# **13B.1** MULTI-BALANCED MODES OF DEEP TROPICAL AND EXTRATROPICAL CONVECTION SELF ORGANIZATION

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## 1. INTRODUCTION

Organized convection such as squall lines occurs frequently with strong low-level wind shears. In mid-latitudes the stronger the wind shear, the more severe the storm is expected (Rotunno et al. 1988), but this may not be the case in tropics. In this study, we aim to investigate the influences of low-level wind shear and midlevel moisture on squall line development in warm tropical, temperate and cold atmospheres. Significant differences exist between tropical and extratropical convective environments (Yi and Lim 2004), which may contribute to a different relationship between convection and wind shear /cold pool interaction in low and high latitudes.

## 2. MODEL CONFIGURATION

The nonhydrostatic numerical model COAMPS™ ‡ (Coupled Ocean/Atmosphere mesoscale Prediction System) (Hodur 1997) is used to conduct numerical experiments of squall lines. The model employs open boundary conditions at the x direction, and periodic conditions at the y direction. The horizontal grid spacing is 2 km and the vertical resolution is 500 m. The study covers a 600 km x 160 km x 17.5 km domain. The cloud microphysics in the model is based primarily on the Kessler warm rain parameterization. For simplicity, the ice process is turned off.

Squall lines are initiated by using a line of 5 ellipsoidal warm bubbles oriented south to north and spaced 40 km apart. The bubbles are centered at x = 150 km, z = 1.75 km (or 0.25 km in some cases). The maximum potential temperature excess of the bubbles is 1K. All simulations last for 6 hours and the Coriolis forcing is not considered.

The model runs in 3-D idealized mode. All boundary conditions/forcings such as radiation and surface fluxes are removed. Uniform sea surface temperature, surface roughness, albedo, and ground wetness are specified over a flat land. Horizontally homogeneous proximity soundings are applied as initial conditions to the entire model domain. Construction of the proximity soundings is described next.

## 3. EXPERIMENT DESIGN

Vertical profiles of temperature, wind and dew point temperature, which represent buoyancy, wind shear and moisture conditions of the environment, are required as input into the COAMPS model at t=0 for the idealized squall line simulations. Sensitivity of the squall line development to the variations in the three input profiles is investigated.

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Three types of principle proximity soundings (PPSs) are constructed by varying the temperature profile at the first place. The variation is made in reference to radiosonde records that reflect typical pre-storm environments in warm, temperate, and cold climate; the profile is correspondingly named warm, **base** and cold sounding. Specifically, the warm sounding is derived from observations at Singapore (Yi and Lim, 2004); the base sounding is adopted from those often used in the study of severe convective storms in US (Rotunno et al. 1988); and the cold sounding is extra-polated from the latter.

The Convective Available Potential Energy (CAPE), i.e., the total amount of buoyancy, is kept the same (1900 ± 10 J/kg) among the three PPSs, though the vertical distribution of buoyancy (the lapse rate) is varied. This is because it is the vertical distribution of buoyancy that characterizes a convective climate regime, while the desired high or low CAPE value can exist in all climates.

Low-level wind shear and mid troposphere moisture are then adjusted on each of the PPSs to find out whether the shear (moisture) exerts the same impact over the different convective backgrounds. Please note, as an idealized study, we use only westerly wind and unidirectional wind shear between 0-3km and constant wind above the height of 3 km.

## 4. RESULTS

### 4.1 Baseline simulations with varied lapse rates

Three simulations using the warm, base and cold soundings are carried out. Note the CAPE in each case is ~1900 J/kg. For all cases, the wind difference between surface to 3 km altitude is 20 m/s, and the relative humidity (RH) averaged between 850 – 400 hPa is 80%. We choose the maximum convective updraft $w_{max}$ to represent the squall line strength. Time evolution of $w_{max}$ shows (see green lines with "x" symbols in Fig. 1 and 2) that under the same total buoyancy forcing, same shear and midlevel moisture condition, the lapse rate plays a leading part in the squall line development -- steeper lapse rate apparently favors more vigorous convection with mean $w_{max}$>15m/s. Tropical convection is weak with mean $w_{max}\approx$ 5m/s.

Considering that the near-surface moisture and stability conditions differ distinctively in tropical and extra-tropical boundary layers, we set the lifted condensation level (LCL) and level of free convection (LFC) lower in the warm case and a bit higher in the cold case. The height of the warm bubbles is adjusted as well to ensure that the initial perturbations have about the same strength. Results from additional experiments (figures not shown) indicate that lower cloud base is disadvantageous to cold pool, thus unfavorable for convection growth. This is another reason for the weakness of the tropical convection self organization.

### 4.2 Effects of low-level wind shear

Table 1 An outline of experiments with varied low-level wind shears. Note, 850-400 hPa averaged relative humidity is 80% and CAPE is about 1900 J/kg in all cases at t = 0.

| | 0-3km wind shear (m/s) | | | |
|---|---|---|---|---|
| | 0 | 10 | 20 | 30 |
| warm | w0 | w10 | w20 | w30 |
| base | b0 | b10 | b20 | b30 |
| cold | c0 | C10 | c20 | c30 |

Fig. 1 illustrates that the low-level wind shear takes dissimilar effects on the squall line development under varied convective environments. The interaction between wind shear and cold pool, which decides essentially the strength and duration of convection, is realized at three separate balanced modes. In the warm tropical mode (Fig. 1a), the largest wind shear leads to the smallest $w_{max}$ growth. The reverse is true in the temperate mode (Fig. 1b), and this positive relation turns more evident in the cold mode (Fig. 1c). The above is true to the simulation from 60 minute onwards. During the convection initiation prior to 60 minute, though, strong wind shear is detrimental to convection in all three modes. This is because the cold pool forms and interacts with wind shear in the late period.

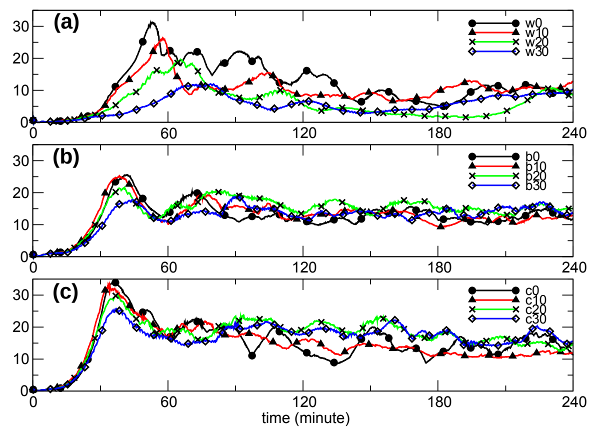


Fig. 1 Time evolution of $w_{max}$ in (a) the warm sounding cases; (b) the base sounding cases; (c) the cold sounding cases. The 0-3km wind shear is 0 or 10 or 20 or 30 m/s in each group of cases.

### 4.3 The role of mid troposphere moisture

The midlevel moisture appears crucial to promote convection in unfavorable wind shear in the tropical mode as shown in Fig. 2a. Given the same shear, more moisture is needed for convection to reach the same strength and duration in the tropical mode than in the other two modes. For midlevel RH ranging from 60-96%, the evolution of $w_{max}$ exhibits almost the same growth during 2-4 hours in the temperate and cold modes. In both Fig. 1 and 2 we notice that convection builds up faster in colder atmospheres.

Table 2 An outline of experiments with varied midlevel moisture. Note, the 0-3km wind shear is 20 m/s and CAPE is ~1900 J/kg in all cases at t = 0. X denotes zero $w_{max}$. Each shaded case in Table 2 is identical with that shaded in the same row in Table 1.

| | 850-400hPa relative humidity (%) | | | | |
|---|---|---|---|---|---|
| | 20 | 40 | 60 | 80 | 96 |
| warm | X | X | wr60 | wr80 | wr96 |
| base | X | br40 | br60 | br80 | br96 |
| cold | cr20 | cr40 | cr60 | cr80 | cr96 |

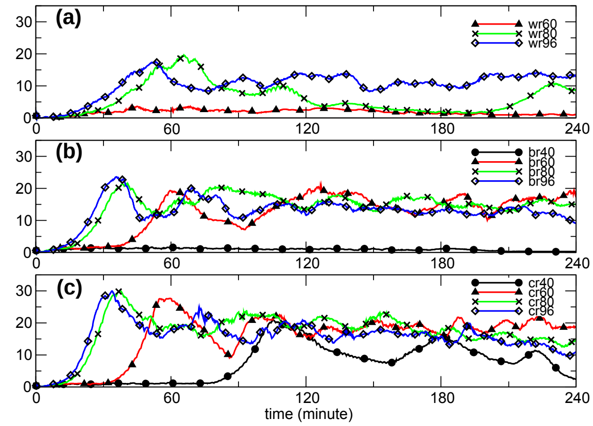


Fig. 2 Same as Fig. 1 except that wind shear is fixed at 20 m/s, and mean midlevel RH is 20 or 40 or 60 or 80 or 96%.

## 5. CONCLUDING AND DISCUSSION

Results from 3-D idealized simulations using the US navy's COAMPS model show that under three different categories of environmental temperature profiles that approximate tropical, temperate, and cold atmospheres that have the same amount of CAPE, the balance between low-level wind shear and cold pool, which sustains the convection self organization and growth, is realized at three different balanced modes — the warm tropical mode, the temperate mode, and the cold mode. Each mode is characterized by a particular set of temperature lapse rate, low-level wind shear, and humidity content that favors maximum convection development. In the warm tropical mode, wind shear is delicately balanced by weak cold pools and becomes insignificant to convection; it is actually negatively correlated with convective growth. Moreover, in the warm tropical mode, variations of midlevel moisture content exhibit greater sensitivity to convection growth, with higher midlevel RH promoting much stronger and longer-lived storms. The convective forcing is found less robust in the tropical mode. Weak wind shear, gentle lapse rate, and low cloud base associated with abundant near-surface moisture, may all contribute to the non-occurrence of supercell storms and tornadoes in the equatorial tropics.

It appears that the atmospheric thermal stratification (lapse rate) generally decides the vigor and power of the linear convection organization. It is supposed that the low-level wind shear and midlevel moisture associated with a certain lapse rate or a certain convective regime act to modify the convection self organization through interaction with cold pool and entrainment of dry surrounding air.

## REFERENCE

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