7th WRF Users' Workshop, 19-22 June 2006, Boulder, Colorado

# A Sensitivity of Squall-Line Structure and Intensity to Environmental Stability and Shear

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# Introduction

- Squall line dynamics and intensity

  - Cold-pool—shear interaction (RKW theory)

  - Impact of moisture in boundary layer & free troposphere

  - Convective instability

- Difference under different temperature environment?
  - – Tropics vs. Midlatitudes

  - Cold-pool strength

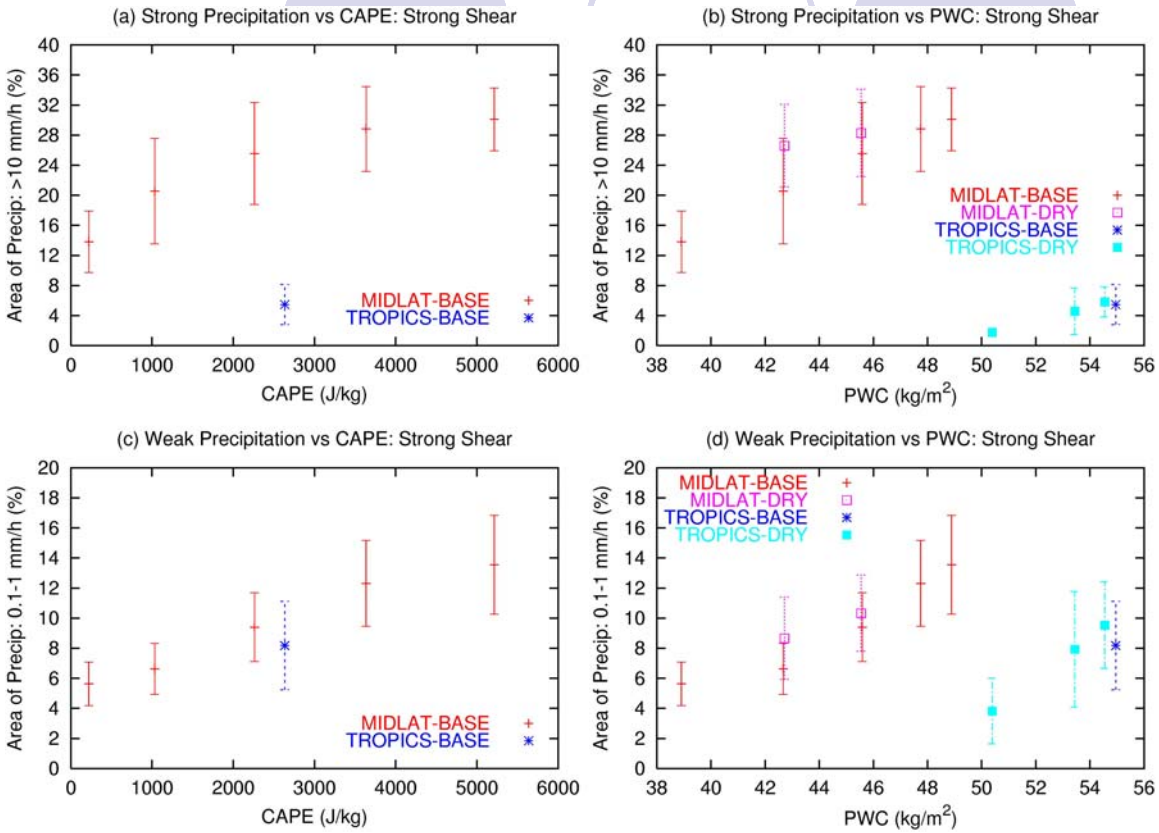
  - moisture content

  - Shear

What determines the squall-line intensity?

# Purpose

Takemi (2006) shows a linear relationship between squall-line intensity and CAPE/PWC under the same stability, but no correspondence between under different stability environments.




(Takemi 2006)

- This study: investigate the effects of environmental stability on the squall-line structure and strength and how they influence shear effects through systematic sensitivity simulations

# WRF Model Configuration

- WRF version 2.1.2 in an idealized mode
- Domain: 300 km (*x*) x 60 km (*y*) x 17.5 km (*z*)

  - Consider *y*-oriented lines
- Grid spacing: Δx=500 m, 70 levels in *z*
- Open at *x* boundaries and periodic at *y* boundaries
- Physics: cloud microphysics, subgrid-scale mixing
- Reference state: Initialized with a single sounding determined with the Weisman-Klemp analytic form

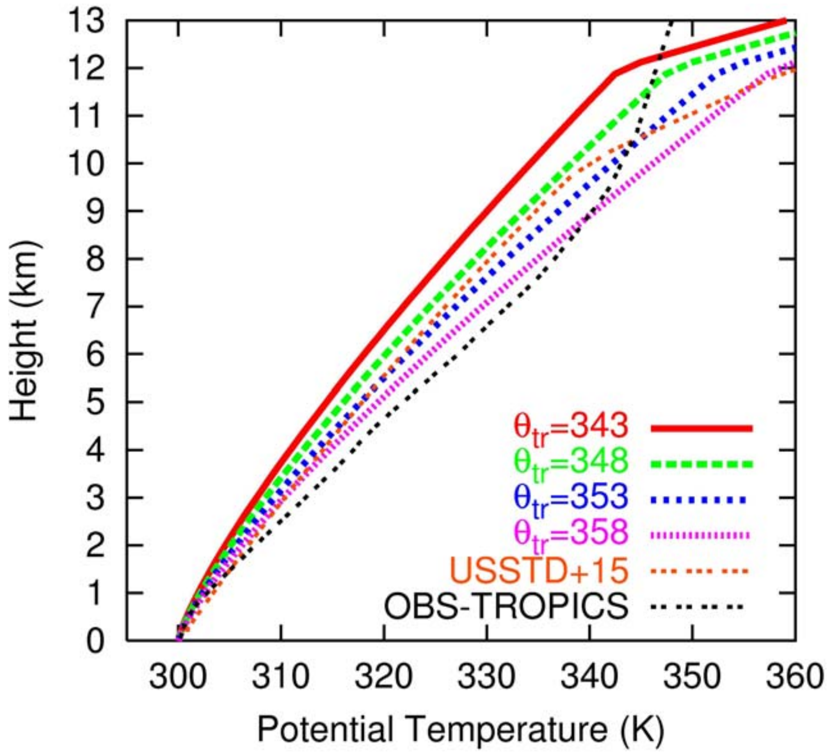
Potential temperature $$\overline{\theta}(z) = \theta_0 + (\theta_{tr} - \theta_0)(z / z_{tr})^{5/4}$$

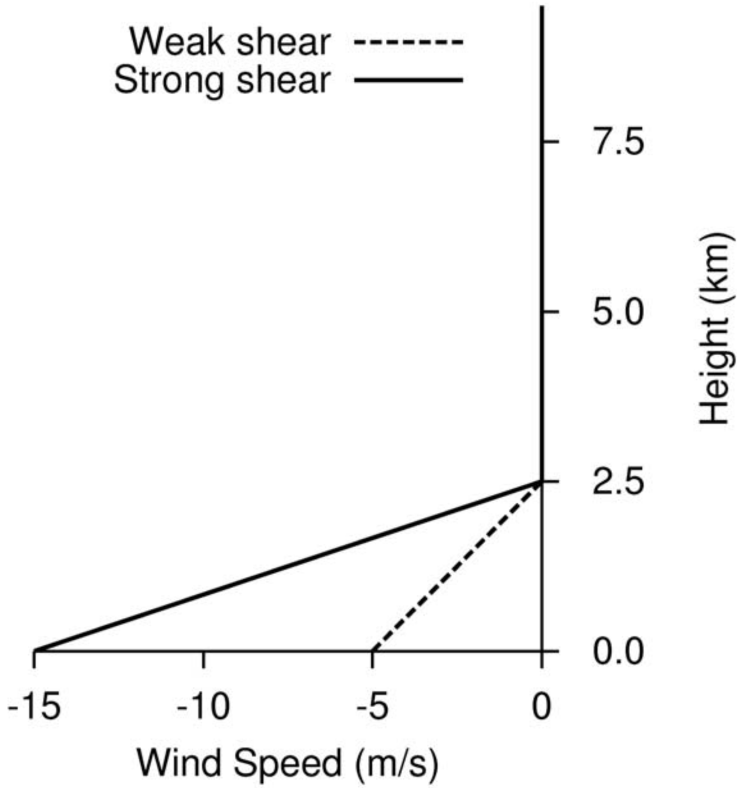
Relative humidity $$RH(z) = 1 - 0.75(z / z_{tr})^{5/4}$$

$$\theta_0 = 300\,\mathrm{K},\ \theta_{tr} = 343\,\mathrm{K},\ z_{tr} = 12\,\mathrm{km}$$

# Experimental Setup

- Stability profile: changed with $\theta_{tr} = 343,\ 348,\ 353,\ 358$
- Shear profile: 5 m/s or 15 m/s in the lowest 2.5 km perpendicular to lines



# List of Experiments

BASE CASES: Boundary-layer $q_v$ fixed

| | $\theta_{tr}$ (K) | $q_{v0}$ (g/kg) | CAPE (J/kg) | CIN (J/kg) | PWC ($mm/m^2$) |
|---|---|---|---|---|---|
| CASE01 | 343 | 16 | 3709 | 21 | 47.6 |
| CASE02 | 348 | 16 | 2668 | 25 | 49.4 |
| CASE03 | 353 | 16 | 1767 | 31 | 51.3 |
| CASE04 | 358 | 16 | 1081 | 38 | 53.4 |

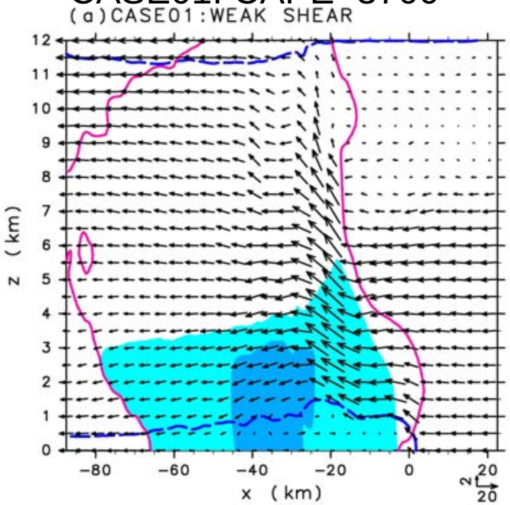
SENSITIVITY CASES: CAPE fixed

| | $\theta_{tr}$ (K) | $q_{v0}$ (g/kg) | CAPE (J/kg) | CIN (J/kg) | PWC ($mm/m^2$) |
|---|---|---|---|---|---|
| CASE11 | 343 | 13.1 | 1734 | 62 | 44.4 |
| CASE12 | 348 | 14.5 | 1772 | 47 | 47.9 |
| CASE14 | 358 | 17.7 | 1772 | 15 | 54.7 |

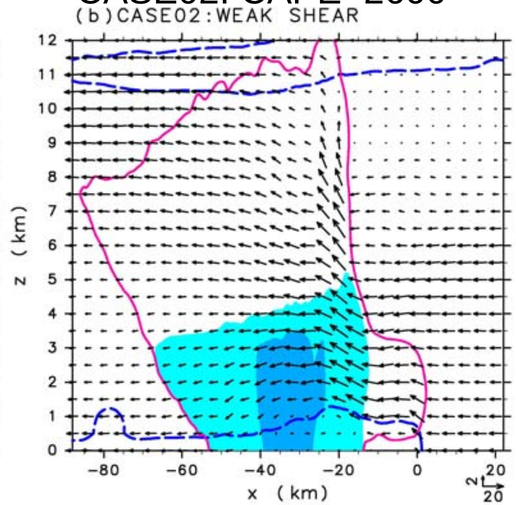
# Line-averaged vertical structure: T=4 h

Weak Shear

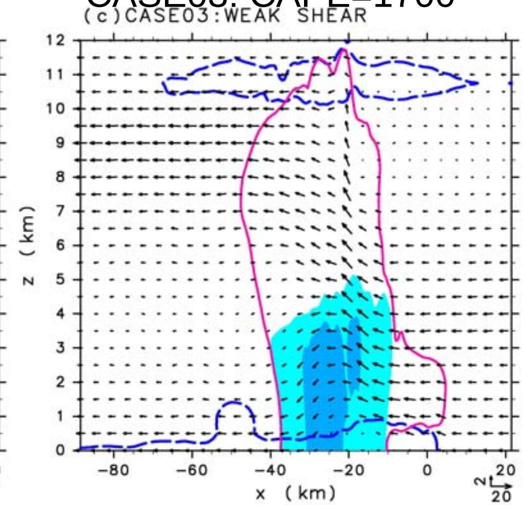
CASE01: CAPE=3700




CASE02: CAPE=2600

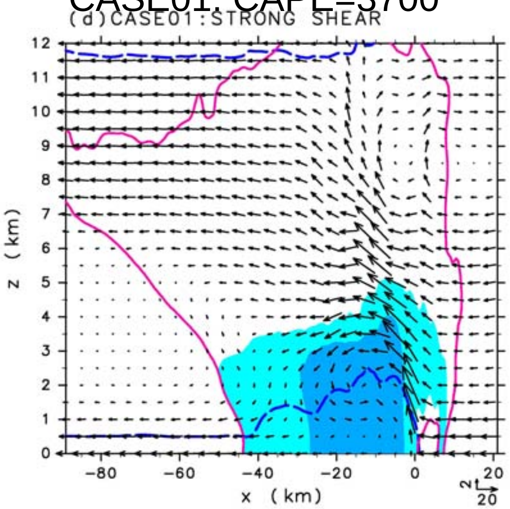



CASE03: CAPE=1700

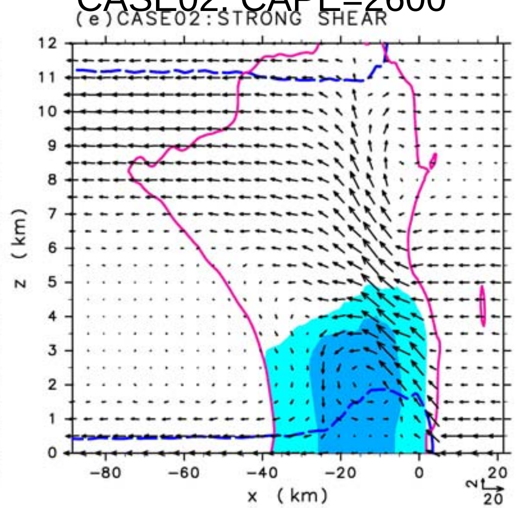



Strong Shear

CASE01: CAPE=3700




CASE02: CAPE=2600




Color: rainwater mixing ratio

Purple line: cloud boundary

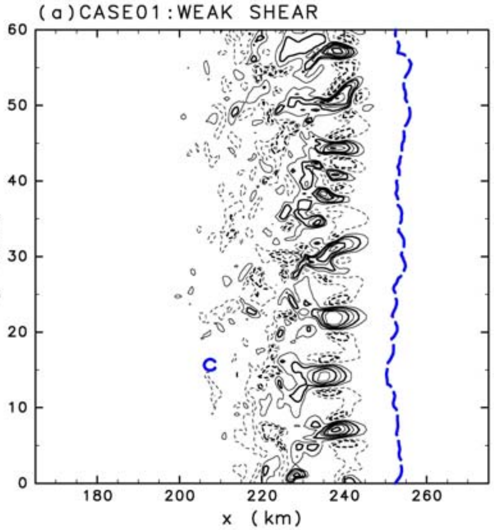
Blue dashed: Cold pool boundary

Vector: wind

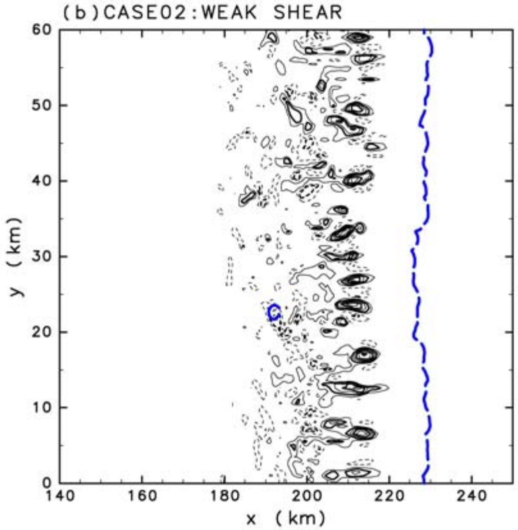
# Horizontal structure @ 3 km: T=4 h

Weak Shear

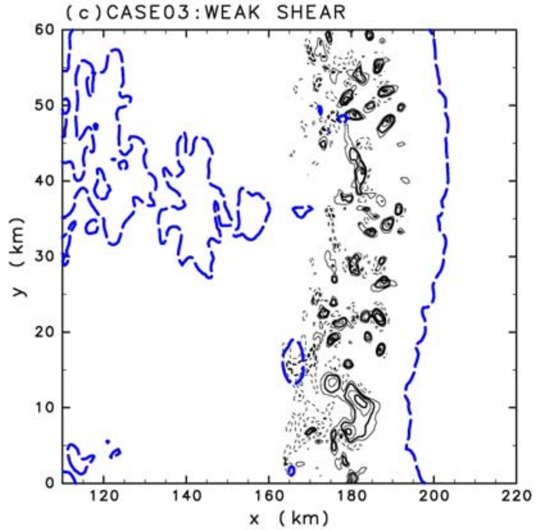
CASE01: CAPE=3700




CASE02: CAPE=2600

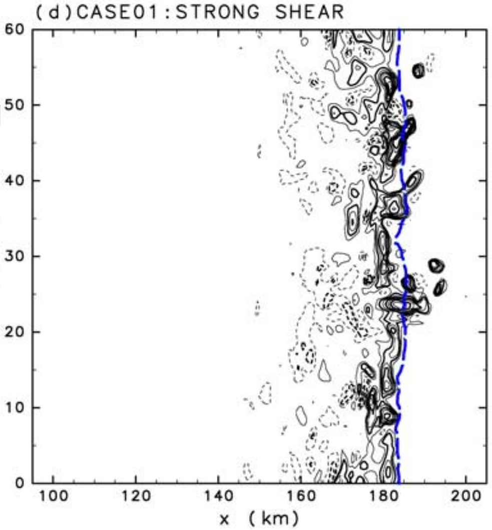



CASE03: CAPE=1700

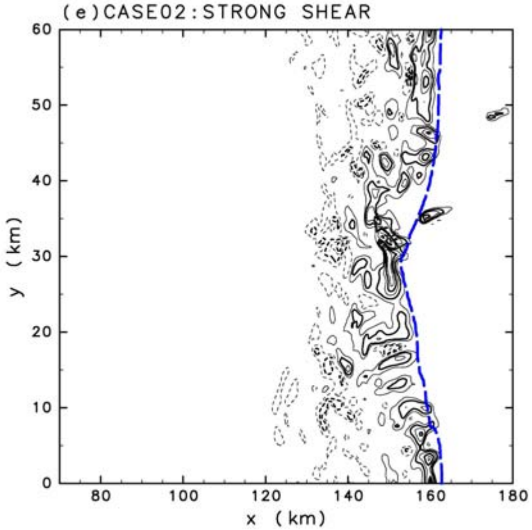



Strong Shear

CASE01: CAPE=3700




CASE02: CAPE=2600

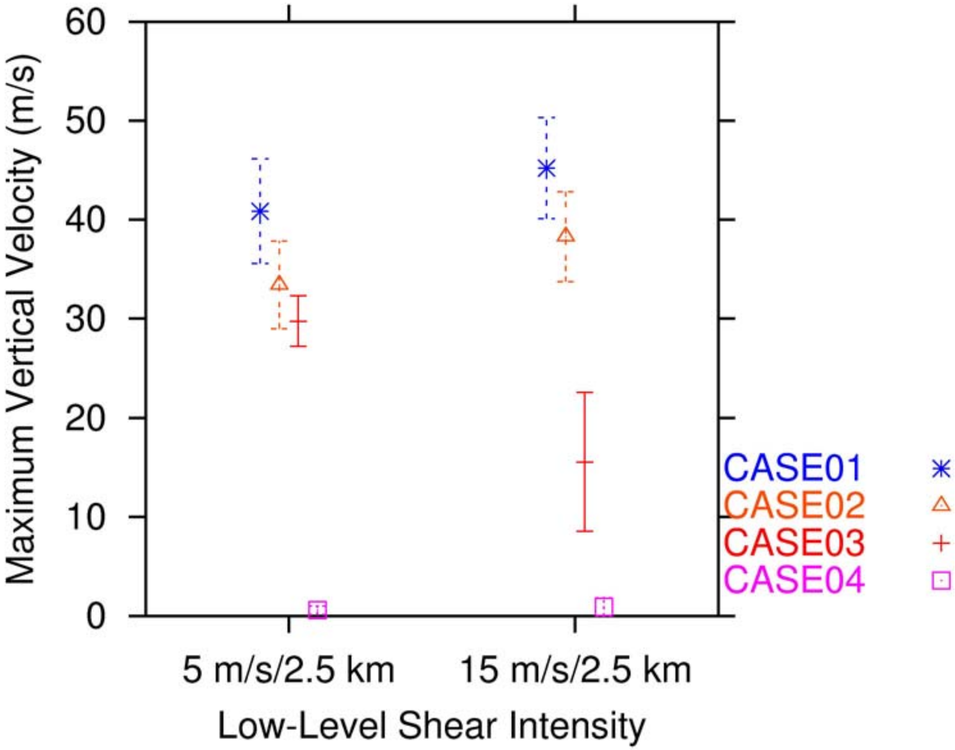


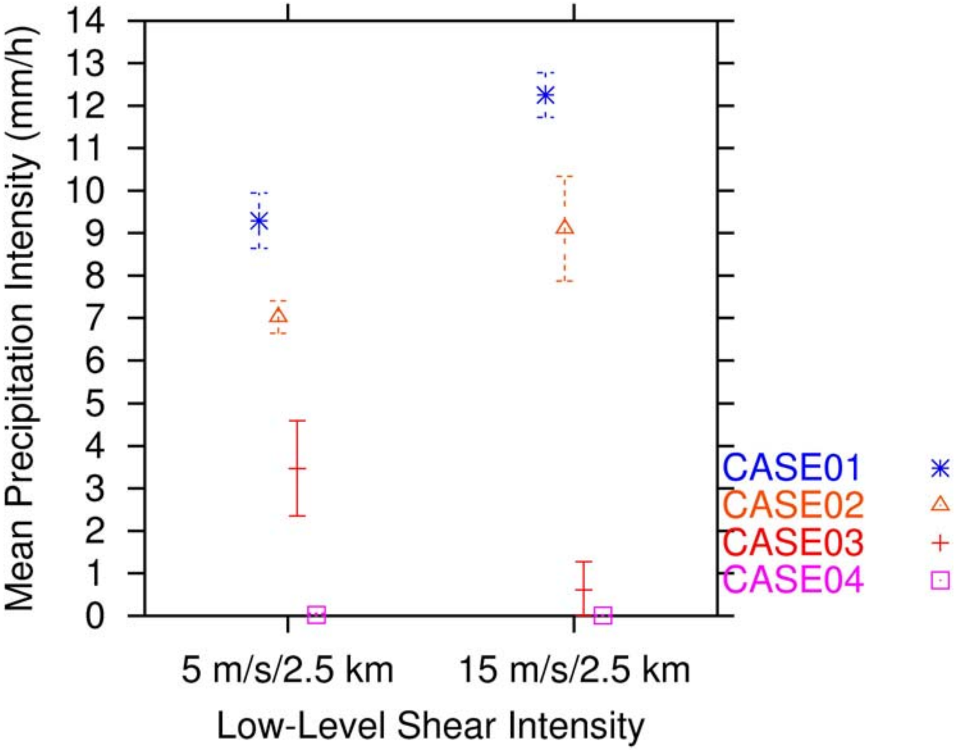

Contour: vertical velocity (C.I.=2.5 m/s)

Blue dashed: Surface gust front

# Statistics of squall line: BASE Cases

Analysis area: 100 km by 60 km around eastward-moving system
Mean and SD: calculated in the analysis area during 2-4 h (5-min output)



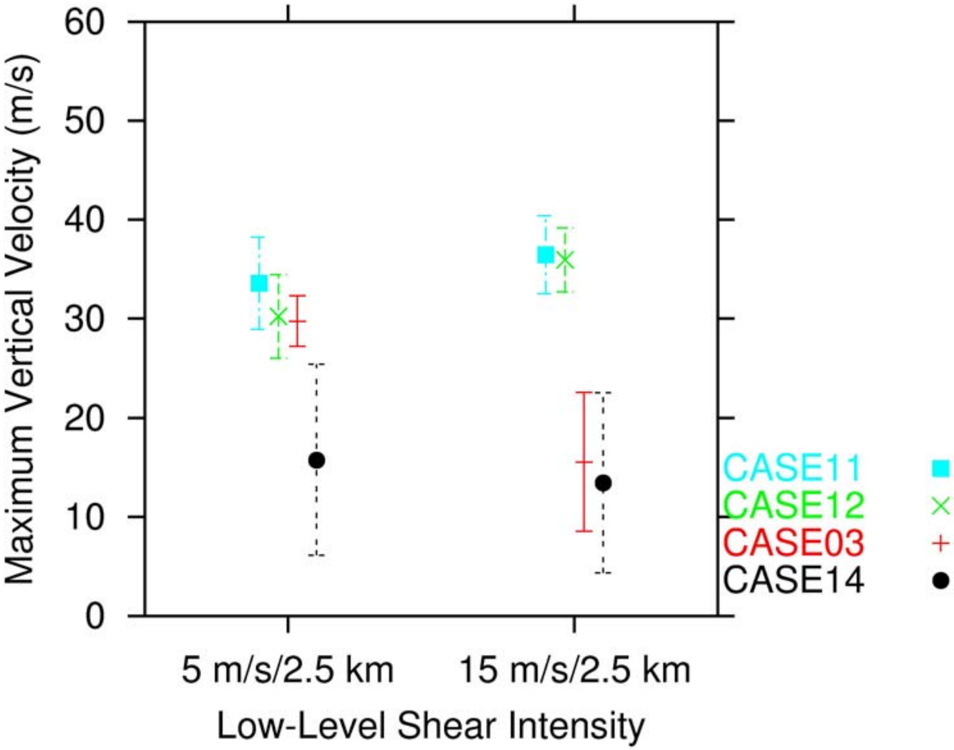




A more CAPE and less CIN (but less PWC) case produces a stronger system.

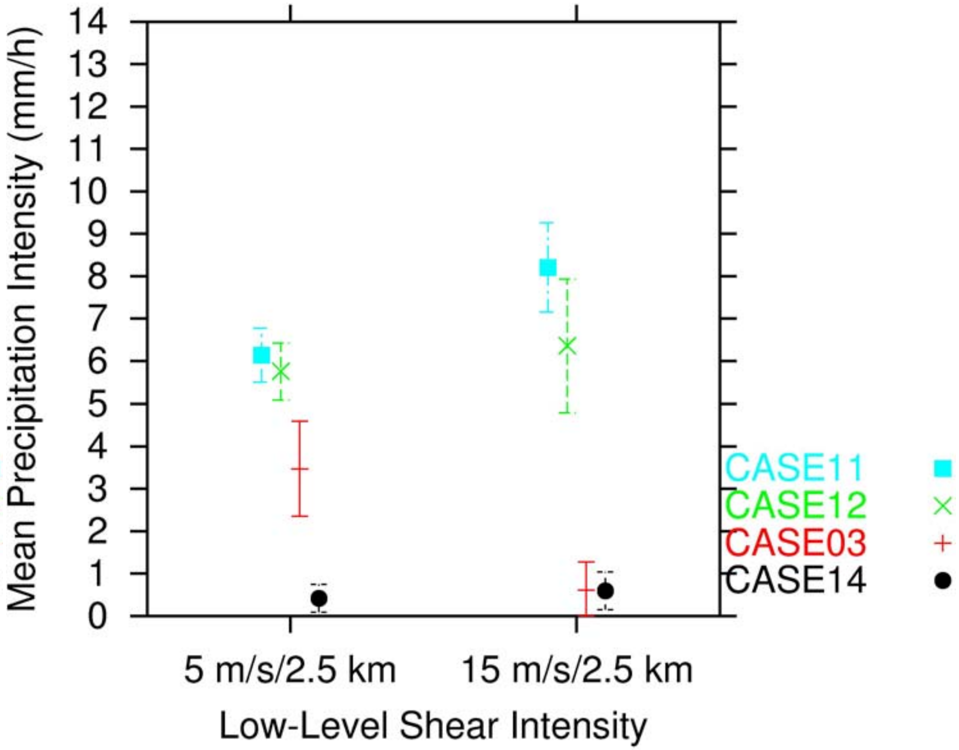
# Statistics of squall line: SENSITIVITY Cases

Analysis area: 100 km by 60 km around eastward-moving system
Mean and SD: calculated in the analysis area during 2-4 h (5-min output)

Maximum Updraft Velocity



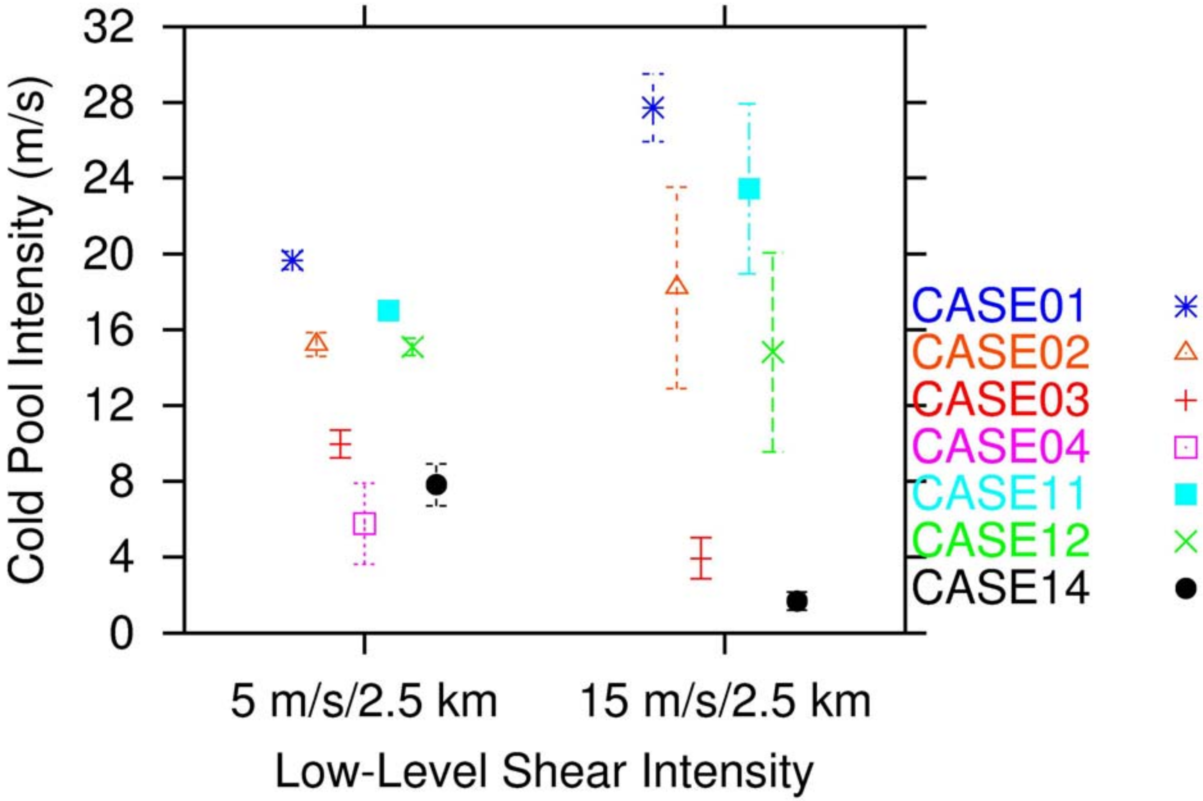

Mean Precipitation Intensity




With equal CAPE, a less PWC and more CIN case produces a stronger system.

# Statistics of cold pool strength

Cold-pool strength: $C = \sqrt{2\int_0^H (-B)dz}$




With equal CAPE, a less PWC and more CIN case produces a stronger cold pool.

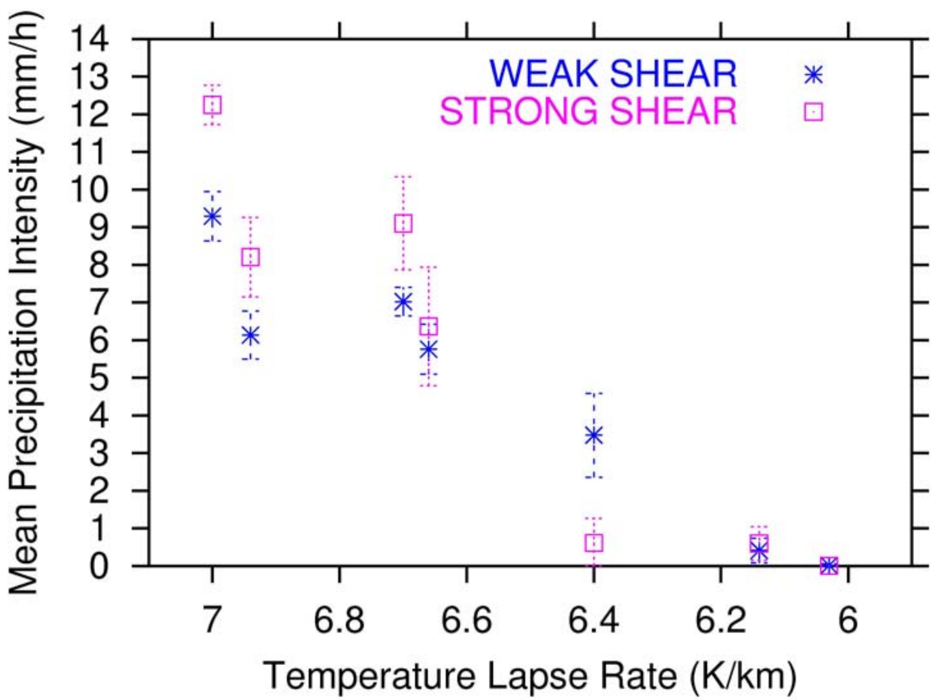
# A static stability parameter

$$\Gamma = -\frac{T_{z(\theta_{e\min})} - T_{z(\theta_{e\max})}}{z(\theta_{e\min}) - z(\theta_{e\max})}$$

$\theta_{emax}$: Height of low-level maximum equivalent potential temperature

$\theta_{emin}$: Height of mid-level minimum equivalent potential temperature

| | CAPE | CIN | PWC | $\Gamma$ |
|---|---|---|---|---|
| CASE01 | 3709 | 21 | 47.6 | 7.00 |
| CASE02 | 2668 | 25 | 49.4 | 6.70 |
| CASE03 | 1767 | 31 | 51.3 | 6.40 |
| CASE04 | 1081 | 38 | 53.4 | 6.03 |
| CASE11 | 1734 | 62 | 44.4 | 6.94 |
| CASE12 | 1772 | 47 | 47.9 | 6.66 |
| CASE14 | 1772 | 15 | 54.7 | 6.14 |



# Summary

- CAPE basically has a close relationship with the intensity of squall lines.
- Even with the same CAPE, the squall-line intensity depends critically on the environmental static stability in a convectively unstable layer.
- With a similar stability, a larger CAPE is more favorable.
- With a more stable stability, the weaker shear is favorable than the stronger shear, because of cold pool strength.

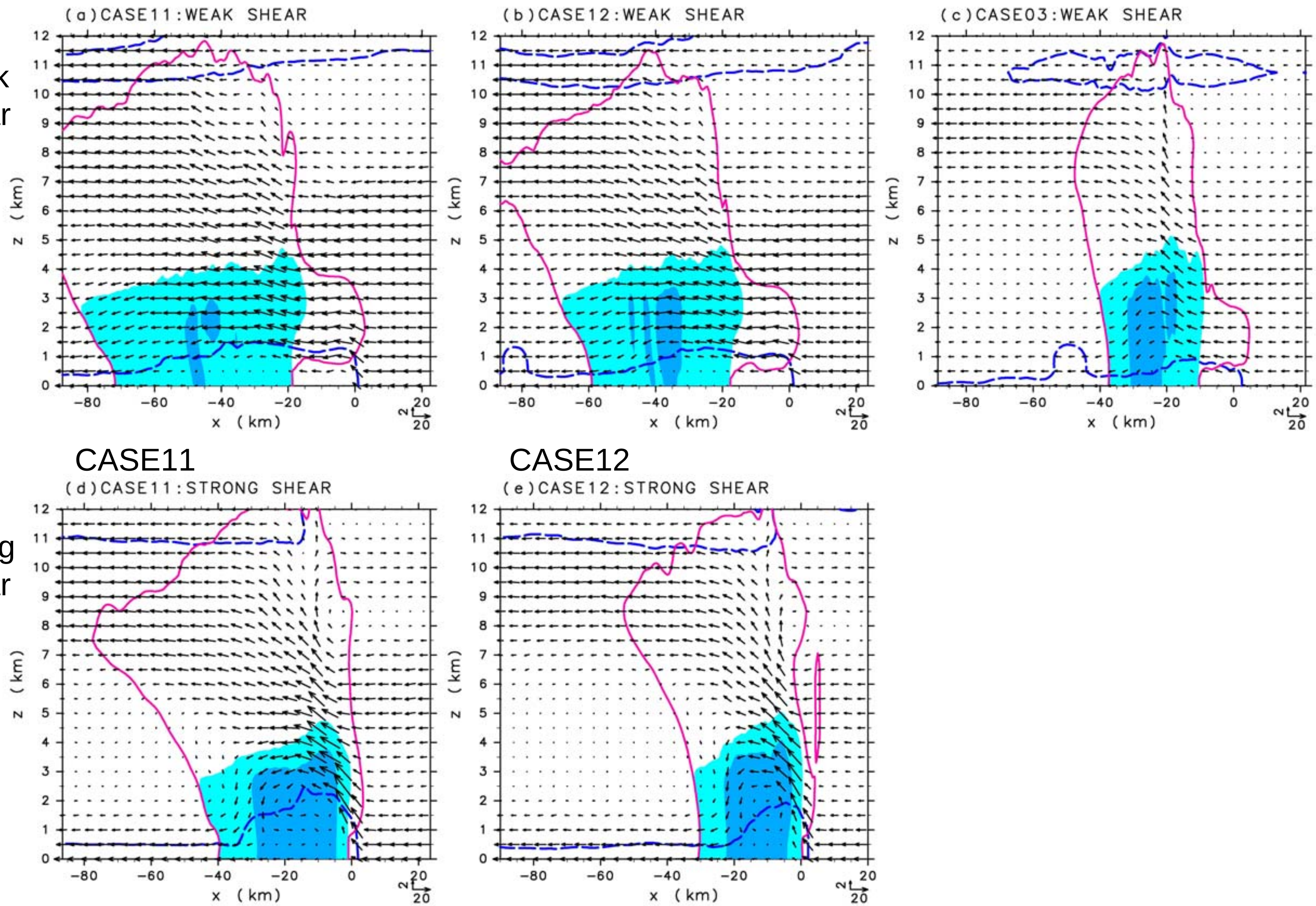
Thank you for your attention!

# Vertical structure – Equal CAPE cases

CAPE=1700

Weak Shear: CASE11, CASE12, CASE03

Strong Shear: CASE11, CASE12



# Horizontal structure – Equal CAPE cases