Simulative improvement of Hurricane Andrew using the Technique of Irreversible Thermodynamic Operators

YING LIU and CHONGJIAN LIU
the Chinese Academy of Meteorological Sciences

1.Introduction

Generally a numerical model employs the horizontal diffusion to control the nonlinear instability or computational aliasing. However, the mathematical expression of the second-order scheme can indeed describe the dissipation in the real sense while the fourth-order one which is often used in the NWP models can not.

In this paper, we will reconstruct the stencil of the (fourth-order) horizontal diffusion according to the principle of the physical dissipation with the result that the improvement in the computational accuracy owing to employing the new approach to the horizontal diffusion scheme in MM5V3 will be reached.

2. Methodology

The horizontal diffusion term F_{HA} of a prognostic variable A will often be introduced by adding an additional term to the right-hand side of the corresponding prognostic equation:

$$\frac{\partial A}{\partial t} = N + F_{HA} , \qquad (1)$$

where F_{HA} is the added diffusion term whose form of central difference is

$$(F_{HA})_i = -K_A \nabla^4 A_i$$
$$= K_A[4 (A_{i+1} - A_i) + 4 (A_{i-1} - A_i) - (A_{i+2} - A_i) - (A_{i-2} - A_i)] , \qquad (2)$$

The discrete form of the irreversible thermodynamic operator reconstructed that meets the second law of thermodynamics should be

$$\nabla_T A_i = 4 (A_{i+1} - A_i) + 4 (A_{i-1} - A_i) + (A_{i+2} - A_i) + (A_{i-2} - A_i) , \qquad (3)$$

where, unlike the terms in square brackets of Eq.(2), all the signs except for the one of the terms of A_i are positive, which is able to ensure the "normal" diffusion toward A_i from all of its surrounding quantities and thus the correct description of the irreversibility or dissipation of an irreversible thermodynamic system such as the atmosphere will be reached. Correspondingly Eq. (2) should be change into the following form:

$$(F_{HA})_i = K \nabla_T A_i , \qquad (4)$$

where K is the definitely positive modified diffusive coefficient.

3.Results

Hurricane Andrew (1992) is one of the most fully studied cases by the MM5. Here the surface minimum pressure and surface maximum wind velocities that are of importance for the description of a hurricane are emphatically analyzed with the purpose to ascertain the effect of improvement when the new diffusion scheme introduced in the previous section is applied to the model (see Fig.1 and Fig.2).

4. Conclusive remarks

In this paper the improvement of forecast accuracy of a mesoscale numerical weather prediction model through introducing the new diffusion scheme suggested in the section of methodology that incorporates the nature of the second law of thermodynamics is illustrated by use of case experiments on a hurricane. The potential of this approach and its extensive prospects of applications would look to further increase since the principle of this methodology are universal.

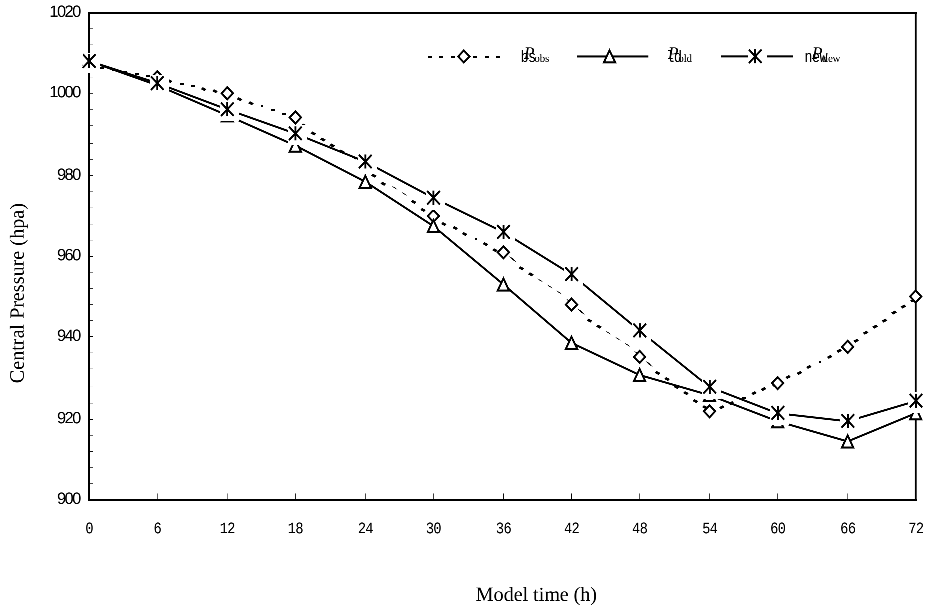

Figure 1. Comparison of the observed change of the surface minimum pressure of the Andrew (1992) with the time from 1200 UTC 21 August to 1200 UTC 24 August, 1992 with the simulated results by the original and improved MM5. P_{obs} – observed pressure P_{old} – simulated pressure by the original MM5 P_{new} – simulated pressure by the improved MM5

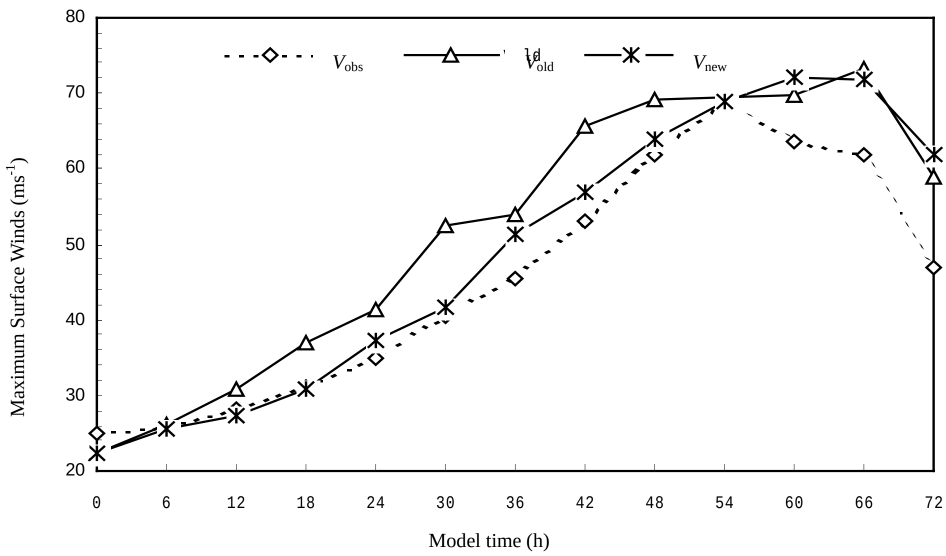

Figure 2. The same as Fig.1 but for the surface maximum wind velocity. V_{obs} – observed wind velocity V_{old} – simulated wind velocity by the original MM5 V_{new} – simulated wind velocity by the improved MM5