Parameterization Tests for the Atmospheric Radiation Measurement Program

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Comparison of Cumulus Parameterizations

Until Atmospheric Radiation Measurement (ARM) data become available, we are using our single-column model as a testbed to improve and validate parameterizations. As an example of this research, we describe a set of numerical experiments undertaken to compare the results of two cumulus convection parameterizations. The two parameterizations are the Kuo-Anthes scheme (Kuo 1974; Anthes 1977) and the Arakawa and Schubert scheme with and without downdrafts included (Arakawa and Schubert 1974; Kao and Ogura 1987; Ogura and Kao 1987).

The model is a one-dimensional diagnostic model (Iacobellis and Somerville 1991a, 1991b) resembling a single column of a general circulation model. The model includes vertical atmospheric transports by convection and turbulent mixing, radiative transfer including interactive clouds, and a surface energy balance coupled to an ocean mixed-layer model. At each timestep, observational analyses are used to supply the model with the horizontal advection of heat and moisture. Output from the model includes time series of sea surface temperature, oceanic mixed-layer depth, atmospheric temperature and humidity profiles, precipitation and surface energy budget components.

The initial version of this model, which incorporated the cumulus parameterization of Kuo-Anthes, was used in a diagnostic study of the onset of the Indian summer monsoon (Iacobellis and Somerville 1991a, 1991b). In that study the model was run for four weeks beginning about three weeks before the onset of the monsoon. A comparison of the results against independent observational data indicated that the column model is capable of simulating the evolution of the heat and moisture budgets prior to and during the monsoon onset.

For the present study, the Arakawa-Schubert (AS) cumulus parameterization has been incorporated. Thus the model can be run with either the Kuo or the AS parameterization. This version of the AS parameterization includes the effects of downdrafts as discussed by Kao and Ogura (1987) and Ogura and Kao (1987).

Initial Experiments

This preliminary work employs the same locations and four-week integration period as that of Iacobellis and Somerville (1991a, 1991b). This period begins at 00UT 27 May 1979 and runs until 00UT 23 Jun 1979. The monsoon onset occurs on approximately 15 Jun 1979. In the following discussion, we denote the initial time as "hour 0" and measure time in hours from 00UT 27 May 1979.

Semi-Prognostic Experiments

The model is first run in a semi-prognostic mode in which the temperature and humidity fields used by the cumulus convection parameterizations are specified at each timestep from FGGE observational data. The results compared here include the convective rainfall, the apparent heating source (Q1), and the apparent moisture sink (Q2) produced by the two cumulus parameterizations. For detailed definitions and discussion of Q1 and Q2, see, e.g., Yanai et al. (1973).

In this section the results of the Kuo parameterization are compared against two variations of the AS parameterization that differ in the specified strength of the downdrafts. The following abbreviations will be used to distinguish the different cumulus parameterizations, with e as defined in Eq. (5.10) of Kao and Ogura (1987):

KUO-SP	Kuo-Anthes parameterization
ASE0-SP	Arakawa-Schubert parameterization, no downdrafts (e = 0.0)
ASE3-SP	Arakawa-Schubert parameterization with downdrafts (e = -0.3)

Rainfall

The three semi-prognostic experiments produce very similar precipitation results, the most notable feature being a large precipitation maximum occurring around hour 480. The timing and to a lesser extent the magnitude of this precipitation maximum are consistent for all three model runs. KUO-SP shows a complete shutdown of convective precipitation for about 40 hours beginning approximately at hour 566, while both ASE0-SP and ASE3-SP show continuous, albeit reduced, convective rainfall for these hours. The addition of downdrafts increases the magnitude of the convective precipitation.

Apparent Heat Source (Q1) and Moisture Sink (Q2)

The observed apparent heat source indicates that the region of maximum convective heating is approximately at 200-300 mb. The Q1 from KUO-SP shows a maximum at around 500-600 mb, while ASE0-SP and ASE3-SP have a maximum near 300 mb. The inclusion of downdrafts has a cooling effect on the 1000-900 mb region, as one might expect.

The apparent moisture sink, Q2, from the observed FGGE data and from KUO-SP are very similar. Both the location (about 800 mb) and magnitude (13°C/day) of the moisture sink maximum are reproduced by KUO-SP. While the model runs of ASE0-SP and ASE3-SP also show a maximum moisture sink in the lower troposphere at about 850-950 mb, the magnitude of the maximum is 3° to 5°C/day lower than that suggested by the observed data. Including downdrafts in ASE3-SP increases the drying in the lower atmosphere as compared to ASE0-SP.

Model-Interactive Experiments

In this set of experiments the vertical profiles of temperature and humidity are determined interactively by the column model rather than by the FGGE observational data. Thus the results of these experiments may tell us something about how sensitive the convection schemes are to model errors in temperature and humidity, but they should not be used to attempt to determine the merits of a given convective parameterization. The following abbreviations will be used to distinguish the different cumulus parameterizations:

KUO-MI	Kuo-Anthes parameterization
ASE0-MI	Arakawa-Schubert parameterization, no downdrafts (e = 0.0)
ASE3-MI	Arakawa-Schubert parameterization with downdrafts (e = -0.3)

Convective Precipitation

The convective precipitation from KUO-MI looks very similar to the precipitation from the semi-prognostic run KUO-SP, indicating that the Kuo scheme (at least the precipitation-producing component) is not very sensitive to the differences between model and observational temperatures and humidities. Model run ASE0-MI shows considerably weaker precipitation totals during the period after hour 460 than the semi-prognostic case (ASE0-SP). The addition of downdrafts to the AS parameterization (case ASE3-MI) greatly enhances the convective precipitation after hour 460.

Apparent Heat Source (Q1) and Moisture Sink (Q2)

The apparent heat sources (Q1) from all three runs show a distinct maximum in the upper troposphere at approximately 200-300 mb. This maximum heating is much sharper than the heating maximum seen in the semi-prognostic cases. The column model is known to have a cold bias in the upper troposphere (500 mb and above) compared with observational data. It appears that both convective schemes are attempting to alleviate this bias by shifting some of the convective heating to the upper troposphere. The convective heating in the mid-troposphere (about 700 mb) has been drastically reduced in runs ASE0-MI and ASE3-MI compared with their semi-prognostic counterparts.

The apparent moisture sink (Q2) from run KUO-MI exhibits a shape that is similar to KUO-SP, although KUO-MI produces a slightly sharper maximum in the lower troposphere than KUO-SP. The distributions of Q2 from ASE0-MI and ASE3-MI are distorted because of the large maximum in the lower troposphere, making any comparison to their semi-prognostic counterparts difficult. However, it is clear that the Q2 term from the AS parameterization is more affected by differences between model and FGGE temperatures and humidities than is the Kuo parameterization. This generalization is also true for precipitation and the apparent heating term Q1.

References

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