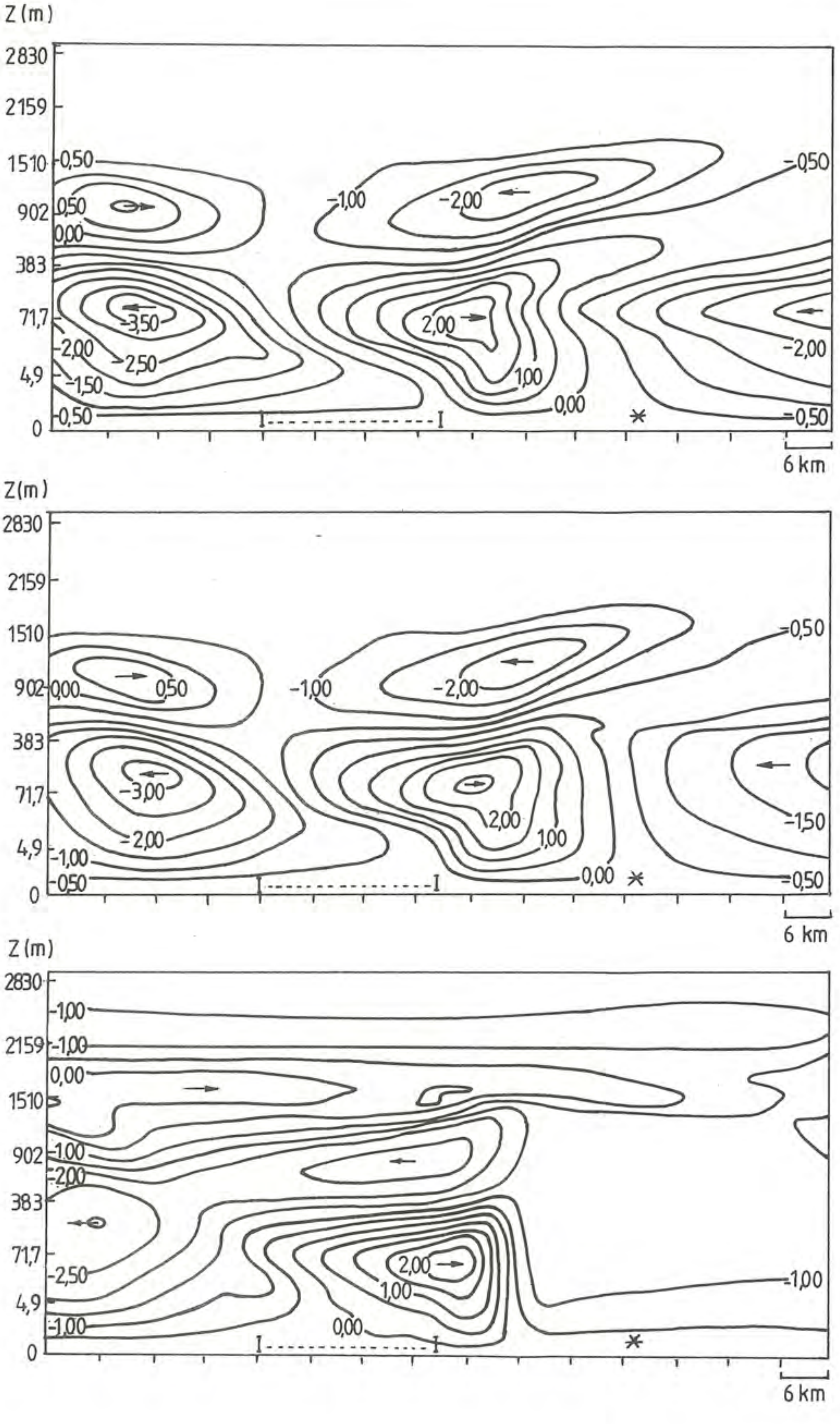

FIGURE 4. Full U component of wind speed at the fully developed stage of the lake breeze circulation.

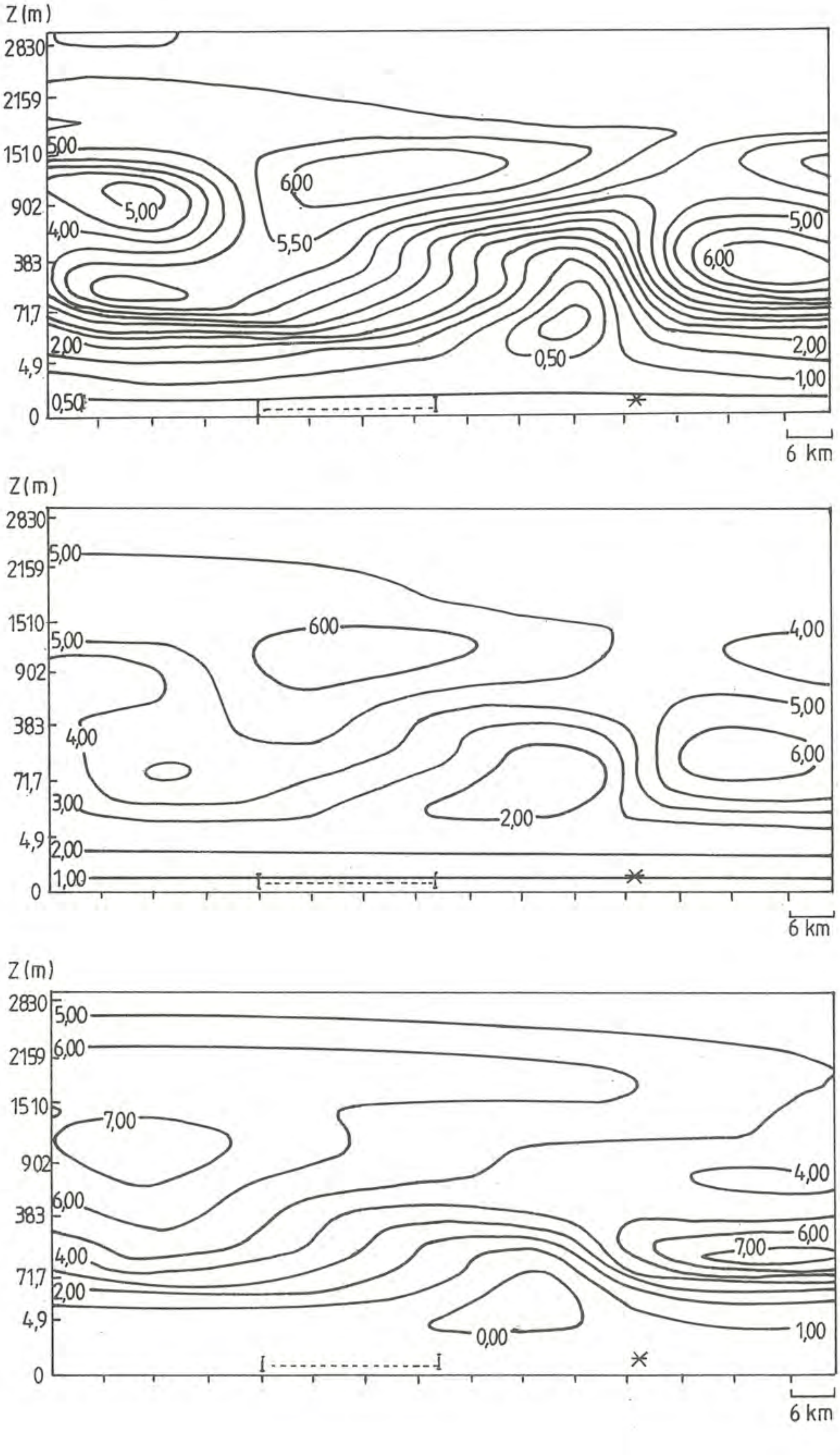

FIGURE 5. Vertical speed and potential temperature ($\Theta - T_{lake}$) fields at fully developed stage of the lake breeze circulation.

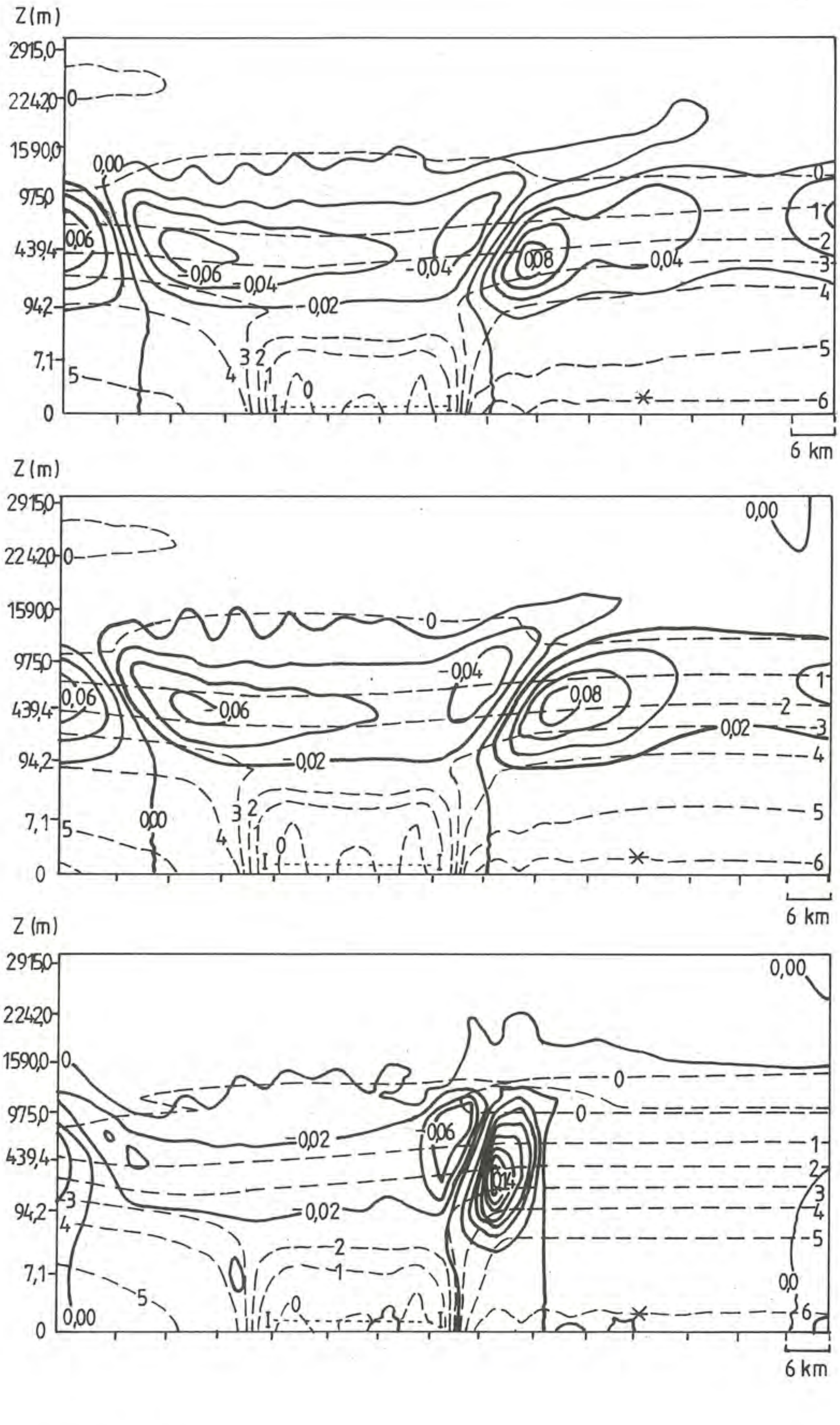

FIGURE 6. The strongest stage of the mesoscale v component of the lake breeze circulation at 2000 local time for (b) and (c), and at 1830 local time for (a).

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