NUMERICAL SIMULATIONS OF SEVERE TROPICAL AND CONTINENTAL STORM

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1. INTRODUCTION

Convective clouds and storms represent one of the most important and challenging problems for forecasters. For this reason, considerable effort has been devoted to studying storm initiation and evolution, as well as the environmental factors governing overall storm structure. A number of three-dimensional cloud models have been developed to simulate the structure, intensity and movement of convective clouds (Cotton and Tripoli, 1978; Klemp and Wihelmson, 1978; Clark, 1979; Tao and Soong, 1986; Wang and Chang 1993; Skamarock et al., 2000; Xue, et. al., 2000; Tao, et. al., 2004; and many others).
Many previous studies using high resolution cloud-resolving models (or convective cloud models) have shown that case-specific simulations are able to represent the storm structure and structure, intensity and movement of convective clouds, radar reflectivity, wind speed and direction, outflow heights. The three-dimensional cloud models developed so far can be classified into two families: one based on anelastic system of equations and the other on the fully compressible system of equations. On the other hand, many previous studies using high resolution cloud-resolving models (or convective cloud models) have shown that case-specific simulations are able to represent the storm structure and kinematics, such as radar reflectivity, wind speed and direction, and outflow heights.

The main motivation of the present study was to understand how the cloud-resolving model behaves when simulating such intensive storms. The model is initialized on two different upper airs sounding representing tropical and continental initial vertical profiles of meteorological data. A 2-d and 3d numerical experiments have been carefully setup in order to simulate storm dynamics, microphysics and heavy precipitation processes. The storm structure is evaluated by comparing the modeled and simulated radar reflectivity through examination of its horizontal and vertical cross sections. The differences in cloud dynamics belongs to difference in potential instability, wind shear and turbulence. Predicted maximum mixing ratios of hydrometeors show differences among cases, as result of different initial moisture content as well as difference in vertical transport of moisture and microphysics production terms. The intercomparison described here also shows differences in rainfall efficiency attributed to differences in the interaction of cloud dynamics and microphysics and precipitation flux processes. The comparative analysis has shown relatively good agreement of selected cases and compare well with observations.

2. DESCRIPTION OF THE MODEL

The present version of the model is a three-dimensional, non-hydrostatic, time-dependant, compressible system with dynamic scheme from Klemp and Wilhelmson (1978), thermodynamics scheme from Orville and Kopp (1977) and bulk microphysics scheme from Lin et al. (1983), with a significant improvement in microphysical parameterization developed by Curic and Janc (1995,1997). The governing equations of the model include conservation equations for momentum, thermodynamics and pressure, four continuity equations for the water substances, and a subgrid scale (SGS) turbulent kinetic energy equation (TKE). More detailed information about the cloud model and the chemistry submodels could be found in studies by Telenta and Aleksic (1988) and Spiridonov and Curic (2003).

2.1 Boundary conditions

Boundary conditions are defined so that the normal component of velocity vanishes along the top and bottom of the model domain. To ensure that a rigid top boundary assumption does not cause vertical oscillations in the numerical simulation, the authors have upgraded the model with a radiative upper boundary condition, as suggested by Klemp and Durran (1983). The lateral boundaries are opened and time-dependent, so those disturbances can pass through with minimal reflection Durran (1981). When the component of velocity normal to the boundary is directed toward the domain (inflow boundary), normal derivatives are set to zero. At outflow boundaries, the normal velocity component is advected out through the boundary with the estimated propagation speed that is averaged in the vertical, and weighted at each level by the approximate local strength of the wave.The pressure boundary conditions are calculated from other boundary values.

2.3 Numerical technique

Model equations are solved on a staggered grid. All velocity components u_i are defined at the edges of the grid, while scalar variables are defined at the mid point of each grid. The horizontal and vertical advection terms are calculated by the centered fourth- and second-order differences, respectively. Since the model equations represent a compressible fluid, a time splitting procedure is applied to achieve numerical efficiency. The scalar prognostic equations, except that for pressure, are stepped from $t-\Delta t$ to $t+\Delta t$ by a single leapfrog step. The terms which are not responsible for sound wave generation in the equations of motion and pressure equation are evaluated at the central time level t.

3. NUMERICAL EXPERIMENTS

3.1. Initial conditions and initializations

The model is initialized on two different upper airs sounding representing continental and tropical initial vertical profiles of meteorological data (Figs. 1,2). For the continental convective cloud simulation, the model is configured to a domain of 120 x 120 x 16 km^3 with 1 km horizontal resolution and 0.5 km vertical resolution.

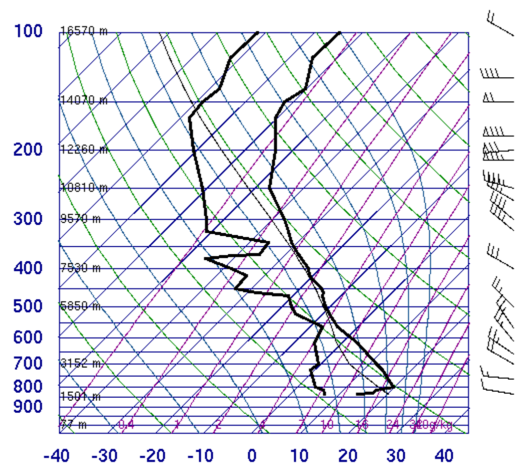

Fig. 1 Upper air sounding for Wyoming on 10July,1996 00 UTC

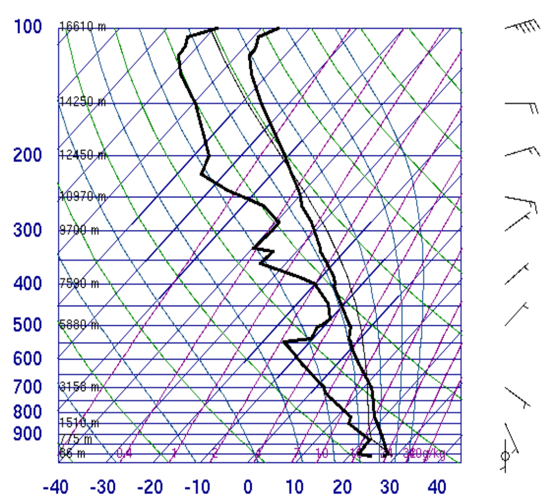

Fig. 2 Upper air sounding for Bangkok, Thailand on 25 July 2007 00 UTC

Initial data and model initialization for a tropical storm are taken from the upper air sounding from Bangkok, Thailand observed on 25 July 2007. A three dimensional simulation for a second case simulation is performed on a smaller domain of 61km x 61km x 16km for a better comparison with the radar maximum range. The horizontal and vertical grid steps are Δx=1km and Δz=0.5km, respectively.

4. RESULTS

Using the same initiation protocol in each of the simulated cases will produce different storm structures and evolution because of the different initial thermodynamics conditions.

4.1. Thermodynamic conditions

The differences in initial vertical atmospheric profiles are obvious. The continental sounding is dry and stable near the surface and unstable and moist with wind shear and strong zonal wind at the middle of the layers. Opposite, the tropical environmental conditions are manifested with low-level moisture, buoyancy air and weak wind veering near surface layers, moisture deficit at 550mb with a weak wind shear, and unstable and moist at the middle part of the atmosphere. The differences in cloud dynamics belongs to difference in potential instability, wind shear and turbulence.

4.2 Microphysical and dynamical parameters of simulated storms

The main characteristics of continental and tropical storm, structural and evolutionary properties are examined by analysis the basic dynamical, microphysical and radar reflectivity parameters. Here, only the dominant dynamical features are illustrated. The maximum calculated updraft has a higher initial value in tropical case relative to continental case and quite similar values in the mature stage of the storm (see Fig. 3). The stronger initial turbulence in tropical case is evident considering time distribution on turbulent diffusion coefficients shown in Fig.4. Opposite, here in the later stage of the simulation time continental storm case shows relatively higher turbulence diffusion versus tropical one. In respect to microphysics we have considered the time evolution of rain water mixing ratios. According to results shown on Fig. 5, we find initial formation and greater values for rainwater mixing ratio in the tropical storm relative to continental storm. Predicted maximum mixing ratios of hydrometeors show differences among cases, as result of different initial moisture content as well as difference in vertical transport of moisture and microphysics production terms. The sensitivity of cloud model simulations to the fine-scale details of the initial conditions raises two distinct multicellural storms with different dynamics, microphysics and rianfall process. Higher convective rainfall efficiency is evidenced in tropical storm relative to continental storm (see Fig. 6). The intercomparison described here also shows differences in rainfall efficiency attributed to differences in the interaction of cloud dynamics and microphysics and precipitation flux processes.The maximum accumulated rainfall at the ground during simulation time in tropical case is 72,1mm, versus 33.5mm in continental case. There is no total accumulated hailfall at the ground in tropical case simulation.

4.3. Comparison of radar reflectivity fields

Comparison of radar reflectivity fields illustrates the capability of convective cloud model to simulate multicellular convection under different (continental and tropical) environments. In both cases, simulated radar reflectivity fileds have a quite good agreement with observed radar echoes. The horizontal cross section of radar reflectivity on continental storm in 90min of the simulation time shown on Fig. 7 is consistent with radar reflectivity recorded by aircraft (see Fig. 8). In tropical case multicell storm in 60 min of the simulation intercomparison clearly illustartes a good coincidence between computed reflectivity and observed by radar.

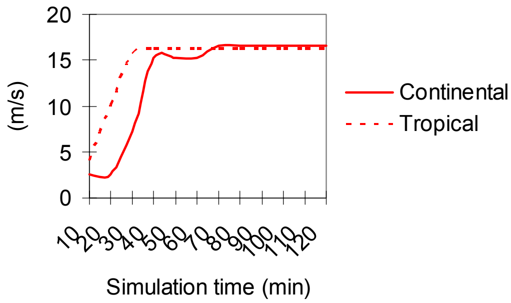

Fig. 3. Time evolution of maximum updraft in (m/s) for continental and tropical storm

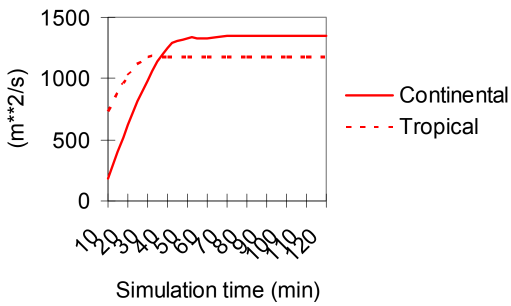

Fig. 4. Time evolution of turbulent diffusion coefficient in (m^2/s) on continental and tropical storm

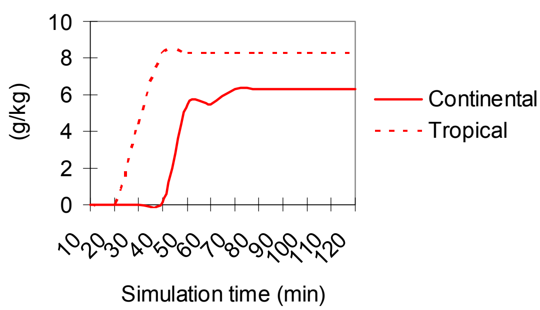

Fig. 5. Time evolution of rainwater mixing ratio in (g/kg) on continental and tropical storm

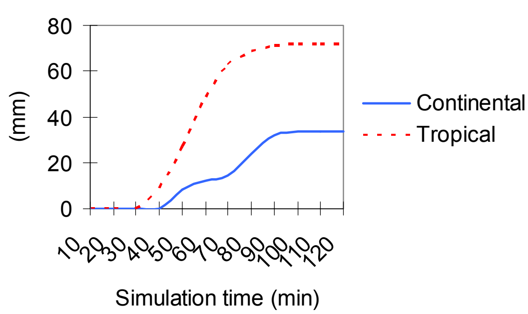

Fig. 6. Time evolution of total accumulated rainfall in (mm) on continental and tropical storm

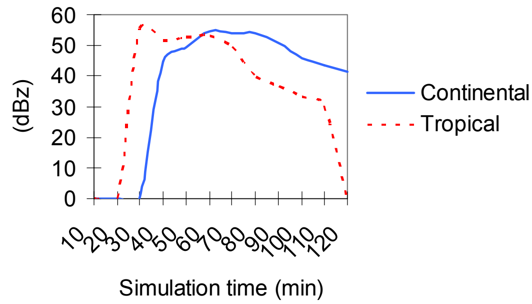

Fig. 7. Time evolution of radar reflectivity in (dBz) on continental and tropical storm

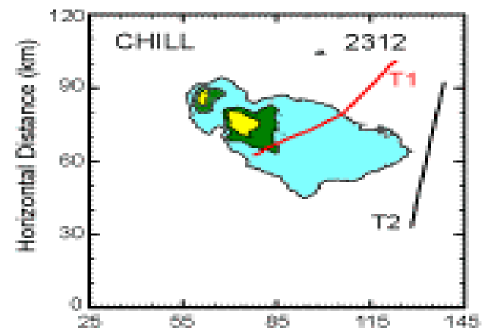

Fig. 8. Observed radar reflectivity in 60 min. (continental storm)

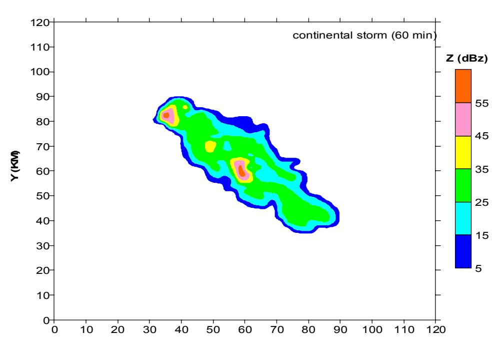

Fig. 9. Horizontal (x-y) cross section of modeled radar reflectivity in 60 min. of the simulation time (continental storm)

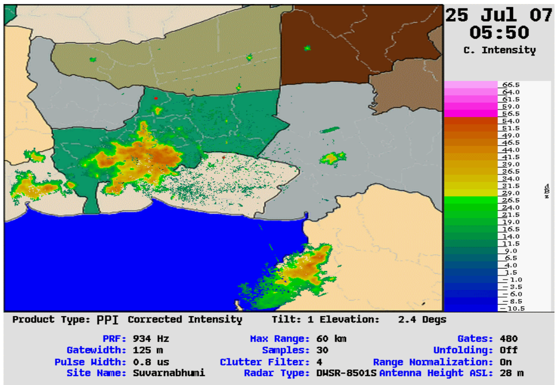

Fig. 9. Observed radar reflectivity (tropical storm)

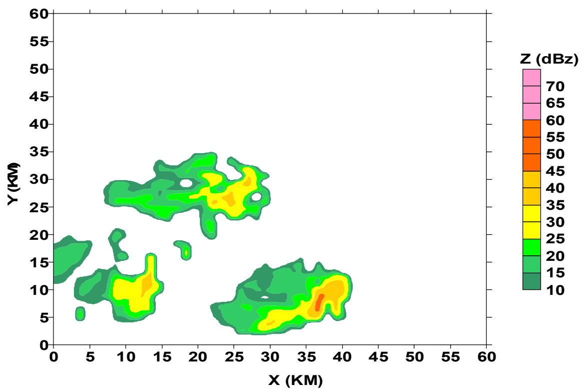

Fig. 10.Horizontal (x-y) cross section of modeled radar reflectivity in 60 min. of the simulation time (tropical).Simulated radar reflectivity (tropical)

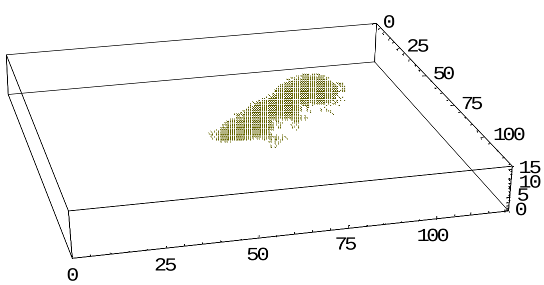

Fig. 12. 3-d view of continental storm in 40 min.

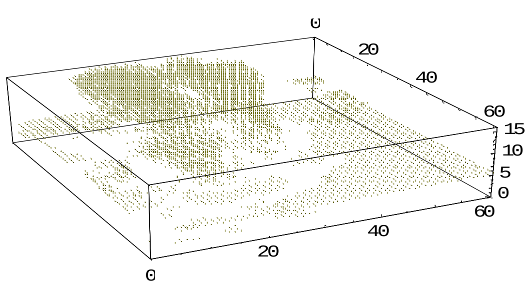

Fig. 12. 3-d view of tropical storm in 40 min

5. Conclusions

The convective cloud model is initialized on two different continental and trpical environments. A 2-d numerical experiments helped in analysing storms dynamics, microphysics and heavy precipitation processes. Tropical storm has shown a more intensive initial convection, associate with strong updrafts, turbulent difusion coefficient and low level moisture relative to continental storm. Continental storm exibits continuos and uniform evolution in the storm mature stage with relatively higher values for turbulence that maintains convection. What is microphysics concern tropical storm has shown an early formation of rainwater with greater mixing ration than in continental storm. The storm structure is evaluated by comparing the modeled and simulated radar reflectivity through examination of its horizontal cross sections. The differences in cloud dynamics belongs to difference in potential instability, wind shear and turbulence. Predicted maximum mixing ratios of hydrometeors show differences among cases, as result of different initial moisture content as well as difference in vertical transport of moisture and microphysics production terms. The intercomparison described here also shows higher rainfall efficiency in tropical case attributed to differences in the interaction of cloud dynamics and microphysics and precipitation flux processes. The comparative analysis has shown relatively good agreement of selected cases and compare well with observations.

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