A Mesoscale Convective System Parameterization Scheme for Use in General Circulation Models

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Cloud-resolving simulations of mesoscale convective systems (MCS) have been used to build a parameterization scheme of the thermodynamic forcing by the mesoscale flow branches of MCSs in models with resolution too coarse to resolve these flow branches. This thermodynamic portion of the parameterization is analogous to the formulation of Donner (1993), with improvements that consist of a more sophisticated convective driver and inclusion of the vertical distribution of various physical processes obtained through conditional sampling of two cloud-resolving MCS simulations. The Wu and Yanai (1994) convective momentum parameterization has also been included as a separate component of the parameterization scheme. The momentum scheme includes a parameterization of the convective-scale pressure gradient force and, therefore, can account for the effect of the mesoscale organization of the convection on the large-scale momentum tendencies.

The mesoscale parameterization is interfaced to a version of the Arakawa-Schubert convective parameterization scheme which is modified to employ a prognostic closure, as described by Randall and Pan (1993). The parameterized Arakawa-Schubert cumulus convection provides condensed water, ice, and water vapor which drives the parameterization for the large-scale effects of mesoscale circulations associated with the convection. In the mesoscale thermodynamic parameterization, determining thermodynamic forcing of the large scale depends on knowing the vertically integrated values and the vertical distributions of phase transformation rates and mesoscale eddy fluxes of entropy and water vapor in mesoscale updrafts and downdrafts. The relative magnitudes of these quantities are constrained by assumptions made about the relationships between various quantities in an MCS's water budget deduced from the MCS simulations. The MCS simulations include one of a tropical MCS observed during the 1987 Australian monsoon season (EMEX9), and one of a midlatitude MCS observed during a 1985 field experiment in the central Plains of the United States (PRE-STORM 23-24 June). In both simulations, the grid spacing on the finest grid is fine enough (1500 m for EMEX9, 2083 m for PRE-STORM) that no convective parameterization scheme is required to sustain convection. The analysis of output from these simulations focuses on conditional sampling of the stratiform region of each system. The conditional sampling of the fine grid data attempts to identify mesoscale updrafts and mesoscale downdrafts within the stratiform region of each system. The thermodynamic part of the scheme is tested by feeding the scheme mean soundings from the simulations and comparing the parameterized tendencies with tendencies diagnosed from conditional sampling of the simulations.

The momentum part of the scheme is tested by feeding the scheme grid mean soundings and comparing the parameterized momentum tendencies with diagnosed momentum budget residuals. For each MCS, an effort is made to see whether including the convective-scale pressure gradient force term improves the performance of the momentum parameterization. For EMEX9, taking this pressure gradient term into account does not improve the results of the momentum parameterization. On the other hand, for the PRE-STORM 23-24 June MCS, including this term does improve the results. Further analysis of the momentum budgets of the cloud-resolving simulations revealed that large momentum flux divergences occur near the tropopause that are not embedded in the conditionally-sampled convective drafts or the mesoscale flow branches. It appears that the strong momentum flux divergences near the tropopause may be either due to gravity waves or non-surface-rooted convective cells in the stratiform anvils.

The decision to activate the mesoscale flow branch parameterization scheme is based on the evolution of the total kinetic energy budget. We propose that total eddy kinetic energy can be partitioned into contributions from the deep convection (CKE) and the mesoscale circulation branches (MKE). Two prognostic equations are then developed for CKE and MKE, respectively. The CKE equation is similar to Randall and Pan's except the definition of CKE is slightly different. The CKE is primarily driven by convective updrafts and downdrafts and, once generated, CKE dissipates at a specified rate. The MKE equation has two fundamental sources. Some of the CKE dissipation due to tall clouds is the first source term for MKE. If sufficient convection is maintained to generate a certain threshold in MKE, then the

MCS scheme is activated. Once activated, the second source would account for further MKE generation due to mesoscale heating, pressure gradient forces, and shear production within the mesoscale circulation branches of MCSs. The sink of MKE is defined as a simple dissipation term with a dissipation that is slower than ordinary deep convection owing to their more balanced character.

We examined the interactions between the CKE and MKE as diagnosed from the output of explicit cloud-resolving simulations of the 23-24 June 1985 PRE-STORM MCS and the EMEX9 tropical MCS. In particular, the CKE and MKE budgets were examined, with a view toward identifying a sufficient amount of MKE generation through CKE conversion to activate the MCS scheme. The plots of CKE and MKE vs time show that CKE associated with deep convection builds up to its maximum value within 30 minutes of the beginning of the model simulation, while MKE usually follows the evolution of CKE to reach its maximum value in one to two hours after the CKE maximum, then gradually decreases to one third of its maximum value in about four hours, which is long enough for an MCS to remain its mesoscale organization.

Currently, we are testing our hypothesis with soundings from non-MCS, deep-convective cases to gain better understanding the behavior of CKE and MKE.

Plans are to test the scheme against independent data sets obtained during Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE) and from the Atmospheric Radiation Measurement (ARM) program Great Plains Cloud and Radiation Testbed (CART) site.

References

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