AN INVESTIGATION OF A SEVERE MULTICELLULAR STORM IN THE TROPICS

Ulrike Wissmeier[1], Robert Goler[2]

[1]*Meteorological Institute, Theresienstr. 37, 80333 Munich, Germany, ulrike@meteo.physik.uni-muenchen.de*
[2]*Meteorological Institute Munich, robert@meteo.physik.uni-muenchen.de*

(Dated: 15 September 2009)

I. INTRODUCTION

Studies of tropical thunderstorms have shown that vertical wind shear has a large influence on storm evolution (*e.g.*, Wissmeier and Goler 2009) and that convergence caused by sea breezes can trigger thunderstorms. In their study of convection in the Darwin area in the “Top End” of northern Australia, Keenan and Carbone (1992) found that initial convective features tend to evolve towards a line of thunderstorms, which is oriented perpendicular to the low-level shear and shows forward-moving squall-like characteristics. A particular phenomenon occurring in the Darwin region is the so-called “Northeaster”, which is a multicellular storm complex or squall line approaching the coastal city from the northeast. A good example of a Northeaster passed over Darwin during the afternoon of 14 November 2005. The automatic weather station at the airport was hit by lightning and stopped recording during the storm. The storm produced wind gusts of up to 93 km h^{-1} which uprooted or snapped trees along a 1 km stretch of a highway adjacent to the airport, and the outward bound section of the highway was blocked. Power supplies to many residents were disrupted for up to an hour. It is the observations relating to this storm that motivate the formulation of the idealised numerical calculations described herein.

The aim of this work is to perform idealised numerical simulations relevant to the Northeaster that occurred on 14 November 2005, and to investigate the influence of the environmental vertical wind shear on the evolution of the model storm system that develops. A particular focus is to examine how the additional lifting and low-level vertical wind shear provided by the sea breeze(s) lead to the formation of a severe multicell complex. In the course of studying the formation of new updraughts, the applicability of the Rotunno-Klemp-Weisman-criterion (Rotunno *et al.* 1988) is tested. The observations of the 14 November case serve as a reality check on the numerical solutions.

II. MODEL CONFIGURATION

To study multicell thunderstorms, especially the Northeaster of 14 November 2005, and the circumstances which leads to their formation the three-dimensional, non-hydrostatic cloud-scale model of Bryan and Fritsch (2002) and Bryan (2002) is used where the ice microphysics scheme is included.

Convection is initialised in an environment with the wind, vertical temperature, and moisture profiles taken from the 14 November 2005, 0000 UTC Darwin sounding. To represent the mid-afternoon conditions when the Northeaster developed, the lowest 1 km of the sounding is modified to give a convectively-mixed boundary layer. The calculated CAPE based on these values is 4129 J kg^{-1}.

The model domain size is (90 x 60 x 28) km^3, with a horizontal grid spacing of 1 km, and a vertical grid, stretched from 120 m at the bottom of the domain to 1 km at the top. Convection is triggered by an axis-symmetric thermal perturbation of horizontal radius 4 km and vertical extent 500 m. A temperature excess of 2 K is specified at the centre of the thermal and decreases gradually to 0 K at its edge.

A number of experiments is performed with a combination of a northerly (Nsb), westerly (Wsb), and/or a northwesterly sea breeze (NWsb). Each sea breeze is initialised using a box of cold air in the north, west, and northwest of the domain at the beginning of the simulation, respectively. The depth and temperature excess of the sea breezes are z_{sb} = 2 km and θ_{sb} = -2 K, respectively, and these values are based on observations of sea breezes in the Darwin region (Todd Smith, Darwin Regional Forecasting Centre, personal communication; May *et al.* 2002). Each experiment is run for 180 minutes, thereby allowing the initial updraught and the subsequent storm system enough time to develop.

III. RESULTS AND CONCLUSIONS

The basic experiment is initialised with a Nsb, a NWsb, and a thermal perturbation which is placed so that convection develops at the Nsb front. Horizontal cross-sections through the initial updraught with its cold pool and the subsequent storm system at mid-levels are shown in Figures 1a and b at times t = 50 and 110 min after model initialisation, respectively. The model output compares well with reality in the following respects:

- Initial cell (see Fig. 1a) progresses to the west;
- New updraughts develop on the gust front of the initial cell, but behind the sea breeze front (formation of a multicell complex, see Fig. 1b);
- New cell development along the southern flank of the multicell complex;
- Propagation speed and direction of the multicell complex (40 km h^{-1}, west-northwest);
- Orientation of the multicell complex (north-northeast/south-southwest); and
- Length of the line of convection (25 to 30 km).

The role of the two sea breezes in the evolution of the multicell complex on 14 November 2005 is studied by modifying the basic experiment. A total of seven sensitivity experiments is considered here. Four experiments investigate the importance of the sea breezes: no sea breezes (EXP1); only a Nsb (EXP2); only a NWsb (EXP3); and the NWsb replaced by a Wsb (EXP4). Two experiments use the basic experiment with the position of the initial convection changed: convection is triggered ahead of the Nsb (EXP5); and convection is triggered behind the Nsb (EXP6). The basic experiment, initialised with different idealised wind profiles, provides the basis for EXP7.

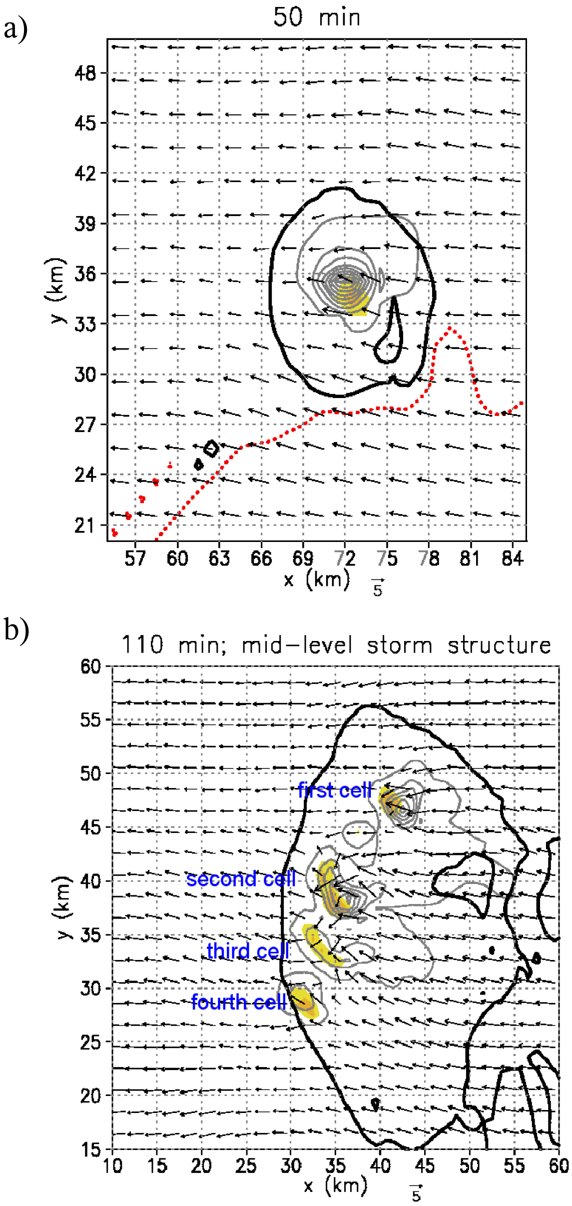

FIG. 1: Mid-level storm structure depicted at a) t = 50 and b) 110 min. The sea breeze fronts and the gust front are denoted by the dotted (red) and solid (black) lines, respectively, and represent the -0.5 K temperature perturbation contour. Vectors represent horizontal flow at z = 4.6 km, and the total precipitation mixing ratio $q_n=q_r+q_s+q_g$ is contoured in grey at 2 g kg^{-1} intervals, with the zero contour omitted. Regions of updraught velocities at z = 4.6 km larger than 5 m s^{-1} are shaded.

The sensitivity experiments, EXP1 to EXP7, show the following:

- A sea breeze can supply lifting to the initial cell what leads to a stronger updraught, to more precipitation loading within the thunderstorm, and to a stronger downdraught and gust front than if there had been no sea breeze or a sea breeze which is located far away from the initial cell.
- A strong updraught and downdraught are not indicators as to whether a (large) multicell complex will develop. Large low-level horizontal convergence is the primary factor determining the regions where new cell development at the gust front of the initial updraught is most likely.
- The low-level convergence at the edge of the cold pool needs to be strong and persist for a sufficient time so that new cells can develop.
- Large horizontal convergence at the gust front is achieved if the strength of the cold pool is comparable to that of the opposing environmental flow. Whether the vertical shear generated by the environmental wind is approximately balanced by the gust front shear can be determined via an equation similar to the Rotunno-Klemp-Weisman-criterion (Rotunno *et al.* 1988).
- The gust front is strong if the initial updraught is tilted significantly, so that the downdraught does not fall into the buoyant air, but supplies a specific region of the cold pool continuously with cool air.
- Updraught tilting is caused by strong environmental wind shear and by the vorticity generated by the sea breeze(s).
- Even though the convergence at the gust front is strong, convection can be suppressed by subsidence from pre-existing neighbouring cells.

The aim of this work has been to provide a deeper understanding of the overall evolution of the Northeasters and of the factors which lead to the development of thunderstorm complexes with squall-like characteristics. Even though the experiments were motivated specifically by thunderstorms in the Darwin area, the basic principles and relations itemised above are likely to apply also to other regions in the tropics and mid-latitudes.

IV. ACKNOWLEDGEMENTS

We wish to express our gratitude to Roger K. Smith for his thoughtful comments, and to George Bryan for kindly making his model available. The first author is grateful to the German Research Foundation (Deutsche Forschungsgemeinschaft) for providing financial support for this study, and to the European Meteorological Society for endowing a travel support fund (Young Scientist Travel Award).

V. REFERENCES

Bryan G. H., 2002: An investigation of the convective region of numerically simulated squall lines. *Ph.D. thesis, The Pennsylvania State University*, 181 pp.

Bryan G. H., Fritsch J. M., 2002: A benchmark simulation for moist nonhydrostatic numerical models. *Mon. Wea. Rev.*, **130**, 2917-2928.

Keenan T. D., Carbone R. E., 1992: A preliminary morphology of precipitation systems in tropical northern Australia. *Quart. J. Roy. Meteor. Soc.*, **118**, 283-326.

May P. T., Jameson A. R., Keenan T. D., Johnston P. E., Lucas C., 2002: Combined wind profiler/polarimetric radar studies of the vertical motion and microphysical characteristics of tropical sea-breeze thunderstorms. *Mon Wea. Rev.*, **130**, 2228-2239.

Rotunno R., Klemp J. B., Weisman M. L., 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, **45**, 463-481.

Wissmeier U., Goler R., 2009: A comparison of tropical and mid-latitude thunderstorm evolution in response to wind shear. *J. Atmos. Sci.*, **66**, 2385-2401.