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ON THE PARAMETERIZATION OF MESOSCALE CONVECTIVE SYSTEMS IN REGIONAL CLIMATE MODELS OVER SOUTHERN AFRICA

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ABSTRACT

Mesoscale Convective Systems (MCS) are organized groups of thunderstorms that range in horizontal dimension from 5-500 km and typically possess lifetimes of 6-24 hours. Vertical motions within MCSs could be as significant as horizontal motions. These updraughts and downdraughts impact heavily on local rainfall, wind, lightning and other forms of severe weather. However, their limited lateral extent and timescale do not often make them evident on synoptic charts. These also keep them at sub-grid levels in most climate models. It seems therefore that a realistic understanding of MCSs lies in the correct formulation of the physics and dynamics associated with them. This is more so in tropical Africa where more than seventy per cent of precipitation is associated with MCSs. These dynamics are examined with a linearised inviscid form of the hydrodynamical equations, solved in shear with the aid of a two-layer model of the atmosphere, which is consistent with the synoptic situation over tropical Africa. The set of hydrodynamical equations were transformed into their equivalents in pressure co-ordinates, and following the elimination of various perturbation unknowns, a frequency equation was obtained after linearization:

$$\frac{\partial^2 \omega}{\partial p^2}+\frac{g\Gamma}{p_s^2}\left(\frac{\alpha^2+\beta^2}{\sigma^2}\right)\left(1 - \mu_1 . \frac{\alpha u_s}{\sigma}\right)\omega = - \mu_2 \frac{f}{\sigma}\frac{\partial}{\partial p}(\beta u_s)$$

where the atmospheric static stability is expressed in units of length as:

$$\Gamma = \frac{R^2 T_s}{g^2}\left[\frac{g}{C_p}\left(1 - \frac{\mu_3 L P_s \partial r}{R \theta_s \partial p}\right) - \gamma\right]$$

Application of boundary conditions stated in Adedoyin(1989b) gave rise to an eigenvalue equation:

$$\begin{aligned}
&\sigma_0^2\left\{\left[2\lambda_1\left(\frac{1+R_1}{1-R_1}\right)+1+D_1\right]-\left[2\lambda_2\left(\frac{1+R_2}{1-R_2}\right)+1+D_2\right]\right\}\\
&+\sigma_0\left\{2\alpha u_1\left[2\lambda_1\left(\frac{1+R_1}{1-R_1}\right)+1+D_1\right]-2\alpha u_2\left[2\lambda_2\left(\frac{1+R_2}{1-R_2}\right)+1+D_2\right]\right\}\\
&+\left\{\alpha^2 u_1^2\left[2\lambda_1\left(\frac{1+R_1}{1-R_1}\right)+1+D_1\right]-\alpha^2 u_2^2\left[2\lambda_2\left(\frac{1+R_2}{1-R_2}\right)+1+D_2\right]\right\}=0
\end{aligned}$$

Results over tropical Africa from this equation confirm the existence, among others, of: a westward-propagating perturbation of wavelength 100 km, phase speed of 7.7 m s^{-1}, period of 3.6 and an

amplification of 1.8 per hour (which has been shown by Adedoyin(1989a) to trigger the dominant MCS in tropical Africa namely, line squalls) and a wave-like disturbance which has a phase speed of 6.0 ms^{-1} in the East-West direction, a wavelength of 2000 km, a period of 3.49 days and growth rate of 3.6 per hour at 500 hPa, which axis Mphale(1999) has shown to be influenced by the Indian Ocean sea surface temperature (a study of the ECMWF analyses of vertical velocity at 400 hPa during a period of convective activities over Botswana, Southern Africa, (15-21 February 1995) confirmed the existence of this wave pattern. These perturbations have direct bearing on tropical Africa MCSs, and the development of mesoscale models based on them, as done by Abiodun(2003), is envisaged to improve current parameterisation schemes in regional climate models. Abiodun(2003) was able to establish: that the University of Uppsala MIUU models could be adapted to simulate tropical MCSs and thereby improve the understanding of the initiation, growth, propagation, and the environmental impact of tropical squall line systems. This result has enormous potential for parameterization schemes in climate models.

Parameterization classification of precipitation as either stratiform or convective in climate models is examined against the backdrop of the model. In the case of convective classification, the model is shown to be useful in informing the choice of its representation in any of the following approaches: traditional, explicit or hybrid. Justifications for using traditional type of cumulus parameterisation include cognisance of these assumptions: significant precipitation and tropospheric heating are produced by convection, even when the grid scale is unsaturated, and large vertical eddy fluxes of heat, moisture, and momentum occur on the unresolved convective scale. The justification for using explicit physics is often resolved based on whether the vertical heat and moisture fluxes on the grid-resolvable scale dominate those on the subgrid (convective) scale or whether or not there is a very strong coupling between the cloud scale and mesoscale, as in a strongly forced, dynamically balanced system. The hybrid scheme assumes that the effect of implicit (parameterised) convective activity is defined on the basis of the resolvable-scale quantities, but that the properties of convective clouds are different from the properties of the grid scale. This means that a closure condition must be specified, such as large-scale conditional instability and low-level convergence. The cumulus parameterisation scheme of the hybrid approach is usually needed to compute the net convective-scale heating and condensate. Also, this scheme assumes that a fraction of the implicit convective condensation is detrained from the unresolved cumulus scale to grid-scale prognostic cloud and precipitation equations. In spite of the problems of double counting of the same physical process (i.e. simultaneous parameterisation and explicit resolving), especially at higher resolutions and the arbitrariness in specifying the amount of precipitation detrained into the environment in the hybrid scheme, it is shown to work best for tropical MCSs.

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