NOTES AND CORRESPONDENCE

Supplementary Note on "A Scheme of Dynamic Initialization of the Boundary Layer in a Primitive Equation Model"

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ABSTRACT

A scheme is presented for improving the previously proposed method of dynamic initialization of the boundary layer in a primitive equation model (Kurihara and Tuleya, 1978). Performance of the revised scheme is shown for the case of a strong vortex superposed on a zonal flow.

1. Introduction

The purpose of this note is to describe an improved scheme for the dynamic initialization of the boundary layer. The dynamic initialization scheme proposed by Kurihara and Tuleya (1978) is able to establish a reasonable structure of the boundary layer when it is applied to a simple zonal flow and also to an isolated hurricane, as shown in their paper. A major point of their scheme is that the time integration of the momentum equation for the boundary layer is performed under a constraint of a fixed mass field. The mass field is determined from the wind field near the top of the boundary layer using the reverse balance equation. The effect of the frictional force is incorporated into the boundary layer as the time integration is carried out. Note that, in the abovementioned special examples, the wind field remains unchanged or changes very little, if the frictional effect is excluded from the integration.

The original scheme was later applied to cases in which a vortex was superposed on a basic background flow. In these cases, a large acceleration of wind was observed in certain areas of the flow field during the dynamic initialization of the boundary layer. This large acceleration was caused by the advection of the vortex away from the pressure low. Throughout the present note, it is presumed that the wind and mass fields at the start of the dynamic initialization are in a state of frictionless balance. By definition, a balanced wind field neither has nor excites divergence. However, it may yield time changes in the vorticity field as was observed by the movement of the vortex. In this case, a time integration of the momentum equation for a fixed mass field causes, even without a frictional effect, a state of dynamic imbalance, resulting in a large local acceleration. This aspect was overlooked in the previous paper.

The above argument suggests that an improved boundary-layer initialization scheme should be one which maintains a balanced flow field if the frictional effect is neglected during the integration. In the scheme described here, artificial forcing is assumed in computing the time change of momentum so that the disturbance is kept from moving while the frictional force induces a divergent component and reduces the rotational component of the wind. A feasible scheme having the above feature was found by trial and error.

2. A revised scheme and its application

The equation for obtaining a momentum change during the boundary-layer initialization process may be written in the symbolic form

$$\frac{\partial \mathbf{v}}{\partial t} = \mathbf{A} + \mathbf{B} + \mathbf{C} + \mathbf{D}, \qquad (1)$$

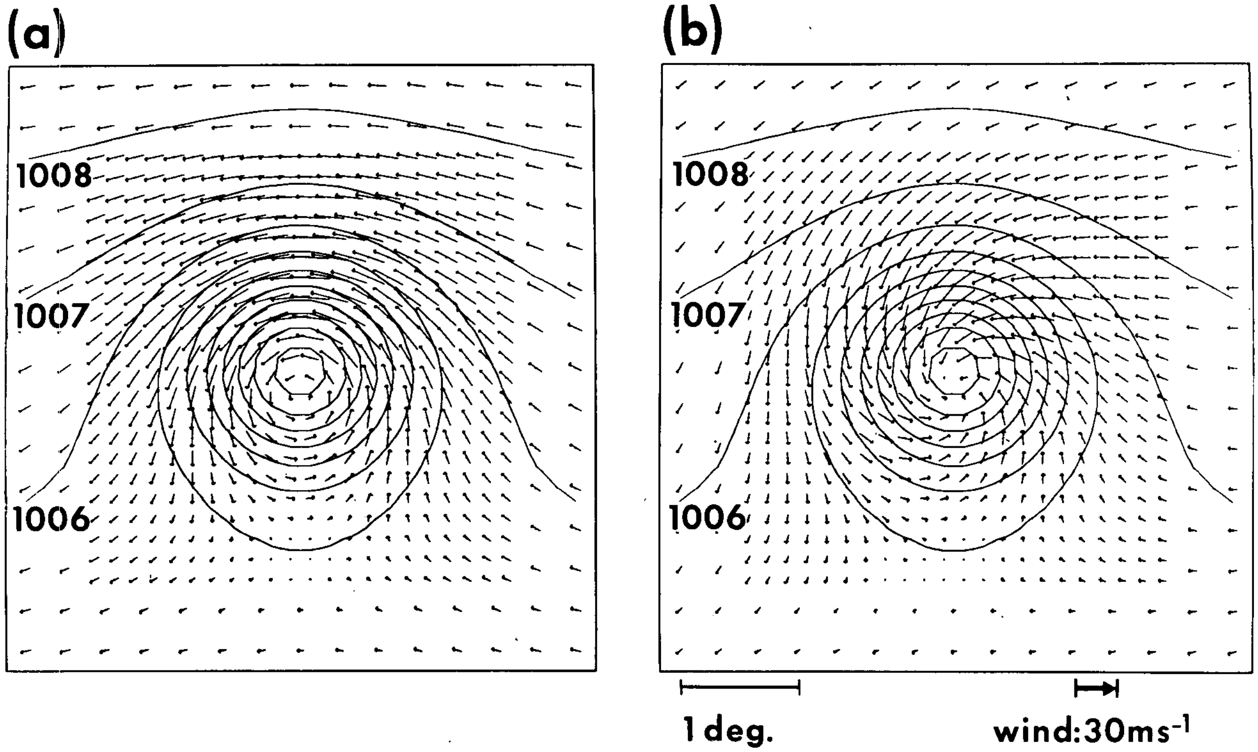

FIG. 1. Wind vectors at the lowest level of the model (~68 m level) and the surface pressure distribution (a) before and (b) after the dynamic initialization of the boundary layer.

where $\mathbf{v}$ is the horizontal wind vector, $\mathbf{A}$ represents an inertial force, i.e., $-\mathbf{v}\cdot\nabla\mathbf{v}$, $\mathbf{B}$ is the sum of the Coriolis force and pressure gradient force, $\mathbf{C}$ a frictional force and $\mathbf{D}$ an artificial forcing term. The problem is how to formulate $\mathbf{D}$ so that the requirements made in the last section are met by (1).

The term $\mathbf{A}$ can be divided into two components,

$$\mathbf{A} = \mathbf{A}_t + \mathbf{A}_n, \tag{2}$$

where $\mathbf{A}_t$ is a component of $\mathbf{A}$ in the direction of the instantaneous wind, i.e., $\mathbf{A}_t = [(\mathbf{A}\cdot\mathbf{v})/|\mathbf{v}|](\mathbf{v}/|\mathbf{v}|)$, and $\mathbf{A}_n$ is a component normal to the wind.

As mentioned before, a balanced wind field at the start of the initialization should not be changed by the integration of (1) if $\mathbf{C} = 0$. No momentum change will occur in the absence of friction if

$$\mathbf{D} = -(\mathbf{A}^0)_t - [(\mathbf{A}^0)_n + \mathbf{B}^0], \tag{3}$$

where $\mathbf{A}^0$ and $\mathbf{B}^0$ denote the values at the start of the integration. The inclusion of the frictional effect will modify the initial wind field in such a way as to cause divergence and reduce vorticity. It is now presumed that if a change in the wind field from the initial state is moderate, an artificial forcing which resembles (3) would prevent the movement of the disturbance. Also, such a forcing should be reduced as the wind speed is decreased by the frictional effect. A simple forcing which will respond appropriately to a gradual change of wind may be formulated as

$$\mathbf{D} = -\mathbf{A}_t - [(\mathbf{A}^0)_n + \mathbf{B}^0](|\mathbf{v}|/|\mathbf{v}^0|). \tag{4}$$

The above empirical formula was chosen after the examination of various different schemes. The first term on the right-hand side of (4), which always works to suppress the advective acceleration in the wind direction, becomes small when the wind speed is lowered. The factor $|\mathbf{v}|/|\mathbf{v}^0|$ is used to reduce the magnitude of the second term for a decreased wind. [The quantity $(\mathbf{A}^0)_n$ is defined as the component of $\mathbf{A}^0$ in the direction perpendicular to wind vector $\mathbf{v}$ at any given instant. It is given by $\mathbf{A}^0 - (\mathbf{A}^0)_t$, where $\mathbf{A}^0 = -\mathbf{v}^0\cdot\nabla\mathbf{v}^0$ and $(\mathbf{A}^0)_t = [(\mathbf{A}^0\cdot\mathbf{v})/|\mathbf{v}|](\mathbf{v}/|\mathbf{v}|)$. The ratio $|\mathbf{v}|/|\mathbf{v}^0|$ was set to 1, if $|\mathbf{v}|$ exceeds $|\mathbf{v}^0|$ for any reason. For very weak wind, $\mathbf{A}$ becomes negligibly small. In such a case, $\mathbf{A}_n$ was set equal to zero by letting $\mathbf{A}_t = \mathbf{A}$.] Note that the forcing (4) reduces to (3) at the start of the integration. Accordingly, if $\mathbf{C} = 0$, the balanced wind field is not altered by the integration of (1). In the case of the two examples in the previous paper (Kurihara and Tuleya, 1978), $\mathbf{D}$ almost vanishes as both terms on the right-hand side of (4) are approximately equal to zero.

The improved dynamic initialization scheme uses (1) with the forcing (4). It has been successfully applied to the case in which a vortex or a wave is superposed on a background zonal flow. In all cases, the disturbance stayed at the initial location during the integration period and a reasonable structure of the boundary layer was established. One example is presented in Fig. 1. The left part of the figure shows the distribution of the wind vectors at the lowest level of the model, i.e., at about the 68 m level, before the boundary-layer initialization. In this example, the wind field was initially independent of height. Fig. 1 also shows the surface pressure field which was obtained from a reverse balance equation. The area shown in this figure is the region of the finest mesh together with a surrounding zone of coarser resolution in a nested mesh model. The finest mesh with a 1/6° latitude-longitude resolution contains a cyclonic vortex, which has a maximum wind speed of 20 m s^{-1} and is superposed on a zonal flow of 10 m s^{-1}. The dynamic initialization for the above wind field was performed by the integration of (1) for a fixed mass field. The physics of the model are similar to those explained in the paper by Kurihara and Tuleya (1978). The wind field, which was obtained after a 12 h integration with a 30 min time step, is shown in the right part of Fig. 1. The vortex did not move and a converging flow pattern with reduced wind speed was established. The adjustment to the flow pattern in the boundary layer was almost achieved by 8 h and the field change after that was small. After the dynamic initialization, the time integration of the model was performed for certain cases. The results indicate that the improved initialization scheme was able to establish a reasonable structure of the boundary layer and the time integration could start with minimal change in the boundary-layer wind.

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