# The Influence of Vertical Wind Shear on Deep Convection in the Tropics

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## I. INTRODUCTION

One does not normally associate severe storms with the tropics due to the weak wind shear normally present. However, during each wet season in Northern Australia (October - May) an average of 12 severe storm events are observed around the Darwin area (Chappel, 2001). During the last four wet seasons (see Table I), the probability of detection (POD) of severe storms was, except for the last season, lower than 25%. The false alarm ratio (FAR), indicating overprediction of severe storms, was over 50%.

One reason for these poor forecasts is that forecasters in Darwin, and perhaps elsewhere in the tropics, currently use conceptual models of storms developed for the mid-latitudes, since such models for tropical environments do not exist. Observations, theoretical studies, and numerical simulations of convective mid-latitude storms (e.g. Weisman and Klemp, 1982, hereinafter referred to as WK82) have shown that certain thresholds for CAPE (Convective Available Potential Energy) and wind shear, often combined together to form a Richardson number, determine which of the three storm types will be produced: single cell, multicell, or supercell.

The aim of this study is to investigate, using a numerical model, how storms in a tropical environment are influenced by vertical wind shear, and whether the thresholds of Richardson number used to classify storm type in the mid-latitudes apply for storms in the tropics.

| Season | Warned events | Successful warnings | Missed events | False alarms | POD | FAR |
|---|---|---|---|---|---|---|
| 2002/03 | 12 | 2 | 11 | 10 | 15% | 83% |
| 2003/04 | 3 | 0 | 12 | 3 | 0 % | 100% |
| 2004/05 | 10 | 3 | 10 | 7 | 23% | 70% |
| 2005/06 | 11 | 5 | 7 | 6 | 42% | 55% |

TABLE I: Severe Thunderstorm Warning Statistics for the seasons 2002/03 - 2005/06. For each season, the number of warned events issued by the Bureau of Meteorology in Darwin, successful warnings, missed events and false alarms are given. Also shown, the Probability of Detection (POD) calculated as the ratio of successful warnings to all events, and the False Alarm Ratio (FAR) calculated as the ratio of false alarms to the sum of successful warnings and false alarms.

## II. THE NUMERICAL MODEL

The numerical model used in this study is the three-dimensional Clark-Hall cloud-scale model (Clark, 1977), employing the non-hydrostatic, anelastic form of the equations of motion. The finite difference approximations are second order in both space and time.

The horizontal domain size is 40 km × 60 km with a constant grid interval of 2 km. The vertical domain extends to 28 km with a vertical grid interval stretching smoothly from 350 m at the lowest grid point up to 1 km at the top of the domain. A sponge is defined in the uppermost 10 km to prevent reflections of waves from the upper boundary. Convection is initiated in the model by a symmetric thermal perturbation of horizontal radius 10 km and vertical radius 1.4 km. A temperature excess of 2 K is specified at the center of the thermal and decreases gradually to 0 K at its edge.

The model is initialized with the vertical temperature and moisture profile from the 00Z Darwin sounding (9.30am local time) on days when severe storms occurred. To represent the mid-afternoon conditions when the storms developed, the 00Z sounding is modified to produce a convectively mixed boundary layer 1 km deep.

The wind profile is initialized as a straight-line hodograph chosen as

$$U = U_s \tanh \frac{z}{z_s} \qquad (1)$$

where $z_s$ = constant. The magnitude of the shear is varied by altering the parameter $U_s$. In these calculations the shear layer has a depth of 6 km and $U_s$ is varied from 0 up to 45 m s$^{-1}$ in steps of 5 m s$^{-1}$. A mean wind speed is subtracted in order to keep the storm in the center of the domain.

## III. RESULTS AND CONCLUSIONS

Three days (YYMMDD = 051114, 011120, 0412127) when severe storms occurred and one day (060207) when a non-severe storm occurred are considered here and compared with simulations for mid-latitude storms. Fig. 1 shows features typical of a Darwin storm compared with those of a mid-latitude storm in an environment without shear.

The maximum vertical velocity $w_{max}$ within the modelled Darwin storms decreases as the shear $U_s$ increases, due to the increase in entrainment (e.g. WK82). The

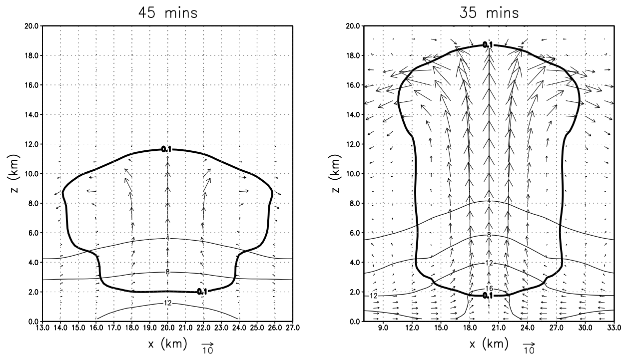


FIG. 1: Vertical cross sections of storm features for the $U_s = 0$ m s$^{-1}$experiment for the mid-latitudes (left) and the tropics (right) at a time when the cloud-top height is at a maximum. Vectors represent wind, the thick line is the 0.1 g kg$^{-1}$ contour of cloud water, and the mixing ratio $q_v$ is represented by the thin lines, contoured at 4, 8, 12 and 18 g kg$^{-1}$.

mid-level moisture profiles from the Darwin soundings are drier than that used by WK82, and for $U_s > 20$ m s$^{-1}$ $w_{max}$ is reduced by up to 50% of that when the WK82 moisture profile was defined above the mixed layer.

As mid-level moisture varies from storm case to case, the Bulk Richardson number is not useful in assessing when storm splitting and thus supercells should occur, since CAPE does not consider entrainment. As a result a non-dimensional number similar to the Richardson number is used here, defined as

$$\mathcal{W} = \frac{w_{max}^2}{\bar{u}^2} \qquad (2)$$

where $w_{max}$ is the maximum vertical velocity within the modelled storm and $\bar{u}$ represents the mean wind shear in the lowest 6 km. Choosing $w_{max}$ from the model implicitly takes into account entrainment into the storm.

For the mid-latitude storms of WK82 modelled here, storm splitting is observed for $\mathcal{W} < 11.3 \pm 2.0$. For the four Darwin cases, storm splitting is observed for $\mathcal{W} < 6.6 \pm 1.8$. An example of a split storm is shown in Fig. 2. The lower value of $\mathcal{W}$ for the Darwin cases means that for a given updraft in the tropics, storm splitting is expected when the mean wind shear is at least 39% of the updraft strength, i.e. $\bar{u} > w_{max}\mathcal{W}^{-\frac{1}{2}}$. In comparison, for mid-latitude storms the mean wind shear only needs to be at least 30% of the updraft strength.

From the small sample of storms considered here, storm splitting to produce supercells in the tropics requires a higher vertical wind shear relative to the storm updraft than for similar storms in the mid-latitudes. This supports the notion held by forecasters at the Darwin Bureau of Meteorology that the Thunderstorm Forecast Guidance System tool, which is used there operationally but developed for mid-latitude storms, over-forecasts supercells in the tropics.

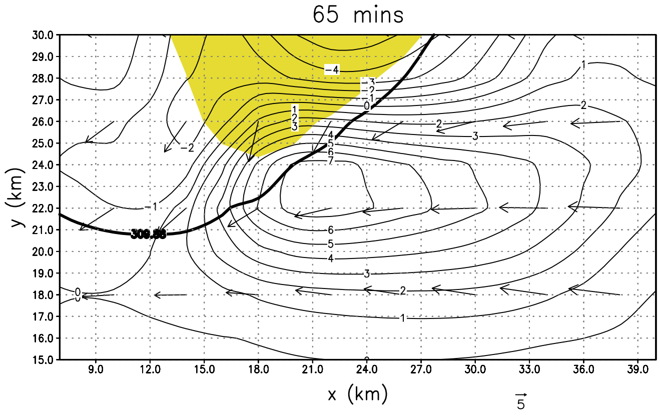


FIG. 2: Horizontal cross section through the supercell propagating to the right of the mean wind 65 mins after model initialization. A mirror image storm propagates to the left (not shown). The model was initialized with a vertical wind shear of 40 m s$^{-1}$. The vertical velocity at mid-levels (4.6 km) is contoured in black. Vectors represent storm relative low-level (175 m) horizontal winds. The surface rain field is indicated by the shaded yellow region and represents the +0.1 g kg$^{-1}$ perturbation contour, while the surface gust front is denoted by the single thick line and represents the −0.5 K temperature perturbation contour.

## IV. REFERENCES

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