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Toward Energetically Consistent Parameterization of Horizontal and Vertical Sub-Grid Mixing for High-Resolution NWP Models

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All numerical weather prediction (NWP) models require parameterizations of sub-grid turbulent mixing in both horizontal and vertical directions. Traditionally, due to the high aspect ratio between the horizontal and vertical dimensions of grids used in NWP models, it is assumed that the parameterizations of horizontal and vertical sub-grid mixing can be parameterized separately and most research efforts in the NWP community to parameterize sub-grid turbulent mixing has been focused on the vertical sub-grid turbulent mixing in the planetary boundary layer (PBL). Consequently, the parameterized vertical sub-grid mixing is formulated according to the vertical mixing theory in the PBL, while the parameterized horizontal sub-grid turbulent mixing in NWP models is formulated to be dependent on the grid-resolved strain rate and used mostly as numerical tuning parameter. Such a framework of parameterizing sub-grid turbulent mixing has a fundamental drawback: the conversion of grid-scale kinetic energy (KE) to sub-grid turbulent kinetic energy (TKE) is not consistently constrained between the vertical and horizontal directions. As the resolution of NWP models increases steadily, such that grid spacing becomes comparable to the typical size of largest energy-containing eddies, a more general and energetically consistent treatment of horizontal and vertical sub-grid turbulent mixing is required to overcome the drawback of the traditional parameterization approach.

This presentation highlights major results from a series of sensitivity experiments with the Advanced Research WRF (ARW) model that were carried out for the purpose of comparing and evaluating a more general and energetically consistent parameterization of horizontal and vertical sub-grid turbulent mixing with two traditional schemes for parameterizing vertical sub-grid turbulent mixing in NWP models that share the same strain-rate-dependent parameterization for horizontal sub-grid turbulent mixing: the K-profile closure and the Mellor-Yamada 1.5-order TKE closure. The same surface layer scheme is used in the sensitivity experiments so that only the sensitivity of the ARW model to different parameterization schemes of the sub-grid turbulent mixing above the surface layer is examined. We will first compare the sensitivity of the asymptotic behavior of the ARW-simulated intensification of an idealized tropical cyclone to the different parameterizations. We will then compare the vertical eddy diffusivities from the two PBL mixing schemes with those estimated from observations. Finally, using the results from the sensitivity experiments and the comparisons of these schemes, we will point out and, more importantly, provide an explanation for an unintended consequence of using the K-profile scheme in the simulation of tropical cyclones: overestimation of vertical eddy diffusivity in the eyewall region. Based on our findings, we will propose a possible route that the research community could take for developing energetically consistent parameterization of horizontal and vertical sub-grid mixing suitable for high-resolution NWP models.