7D3 PERFORMANCE OF THE EMANUEL CUMULUS PARAMETERIZATION SCHEME IN NOGAPS: IMPACT OF RECENT MODIFICATIONS

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1. Introduction

Recent implementation of the Emanuel cumulus parameterization scheme (Emanuel 1991, Emanuel and Zivkovic-Rothman 1999) in the U. S. Navy Operational Global Atmospheric Prediction System (NOGAPS) in place of the Relaxed Arakawa-Schubert scheme (Moorthi and Suarez 1992) has resulted in an overall improvement in the performance of NOGAPS, especially for tropical cyclone predictions. The Emanuel scheme, however, shows some weaknesses. Among them, the most significant characteristics are a warm bias at upper levels, a weak wind bias at all levels, and under-prediction of heavy-precipitation events.

Unique features of the Emanuel scheme include a prognostic determination of the cloud-base mass flux to maintain a sub-cloud layer quasi-equilibrium, distribution of the undiluted cloud mass flux rising through the cloud base into higher levels, and the breakdown of the mixing cloud mass flux at each level into sub-cloud drafts based on the buoyancy-sorting concept (Raymond and Blyth 1986). These features are critical to the performance of the scheme. In this report, we will discuss the results from our recent modification to the scheme, mainly centered on the aforementioned features.

2. Vertical profile of mixing cloud mass flux

The monthly mean zonally averaged vertical heating rate generated by convection using the Emanuel scheme shows two maxima, one at lower levels and another one near 200 mb. Comparison of the vertical heating profile with tropical observations such as in Yanai et al. (1973) indicates that the zonally averaged heating has only one major maximum located in the mid- to lower troposphere. Detailed analyses of the scheme indicate that the vertical heating profile is closely related to the vertical profile of the mixing cloud mass flux, which depends on the vertical profile of the buoyancy gradient. Because buoyancy is generally largest in the middle of convective clouds and vanishes near cloud base and cloud top, the vertical gradient of buoyancy tends to have a minimum at mid- to lower levels, and greater values above and below this point. This appears to be the reason for the observed double-peaked distribution of convective heating in the model. Thus we modify the scheme so that the vertical profile of the mixing cloud mass flux is a function of buoyancy instead of the buoyancy gradient. This modification removes the secondary heating maximum near 200 mb, and produces a profile that conforms more closely to the observed tropical heating profiles. In a long- term update cycle integration, this modification leads to an improvement of the statistical scores globally. The prediction of tropical cyclones for August and September of 1999 has been improved, with the average 120h distance error reduced from 295 nm to 250 nm. This modification was implemented into the operational NOGAPS in May 2001.

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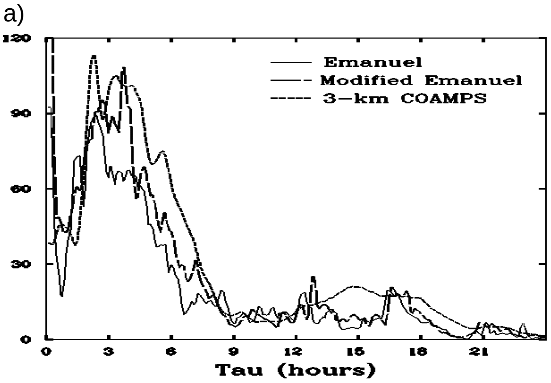
3. Determination of cloud base

The Emanuel scheme suffers from insufficient precipitation for heavy events, too much light precipitation, and a phase error for the onset of precipitation. To investigate these problems, we use COAMPS™ (Hodur 1997) as a test bed for potential improvement of the scheme.[1] Parameterization performance is studied in a single column model (SCM) version of COAMPS (Ridout 2001) that is forced using data from a COAMPS 24h explicit simulation on a 3-km grid of convection that occurred in Oklahoma and Kansas in August 1995. A series of coarse resolution (54-km) simulations with the SCM using the Emanuel scheme is compared with the corresponding area-averaged high-resolution (3-km) COAMPS data. One feature that stands out in this comparison is that the updraft mass flux in the Emanuel scheme extends down to low levels throughout the period of integration, whereas in the high-resolution run, the updraft originates from higher levels as the convective event progresses. In the original Emanuel scheme, the source level for convection is chosen to coincide with the low-level maximum in moist static energy. This selection criterion appears reasonable, but can lead to underprediction of precipitation because the associated cloud base mass flux, which is based on parcel buoyancy near and below cloud base, can be unrealistically small. The resultant underprediction of heavy rainfall in the SCM is consistent with what is observed in NOGAPS. To correct for this weakness in the scheme, we have tested a revised treatment that selects the source level so as to maximize parcel buoyancy at the corresponding lifting condensation level. The modified treatment improves on the original scheme by assuring that the magnitude of the updraft mass flux is more realistically represented. Testing of this modification in the COAMPS SCM indicates that the parameterization can now more adequately represent the range of updraft source levels.

[1] COAMPS™ is a trademark of the Naval Research Laboratory.

The change gives a positive impact on the amount of convective precipitation (Fig. 1) and a reduction in the temperature error at mid- to upper levels. This modification, along with a change to cap convection at the level of vanishing buoyancy rather than vanishing CAPE, was made to the current operational version of NOGAPS for testing. Note that the operational version already contains the modification made to the vertical profile of mixing cloud mass flux, discussed in section 2. A two-month series of 5-day forecasts in an update cycle integration shows very encouraging results (Fig. 2). This modification is in the beta-test period for potential implementation into operational runs.

a)



b)

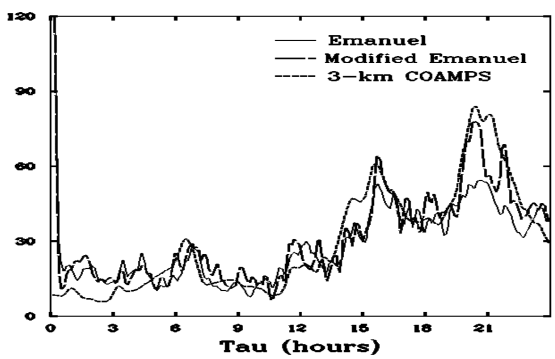
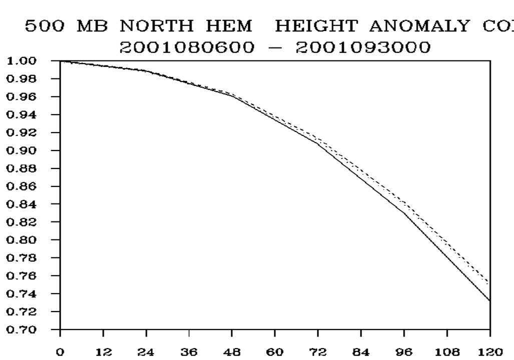


Figure 1. Convective precipitation from the SCM simulations compared with the corresponding 3-km COAMPS rainfall (mm day^{-1}); a) August 1995 U.S. High Plains, b) December 2000 tropical Pacific.

a)



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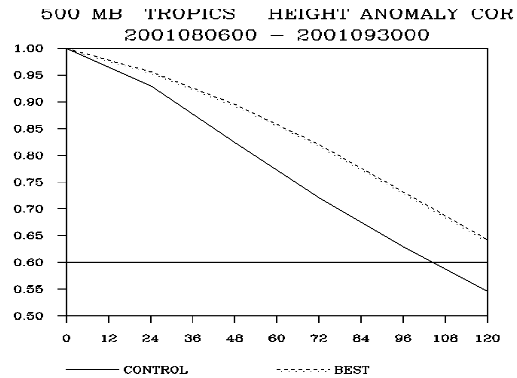

Figure 2 (a) Comparison of the anomaly correlation at 500 mb for the Northern Hemisphere; b) Comparison of the anomaly correlation at 500 mb for the Tropics (30S to 30N). The solid line is the control and the dashed line uses the modified Emanuel scheme.

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