A Positive-Definite Solution for an EDMF PBL Scheme that Includes a Moist Adjustment Process

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1. Introduction

The eddy diffusivity and mass flux (EDMF) PBL scheme in the operational Global Forecast System (GFS) uses the following equation to represent the contribution of subgrid transport to the grid-mean cloud water budget equation:

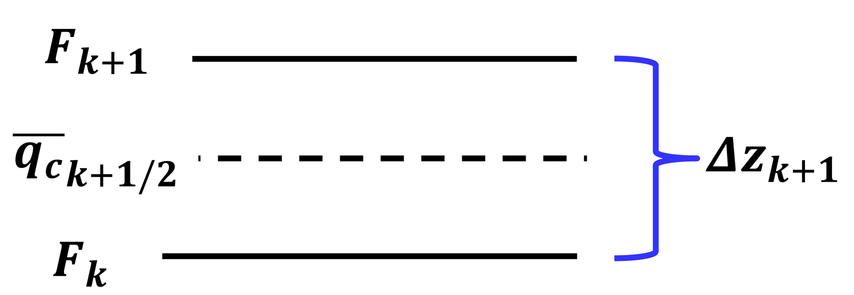
$$\frac{\partial}{\partial t}\overline{q_c} = -\frac{1}{\rho}\frac{\partial}{\partial z}F,$$

where $\overline{q_c}$ is the specific mixing ratio of cloud water, F is its total vertical transport flux due to both local and nonlocal mixing, and ρ is the density of moist air. Discrete numerical procedures to solve this equation must be positive-definite for its solutions to be numerically and physically consistent. This study focuses on using a flux-corrected-transport method to develop a numerical procedure for obtaining positive-definite solutions.

2. The Flux-Corrected-Transport Method

A well-established approach for obtaining a positive definite solution of the above equation is to apply the flux-corrected transport (FCT) method. This general FCT method is simple to use if all that is required is a positive definite transport result. In most NWP models, the equation in question is discretized as the following:

$$\frac{\overline{q_c}_{k+1/2}^{n+1} - \overline{q_c}_{k+1/2}^{n}}{\Delta t} = -\left(\frac{F_{k+1}-F_k}{\Delta z_{k+1}}\right)$$

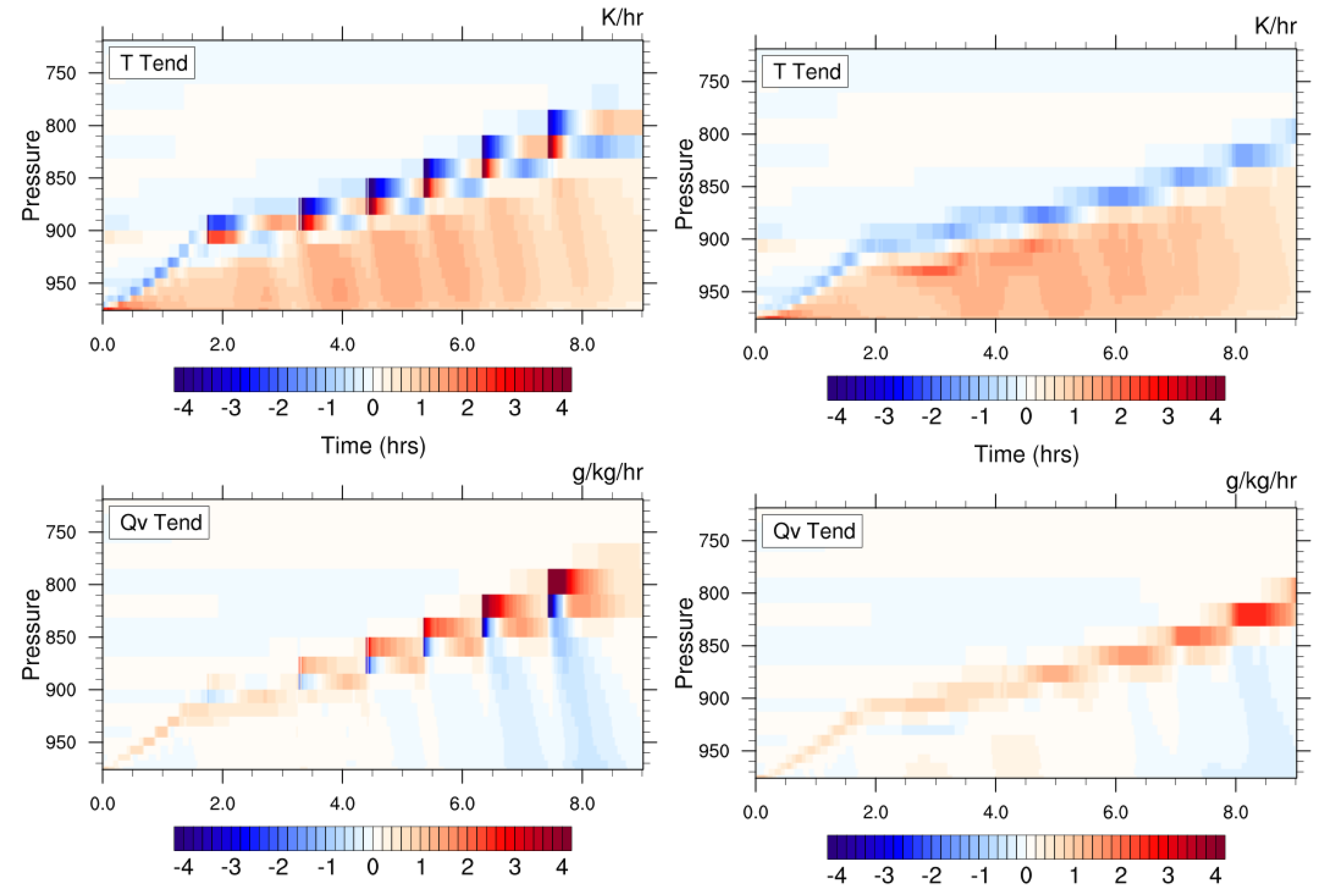


Following Smolarkiewicz (1989, MWR, p. 2626), this discrete form can be used to derive a positive definite transport scheme. That is, the above discrete equation will be positive definite if the actual fluxes are replaced by corrected fluxes of the form:

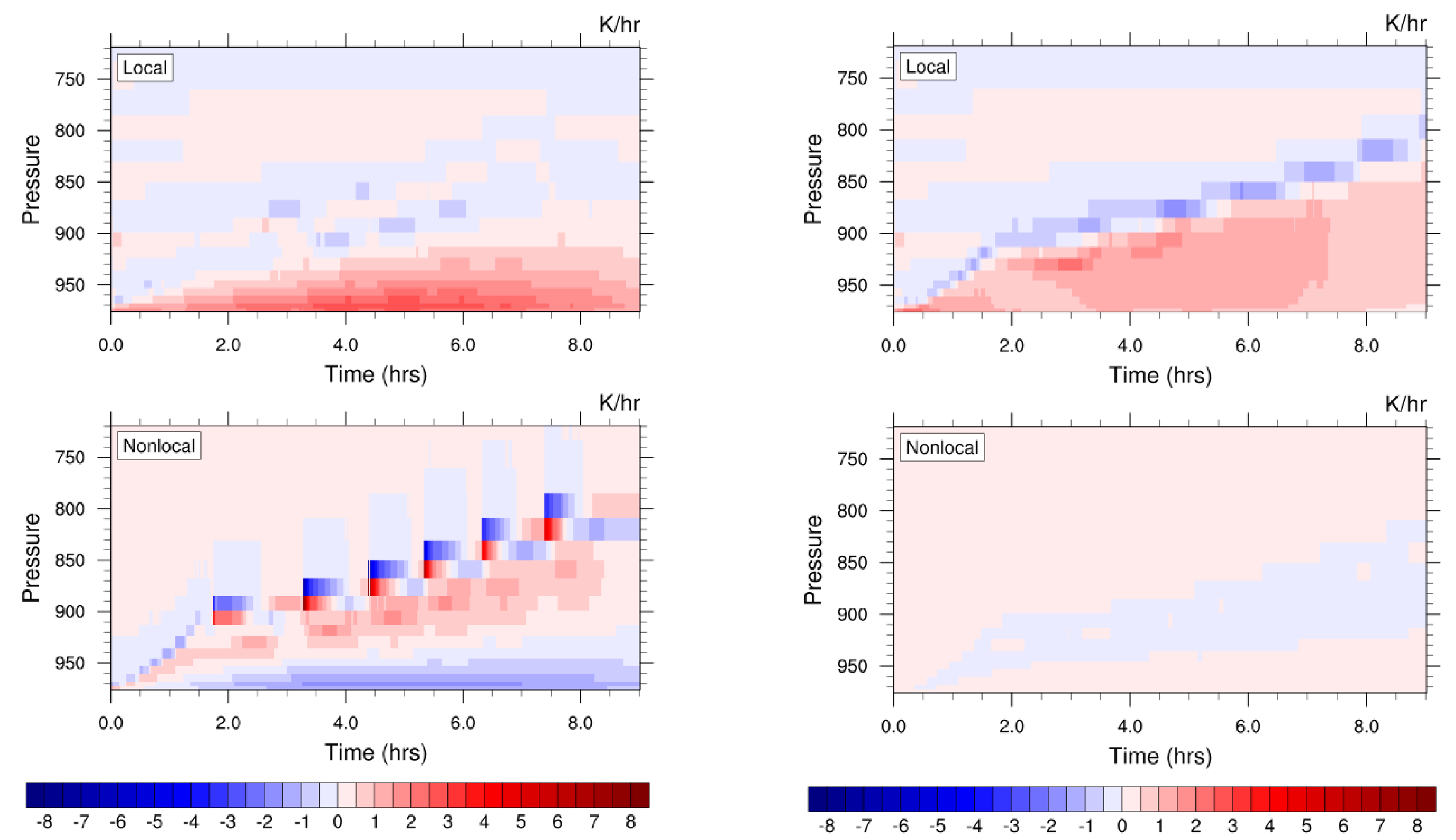
$$CF_{k+1} = max\left(0, min\left(F_{k+1}, \overline{q_c}_{k+1/2}^{n}\frac{\Delta z_{k+1}}{\Delta t}\right)\right).$$

This correction ensures that the outgoing flux is not large enough to cause $\overline{q_c}_{k+1/2}^{n+1}$ to become negative.

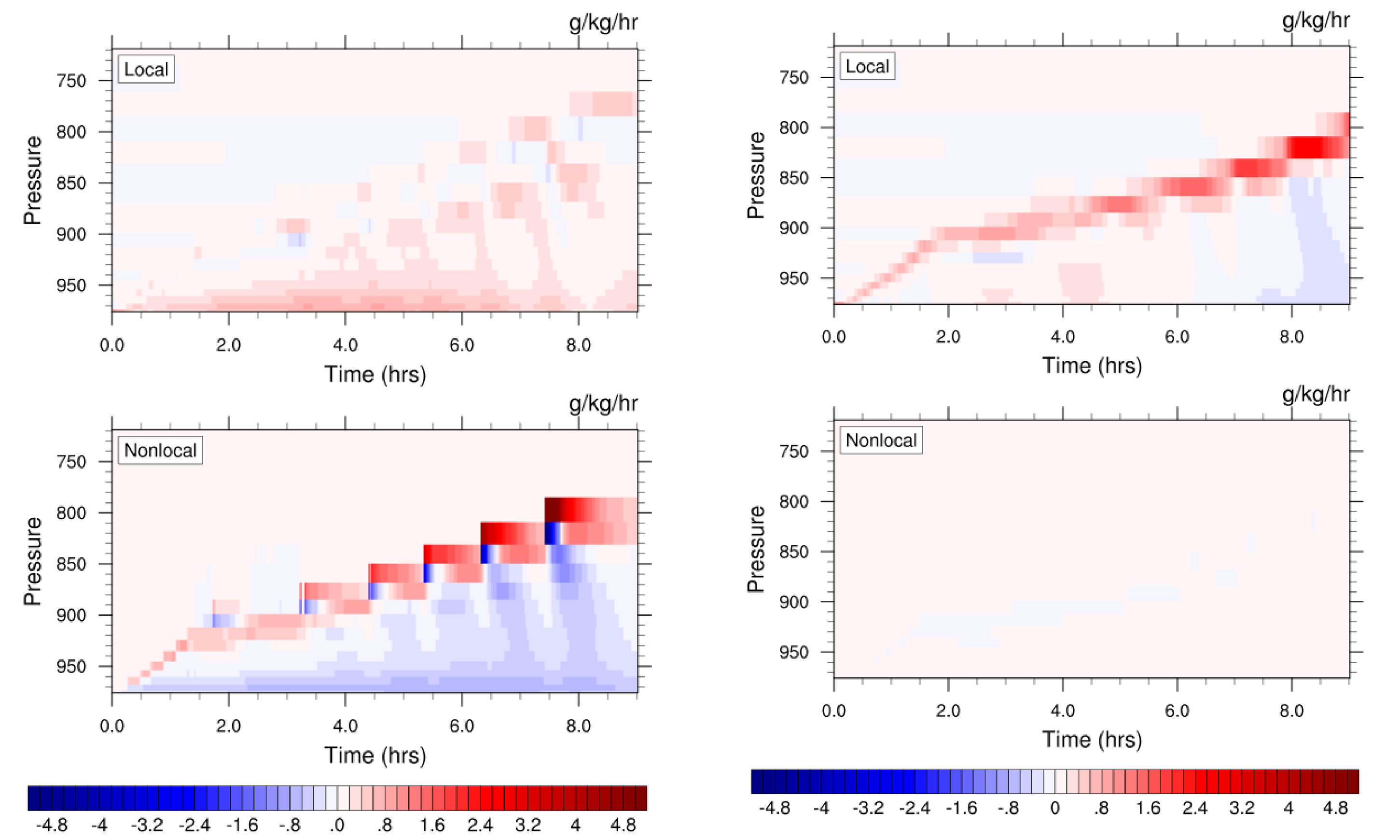
3. A Case Study of a Convective PBL Using SCM Sensitivity Experiments to Illustrate the Existing Problem and a Positive-Definite Solution



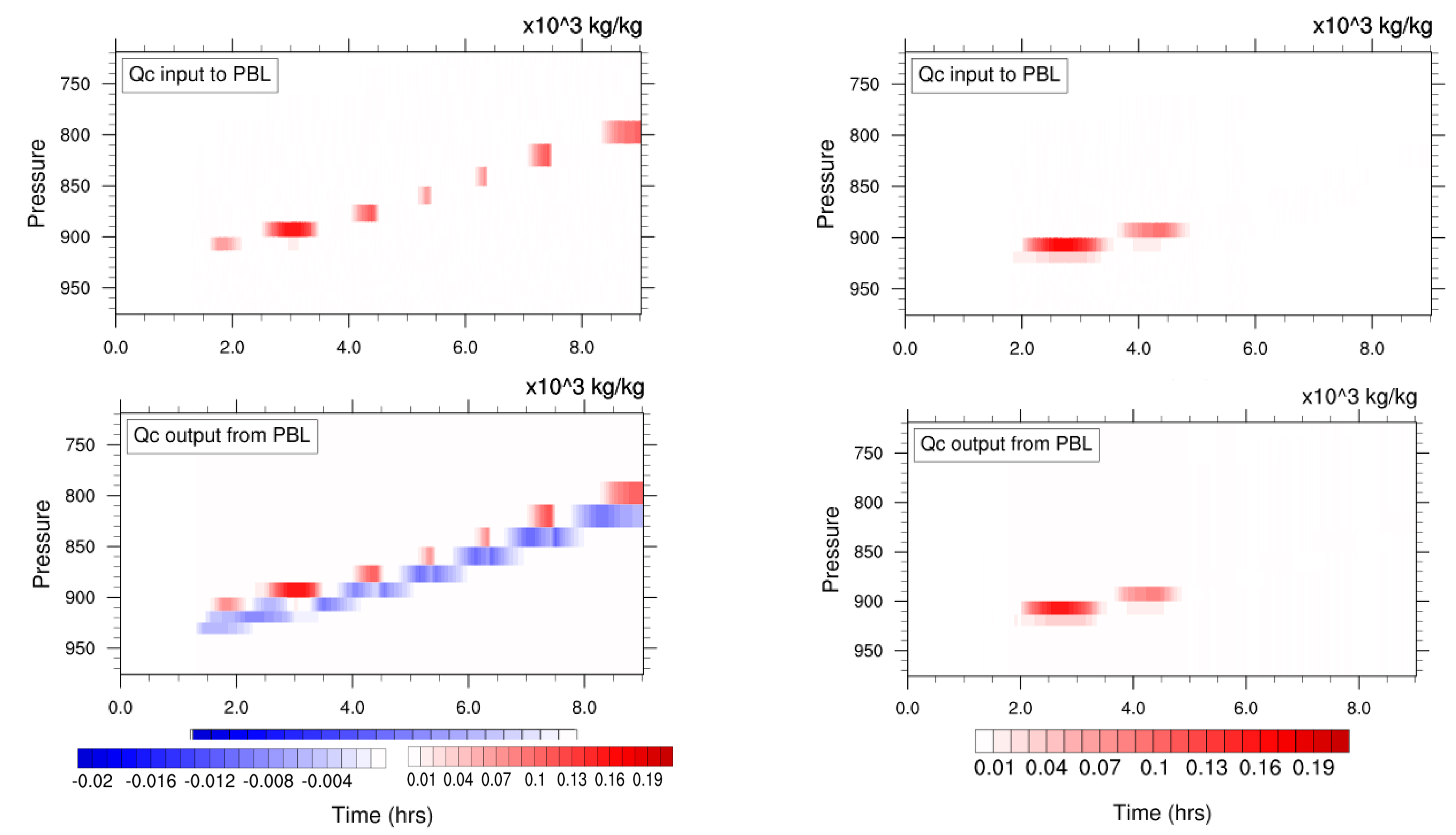
Simulated temperature (top panels) and specific humidity (bottom panels) tendencies from the EDMF PBL scheme for the control run (left panels) and the run with the positive-definite solution (right panels).



Simulated temperature tendency due to the local (top panels) and nonlocal (bottom panels) mixing from the EDMF PBL scheme for the control run (left panels) and the run with the positive-definite solution (right panels).



Simulated specific humidity tendency due to the local (top panels) and nonlocal (bottom panels) mixing from the EDMF PBL scheme between the control run (left panels) and the run with the positive-definite solution (right panels).



Simulated cloud water input to (top panels) and output from (bottom panels) due to the local (top panels) and nonlocal (bottom panels) mixing from the EDMF PBL scheme between the control run (left panels) and the run with the positive-definite solution (right panels).

4. Conclusions

- **The discrete governing equations for the EDMF PBL scheme in the operational GFS are not positive-definite. There is a need to design an effective numerical procedure to ensure the solution of the scheme is positive-definite.**
- **Including the detrained cloud water tendency and its associated temperature and moisture tendencies in the traditional tridiagonal solver for the scheme is the reason for the unphysical distributions of temperature, moisture and cloud water near the simulated PBL top.**
- **A positive-definite numerical procedure demonstrated above is based on a physically and numerically consistent approach, in which the local tendencies are obtained using the traditional tridiagonal matrix solver, but the nonlocal mass-flux-generated tendencies are obtained from a direct solution of the mass flux equation in the same way as those due to shallow or deep convection in the GFS physics suite.**
- **The flux-corrected-transport method is applied in the proposed numerical procedure to ensure that the method for obtaining the total tendencies due to both local and nonlocal mixing is positive-definite.**