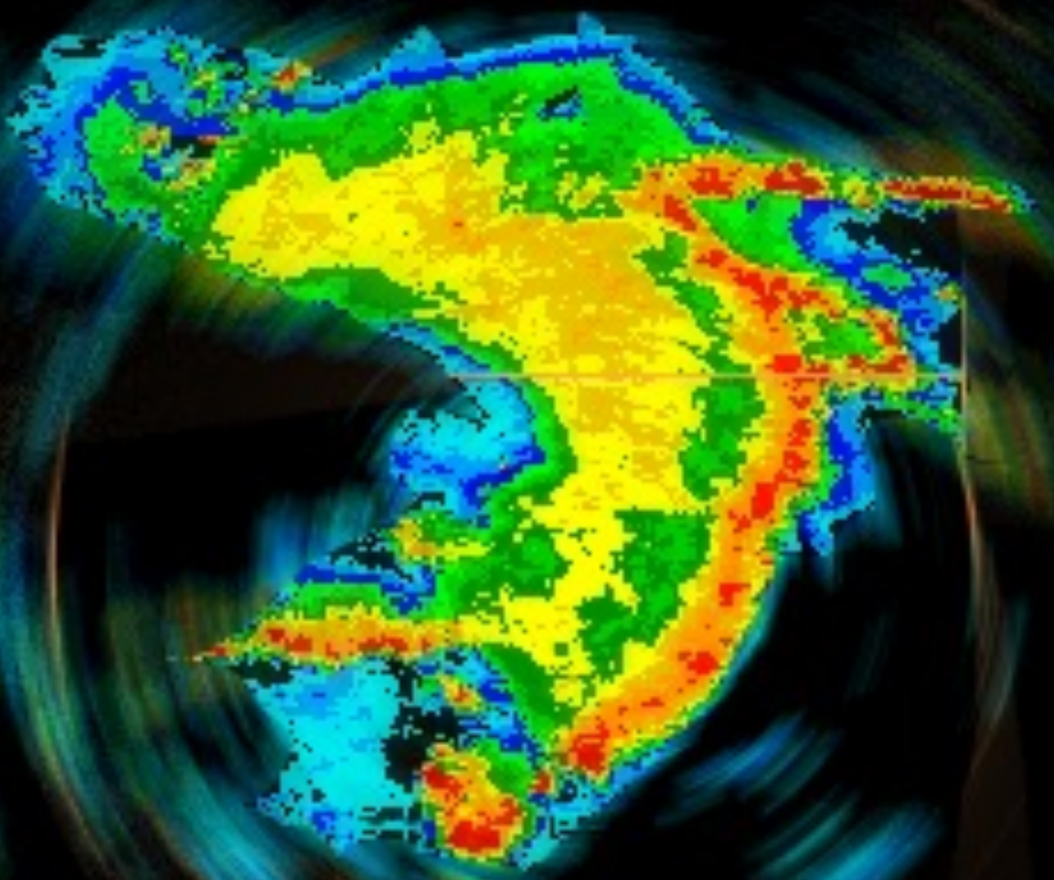
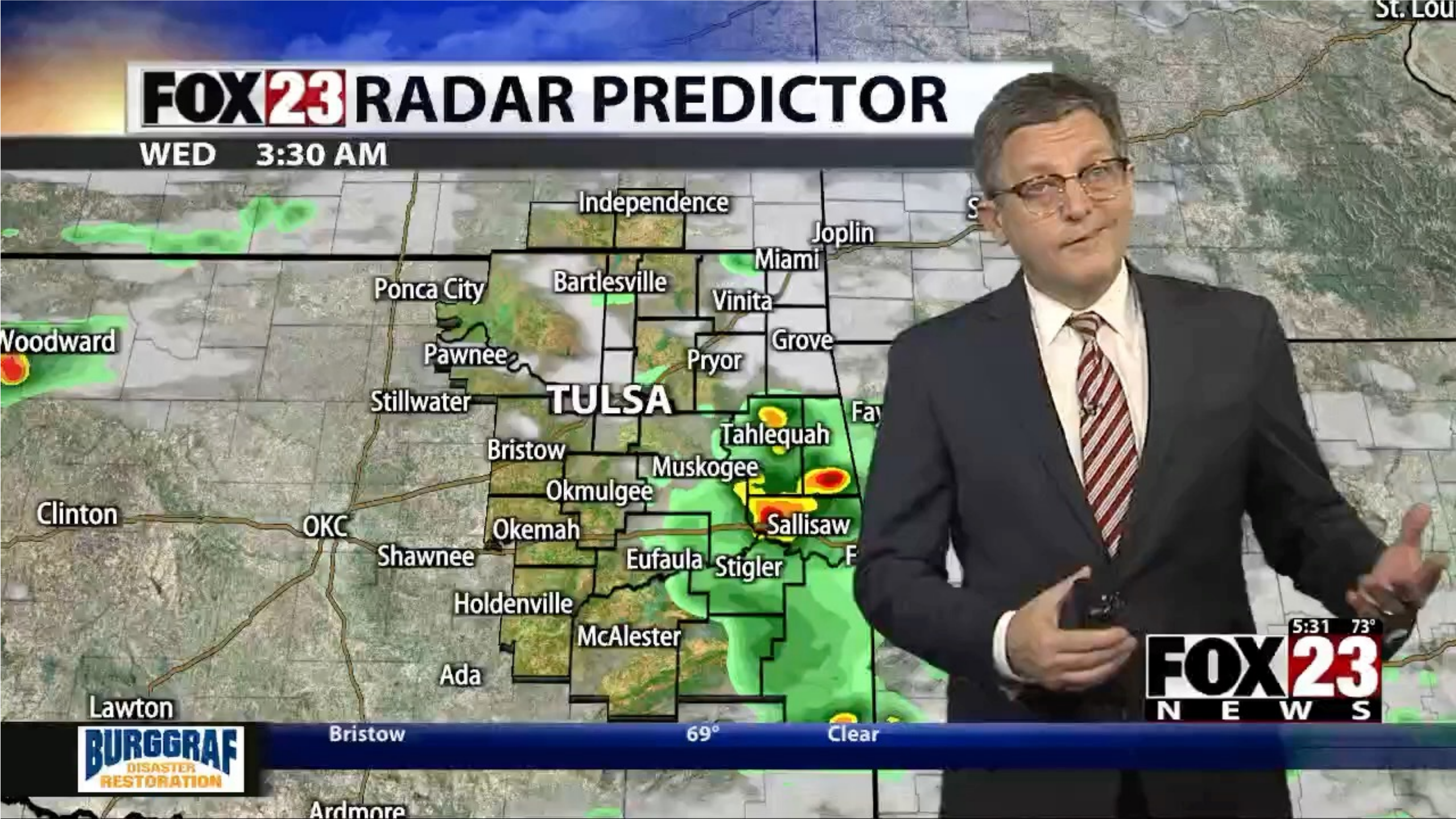
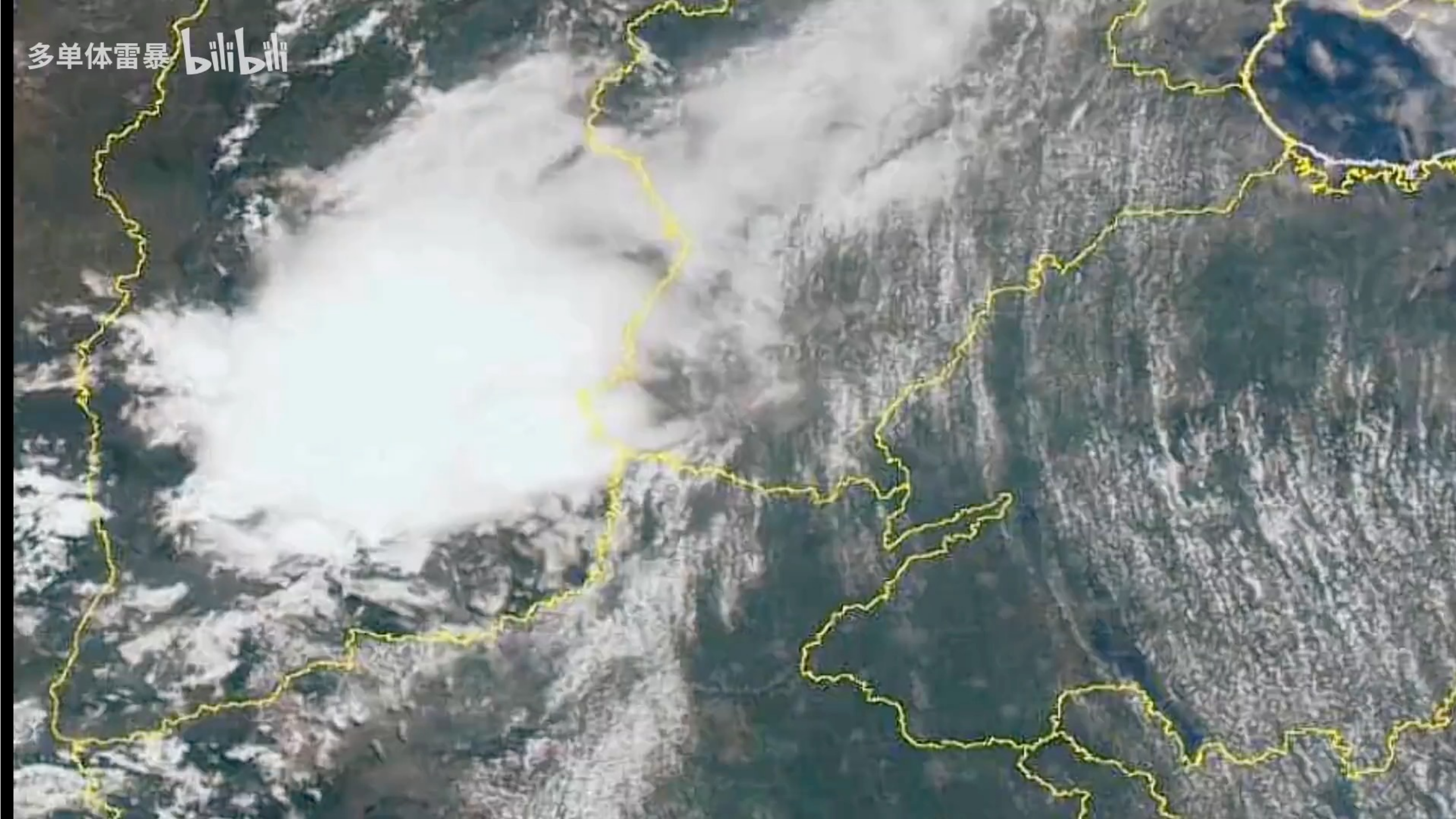
Mesoscale Convective System



- Squall Line
- Bow Echo
- MCC

Thunderstorms over the South China Sea, as seen from the International Space Station in 2016


FOX23 RADAR PREDICTOR
WED 3:30 AM
Independence
Joplin
Miami
Ponca City
Bartlesville
Vinita
Grove
Pawnee
Pryor
Stillwater
TULSA
Tahlequah
Bristow
Muskogee
Okmulgee
Clinton
OKC
Okemah
Sallisaw
Shawnee
Eufaula
Stigler
Holdenville
McAlester
Ada
Lawton
Ardmore
5:31 73°
FOX23 NEWS
BURGGRAF DISASTER RESTORATION
Bristow 69° Clear


多单体雷暴

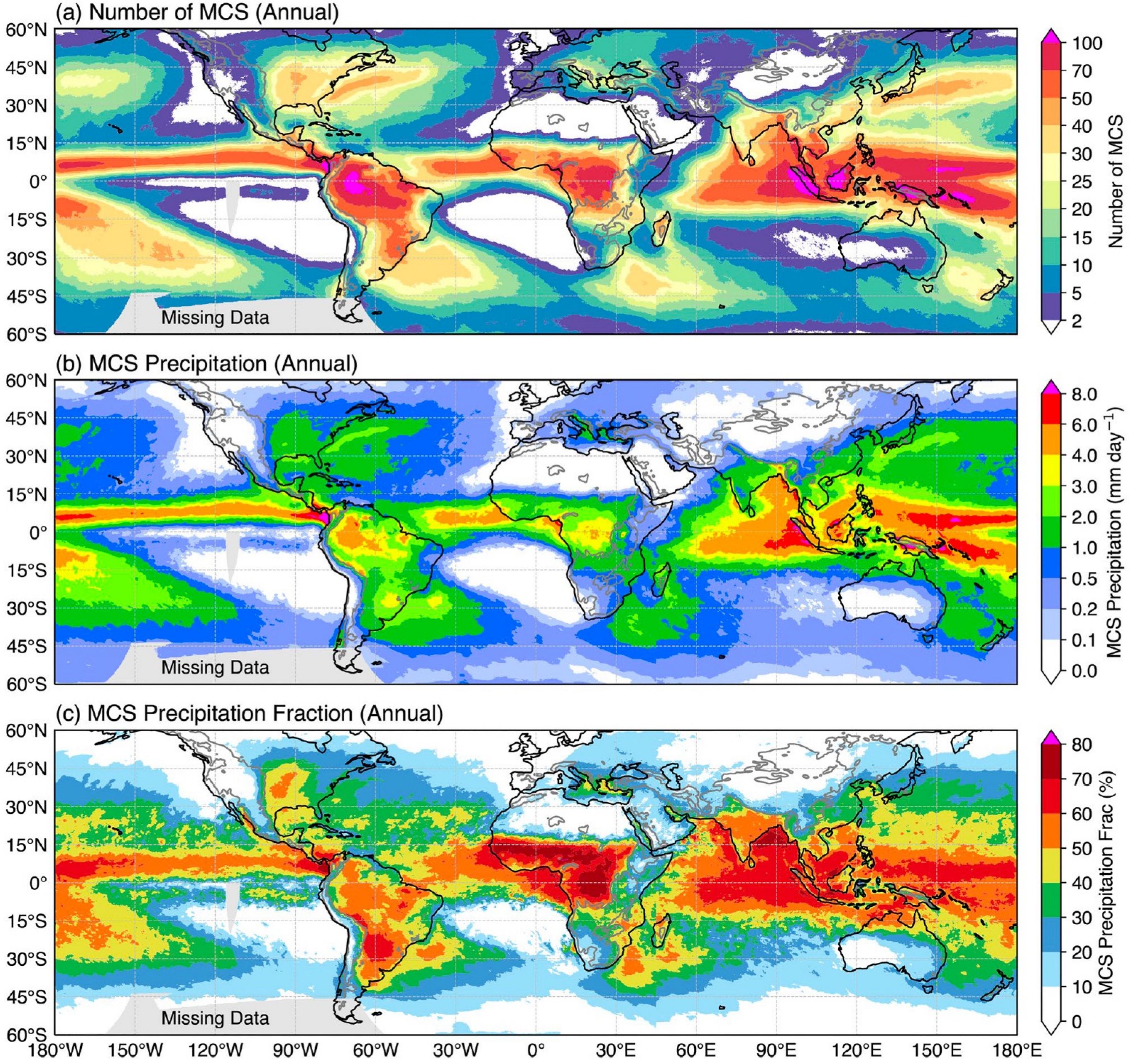


Figure 10. Annual mean global distribution of (a) the number of MCS, (b) MCS precipitation amount, and (c) percentage of MCS precipitation to total precipitation between 2001 and 2019. Dark gray contours show terrains higher than 1,000 m. The gray shaded regions over the Southern Pacific Ocean have frequent (>25%) missing T_b data that affects MCS tracking and is therefore masked out. MCS, mesoscale convective system.

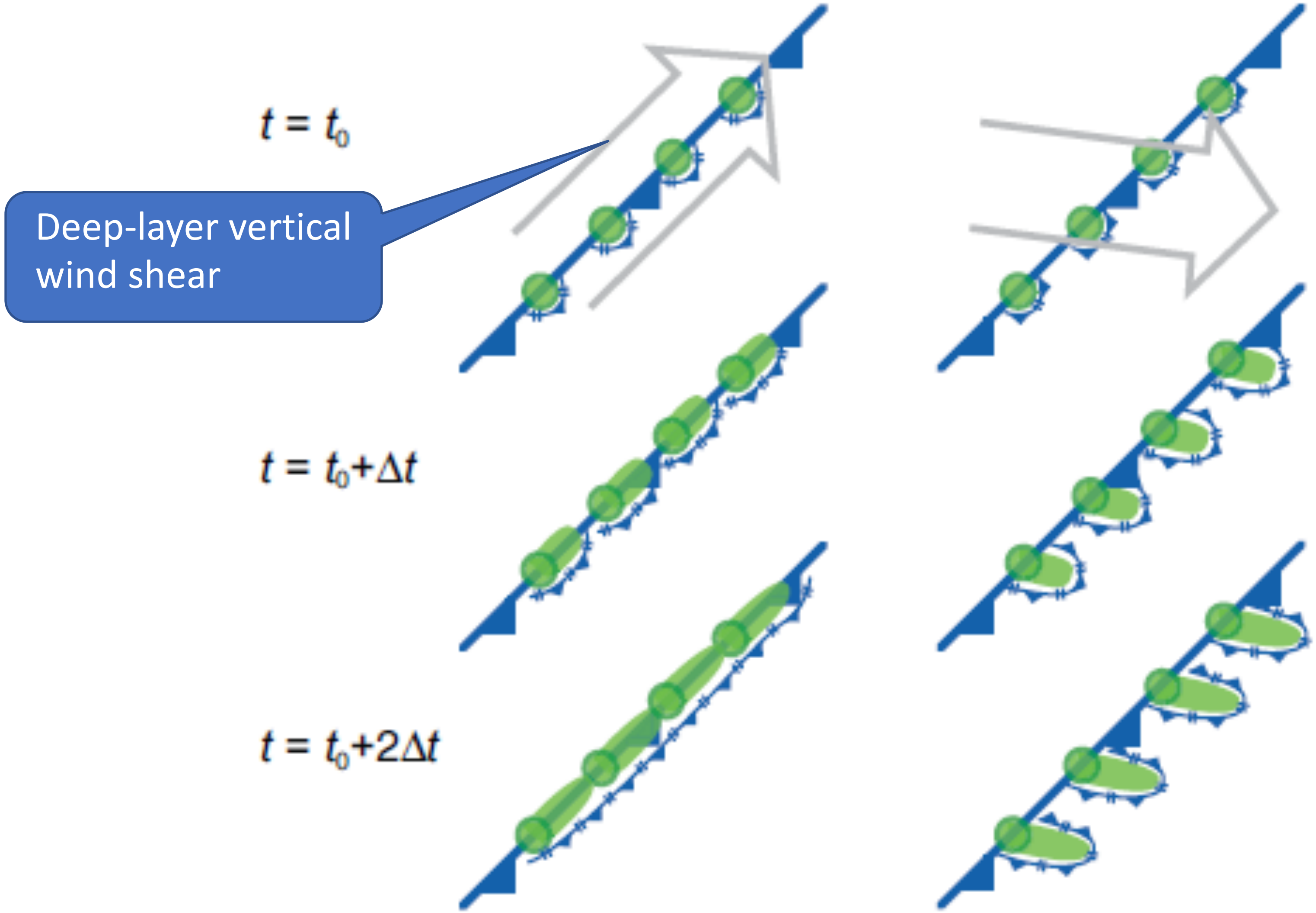
Feng (2021)

MCS的定义

- A cloud system that occurs in connection with an ensemble of thunderstorms and produces a contiguous precipitation area on the order of 100 km or more in horizontal scale in at least one direction.

(AMS 2015)

Upscale growth of convection



Formation

Commonly at night ?

- MCS forms several hours after isolated convections. The initiation of the isolated convection usually does not occur until the late afternoon or evening hours
- Nocturnal low-level wind maximum

MCS的分类

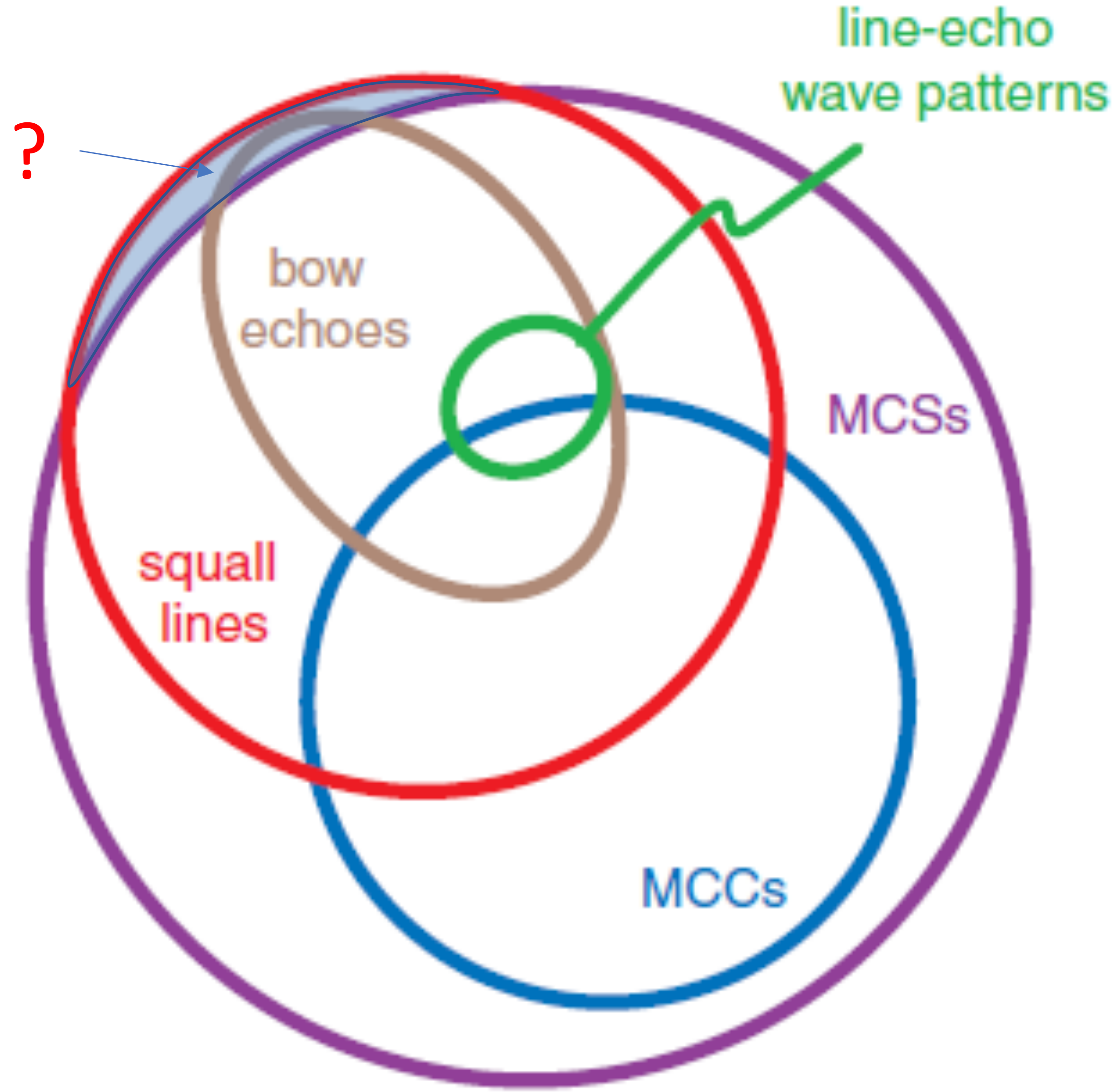
- Type I MCS

  driven by air mass boundary

- Type II MCS

  driven by their own cold pools

Relationships among Sub-classifications of MCSs

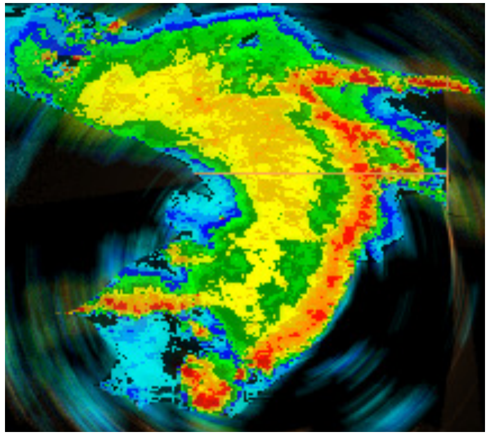


Squall line

- Squall line: a larger length-to-width ratio
  - A line of active thunderstorm, either continuous or with breaks, including contiguous precipitation area resulting from the existence of the thunderstorm
  - Bow echo

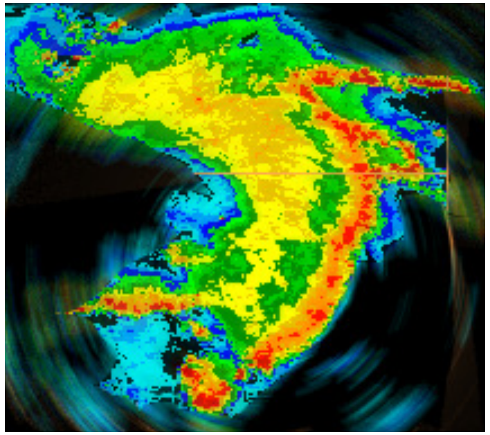
    Arc-shaped or bowing radar reflectivity structures within squall lines

Squall line identifications using radar



	Bluestein & Jain 1985	Chen &Chou 1993	Geerts 1998	Parker & Johnson, 2000
Time	11 years of Spring months (71-81)	2 months TAMEX May-June 1987	1 year, 94/5-95/4	2 months, May of 96,97
area	Oklahoma	Taiwan	Southeast US	Central US
Focus	Formation BL,BB,BA,EA	General characteristics	Survey	Organizational TS/LS/PL
population	150	6	187	88
Definition of linear MCS	LWR of 5:1, Length: 50km Width: ≤ 50km Last:≥ 15min No dBZ limit	12-20dBZ ≥150km ≥5h LWR of 36-41dBZ ≥3:1 at mature	20dBZ ≥100km last ≥4h 40dBZ lasts ≥ 2h LWR ≥ 5:1	40dBZ ≥ 100km ≥ 3h Share a common leading edge

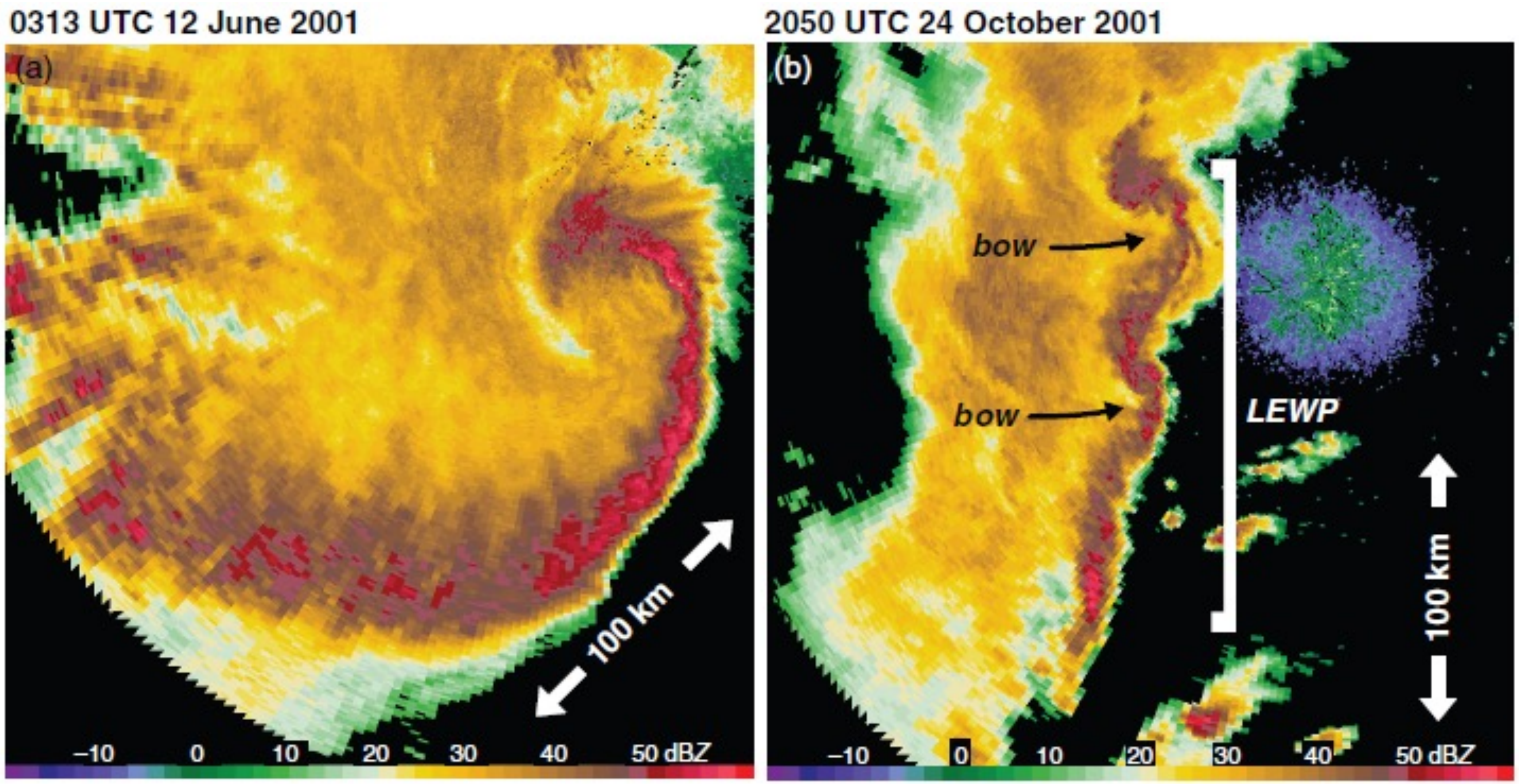
Squall line identifications using radar



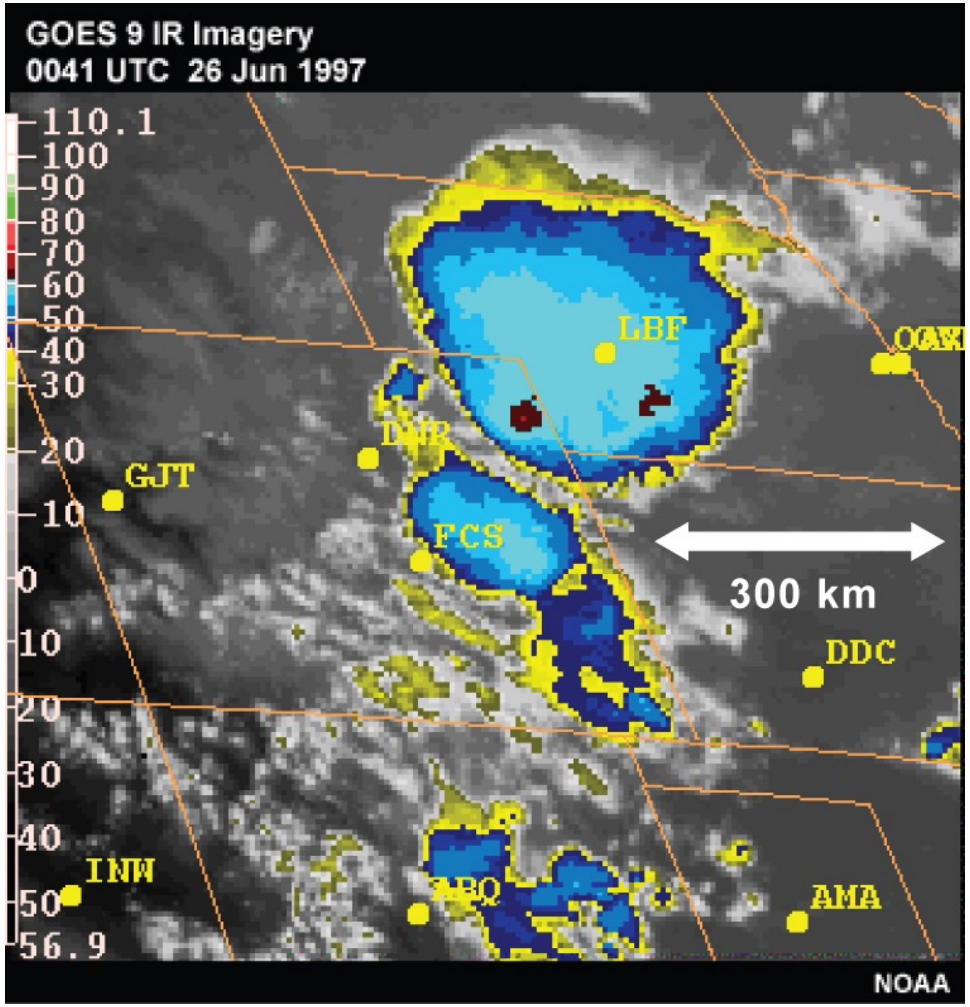
	Meng & Zhang 2012	Meng et al. 2013
Time	3 years (2007-2009)	08,09
area	China	East China
Focus	General characteristics	General characteristics
population	17	96
Definition of linear MCS	Contiguous or quasi-contiguous region of 40-dBZ that extends at least 100 km, exists for at least 3h, which has a linear or quasi-linear convective area with an apparent common leading edge. The"quasicontinuous" is realized here by requiring the 35-dBZ band in which the 40-dBZ line is embedded is strictly continuous.	A contiguous band of 40-dBZ reflectivity extends at least 100 km and lasts at least 3 h. The 40-dBZ region has a linear or quasi-linear shape with an apparent common leading edge.

A bowing shape squall line

Line echo wave pattern



MCC



云顶温度低于-32 ° C 的云的面积不小于10万 km²

或者

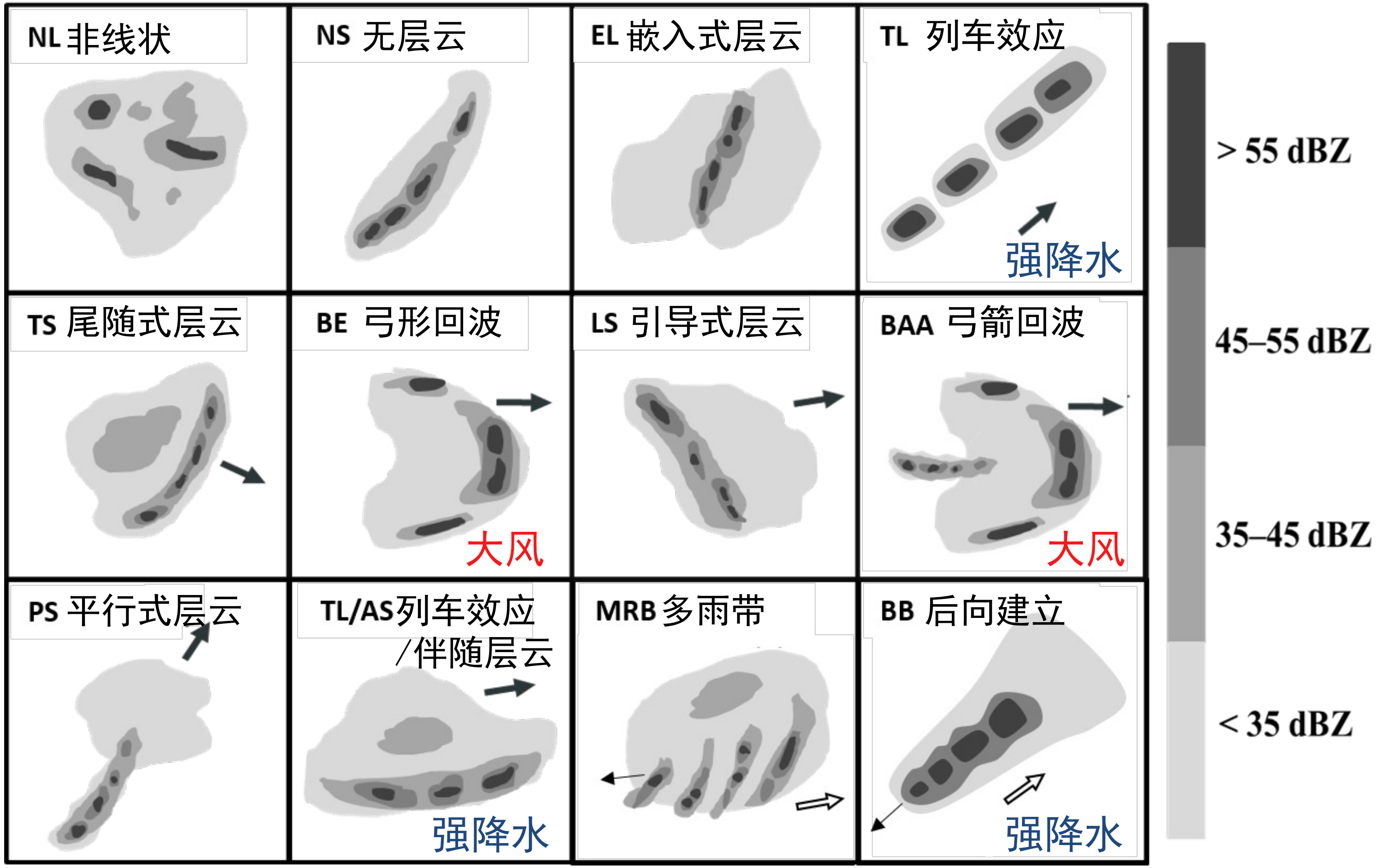
云顶温度低于-52°C 的云的面积不小 5万 km²

的时间至少维持6小时

在面积最大时长短轴之比不小于0.7

The anvil is fairly circular, regardless of the radar appearance

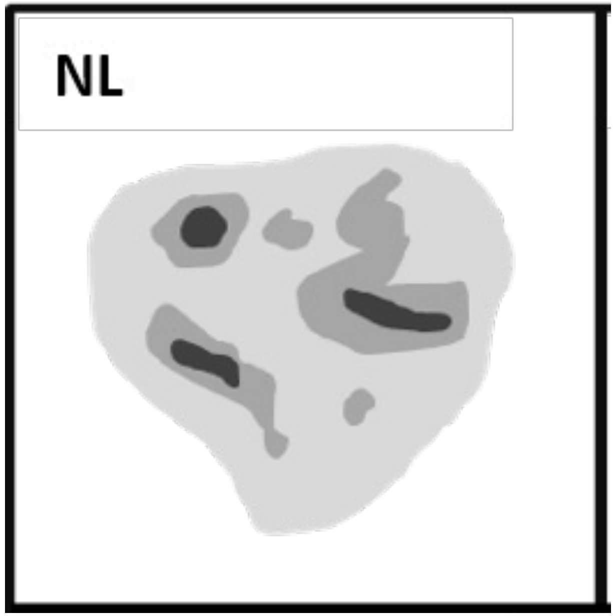
MCS 的组织形态



Chappell,1986;Doswell et al., 1996; Schumacher and Johnson,2005;
Keene and Schumacher, 2013; Zheng et al., 2013; Wang Hui et al., 2013

Linear vs. NL mode

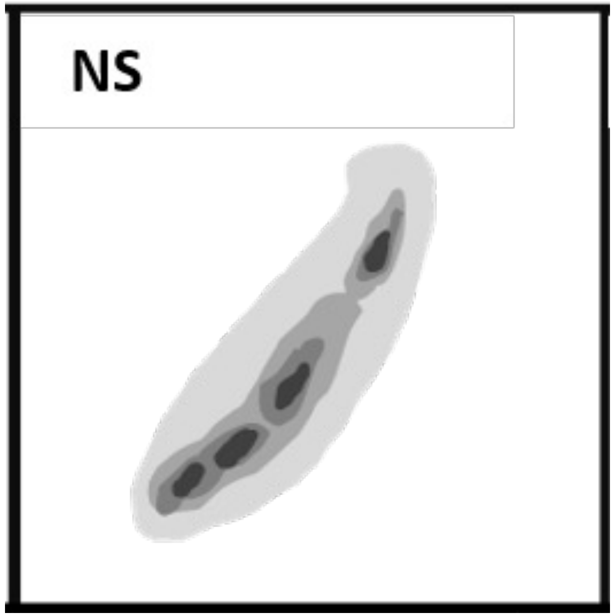
- An MCS is defined to have a linear mode if the radar reflectivity of ≥40 dBZ has a length-to-width ratio of at least 1.8.



(Li and Meng 2021 JGR)

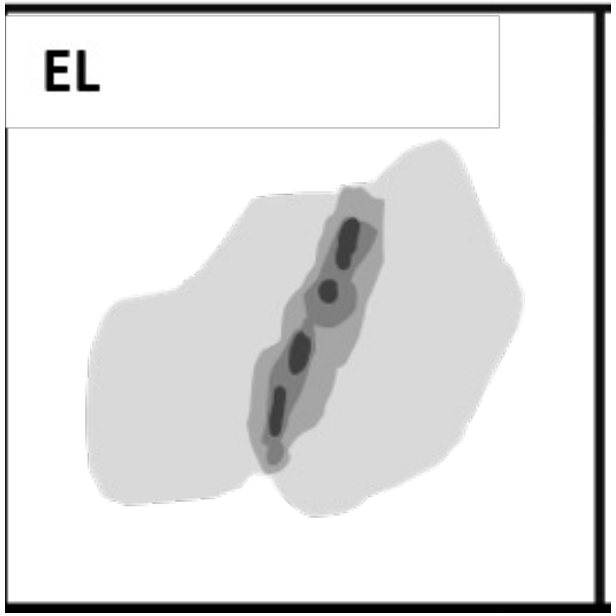
NS: no stratiform precipitation

- A strong **reflectivity gradient** is observed at both the leading and trailing edges
  - The **maximum widths** of the preline and postline **stratiform** precipitation are less than the maximum width of the convective line.
  - **Other linear modes** are distinguished from the NS mode by having the **maximum width** of the preline or postline stratiform precipitation greater than the maximum width of the convective line.



EL: embedded lines

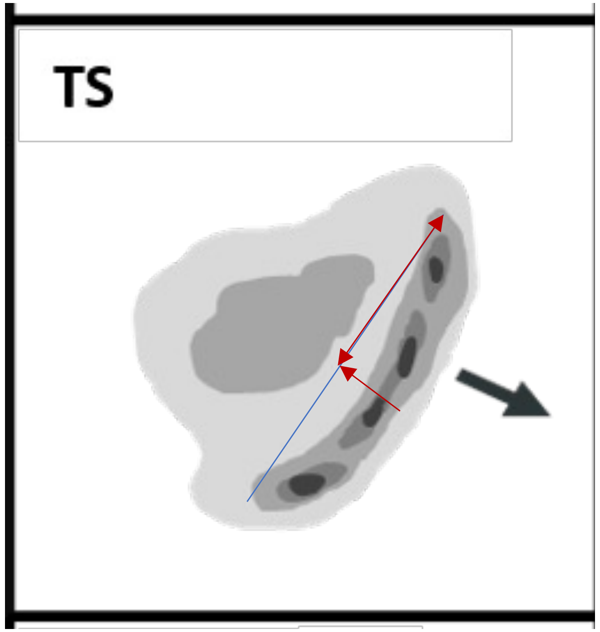
- At least 2/3 of the convective line is **embedded** in a large area of stratiform precipitation.
- **The maximum widths** of the preline and postline stratiform precipitation are both larger than the maximum width of the convective line.



TS: trailing stratiform precipitation

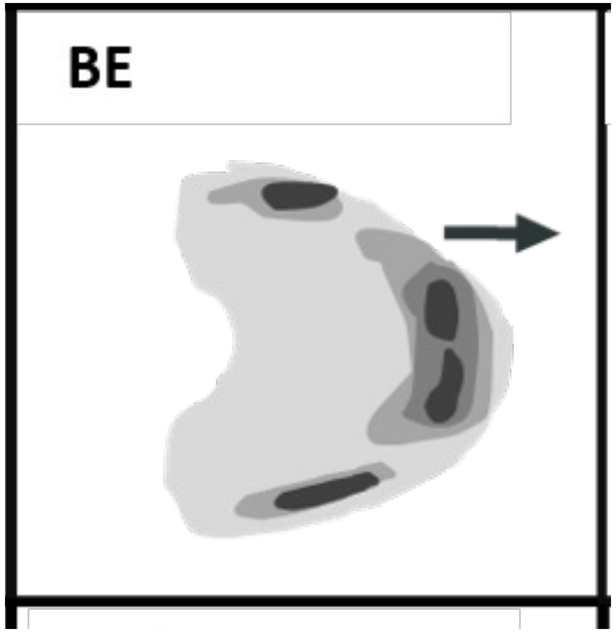
Stratiform precipitation is dominantly located **behind** the convective line with respect to the direction of the movement of the MCS

- MCS **moves** generally perpendicularly to the convective line.
- The **maximum width** of the trailing stratiform precipitation is larger than the maximum width of the convective line.
- There is usually a great **reflectivity gradient** at the leading edge of the MCS.
- **The distance from the apex** of the leading edge to the straight line connecting the two ends of the convective line is smaller than half the total distance of the straight line from end to end, which is used to distinguish it from the **bow echoes** mode.



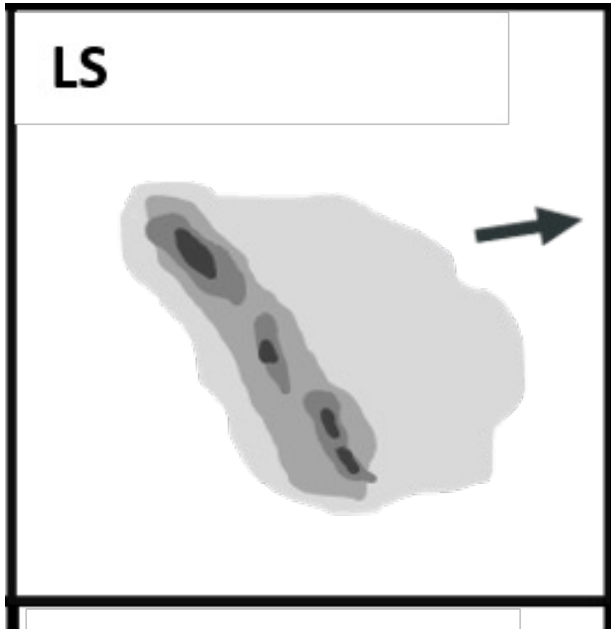
BE: bow echoes

- Similar to the TS mode, but with the **distance** from the apex of the leading edge to the straight line connecting the two ends of the convective line being at least half the total distance of the straight line from end to end.
- The convective reflectivities have the shape of a **bow** or crescent and a great **gradient** exists at the convex region.



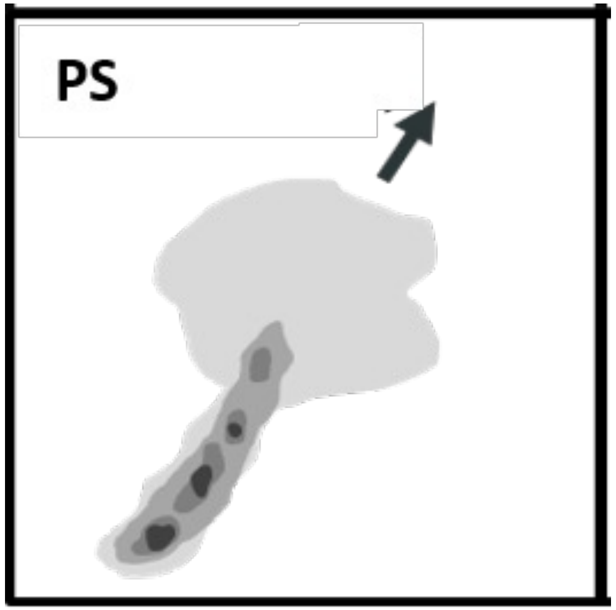
LS: leading stratiform precipitation

- Similar to the TS mode, except stratiform precipitation is dominantly located **in advance of** the convective line with respect to the direction of the movement of the MCS.
- A great **reflectivity gradient** exists at the trailing edge of the MCS.



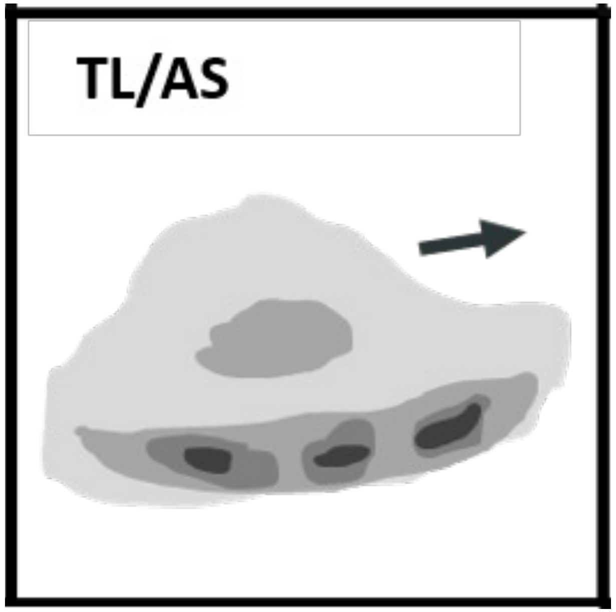
PS: parallel stratiform precipitation

- The convective line has **at most 1/3** of its length embedded in the downstream stratiform precipitation
- The stratiform precipitation **move**s roughly **parallel** to the orientation of the convective line (generally **less than 30** ° from the orientation of the convective line) with a **maximum width** larger than the maximum width of the convective line.
- The other at least **2/3** of the **convective line** has a strong reflectivity gradient at both the leading and trailing edges.



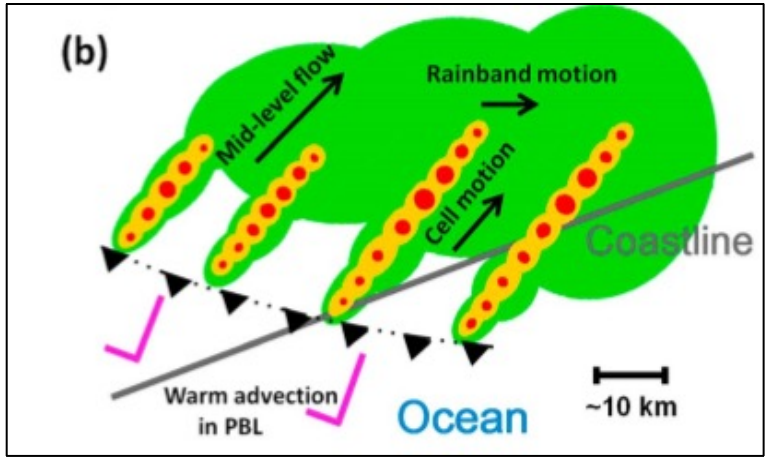
TL/AS: training line/adjoining stratiform

- The convective line has at least 2/3 of its **length adjoining with** stratiform usually on the north side,
- The stratiform has a maximum **width** larger than the maximum width of the convective line.
- Both stratiform and convective precipitation **move** along the orientation of the convective line.

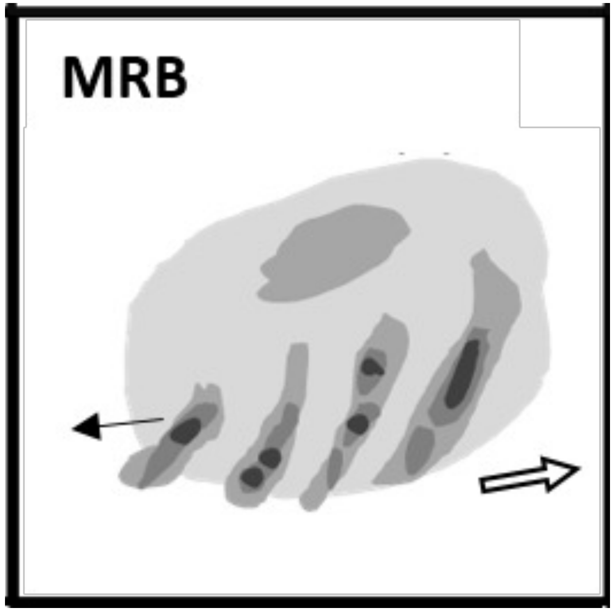


MRB: multiple rain bands

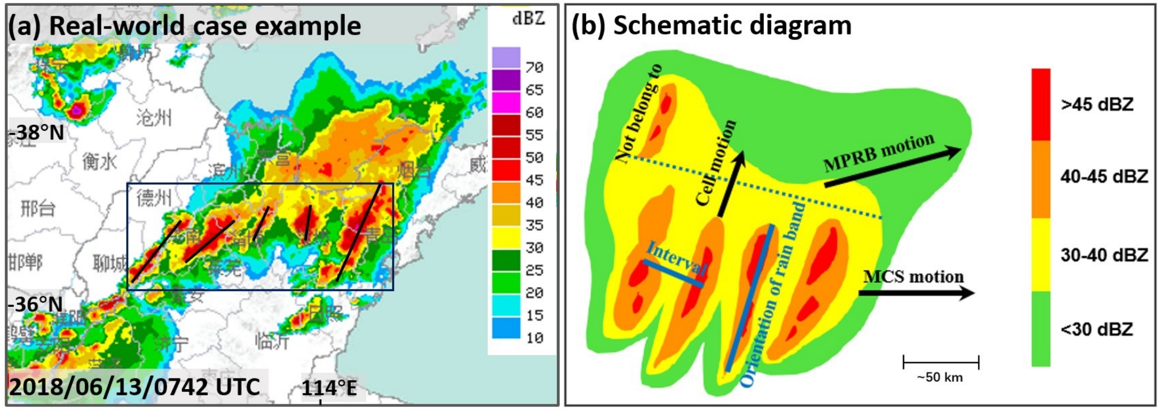
- There are at least **four** approximately **parallel** convective lines with at least **one** convective line having a length of ≥**100 km**.
- These convective lines are partly or completely **embedded** in stratiform precipitation.



(Wang et al., 2014)



MRB: multiple rain bands



MCS: the area with reflectivities above 30 dBZ longer than 100 km along at least one direction and the sustaining of 40 dBZ value persists for longer than 3 hours.

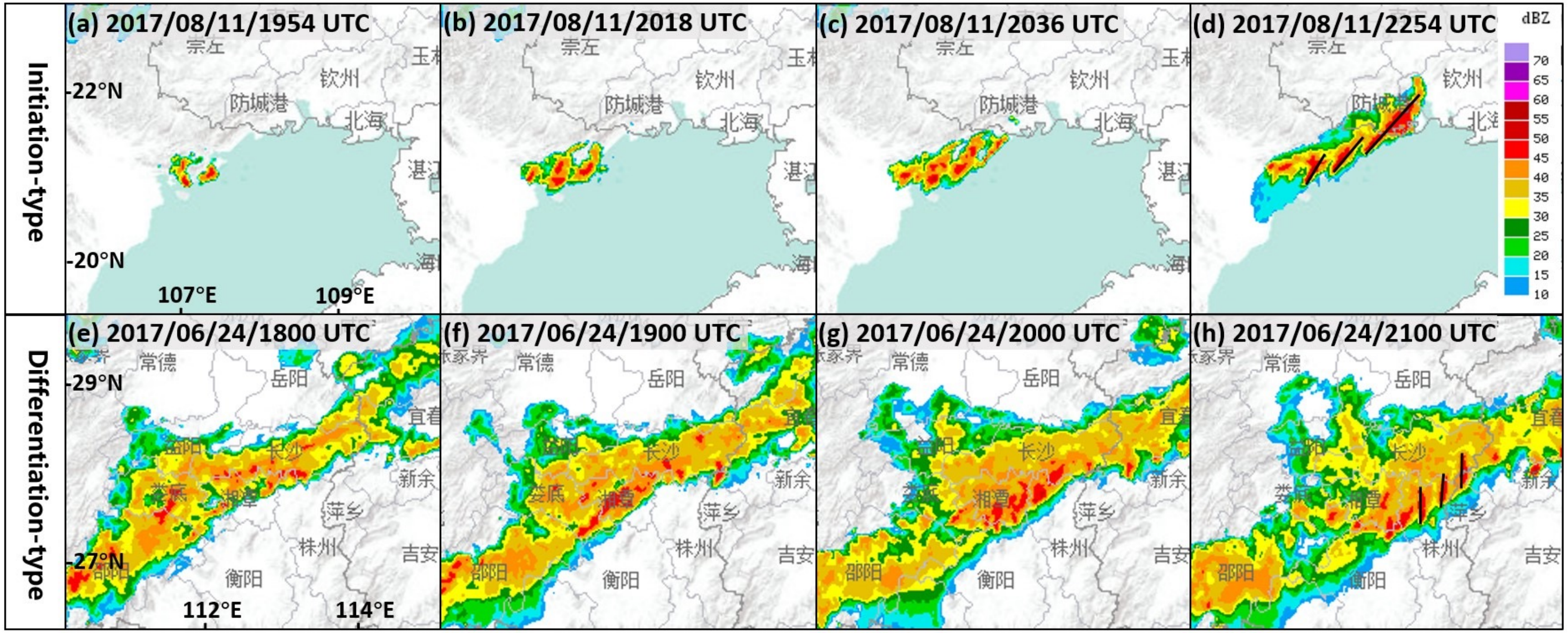
Rain band: continuous convective line with a length of more than 30 km and a long-axis to short-axis ratio greater than 2.

(1) At least **3** rain bands exist **simultaneously** for more than 20 minutes.

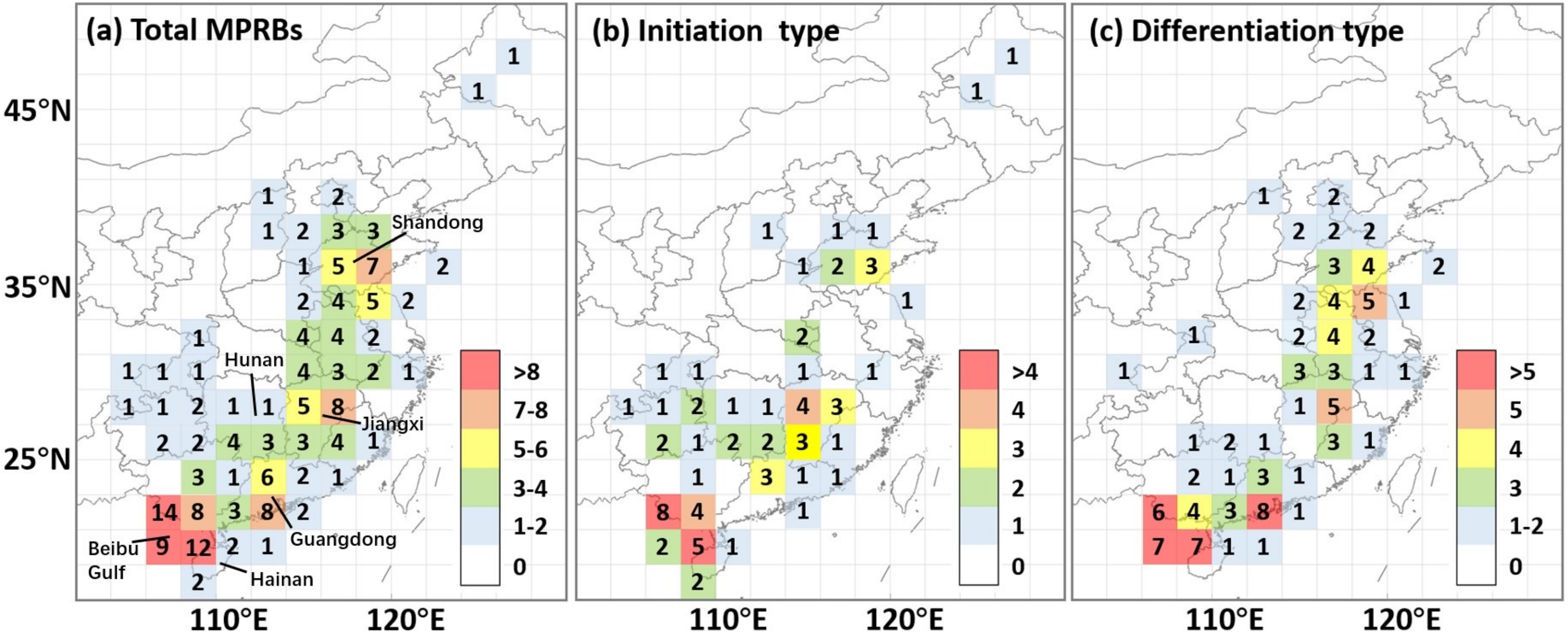
(2) The **angles** between the long axis of all rain bands are less than 45°

(3) At least there is one line parallel to the minor axis of the rain band intersecting with other rain bands.

（Wang， Meng et al. 2023, MWR)



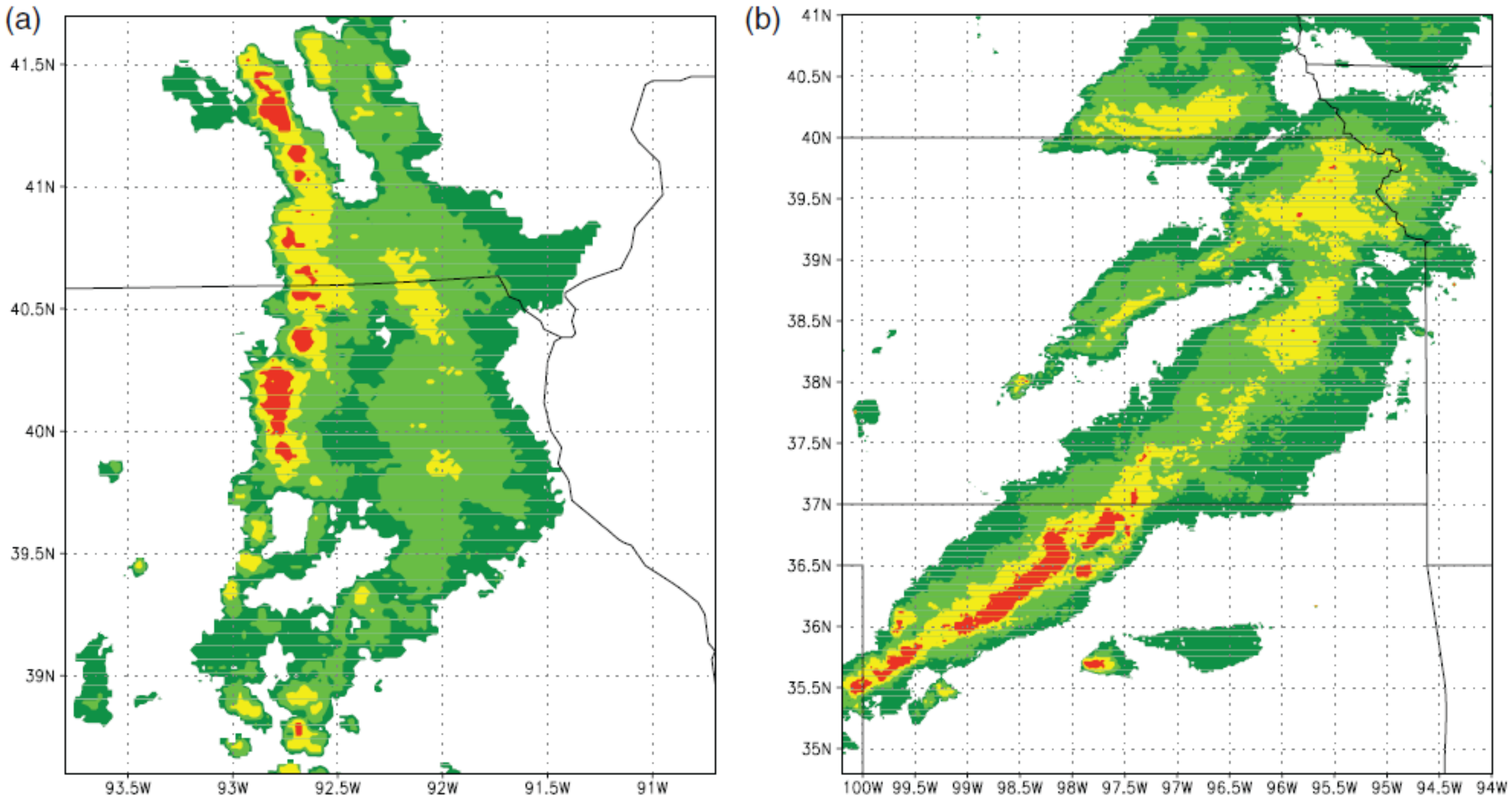
Initiation-type
Differentiation-type
(a) 2017/08/11/1954 UTC
(b) 2017/08/11/2018 UTC
(c) 2017/08/11/2036 UTC
(d) 2017/08/11/2254 UTC
(e) 2017/06/24/1800 UTC
(f) 2017/06/24/1900 UTC
(g) 2017/06/24/2000 UTC
(h) 2017/06/24/2100 UTC
22°N
20°N
107°E
109°E
29°N
27°N
112°E
114°E
dBZ
70
65
60
55
50
45
40
35
30
25
20
15
10



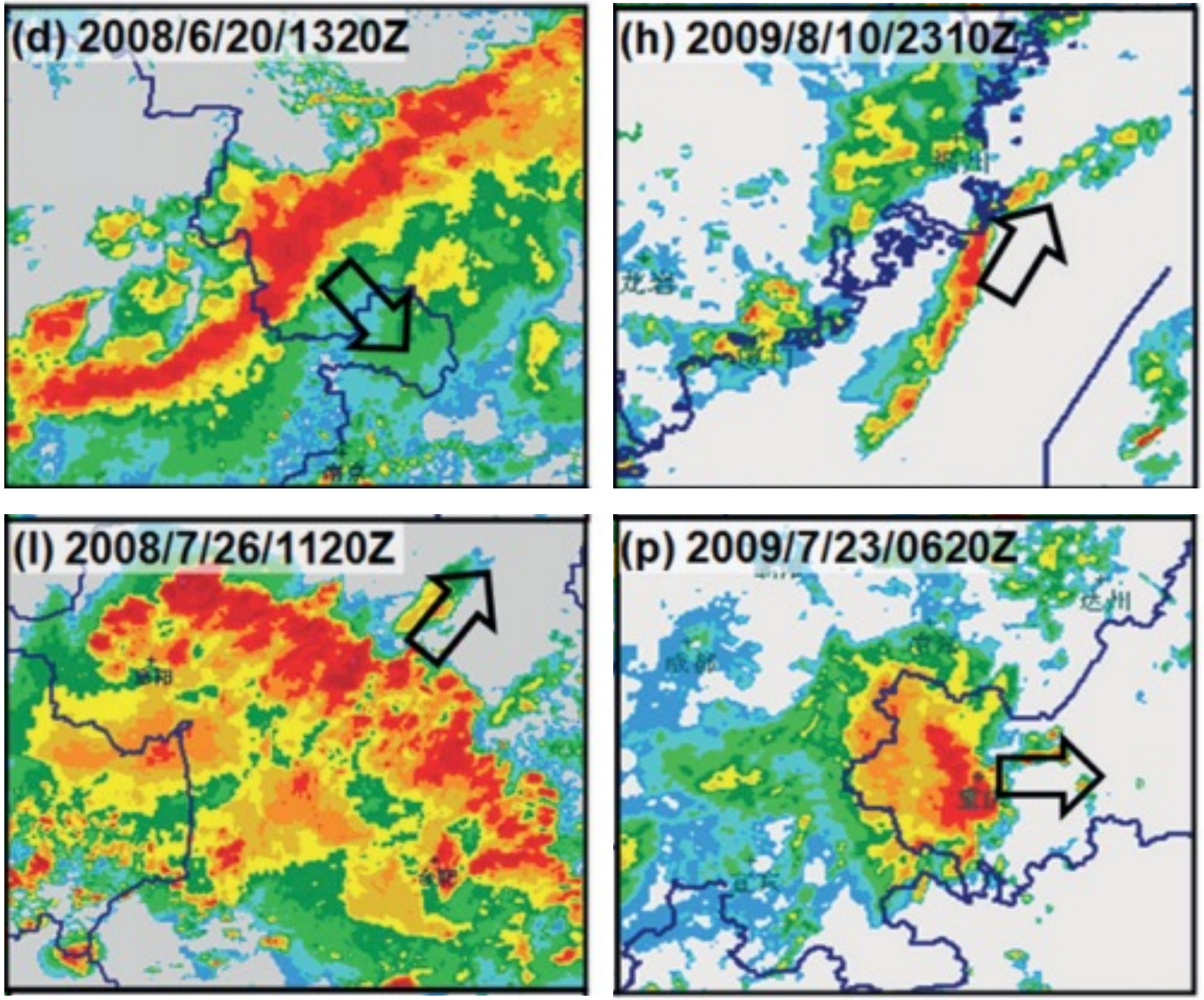
(a) Total MPRBs
(b) Initiation type
(c) Differentiation type
Shandong
Hunan
Jiangxi
Guangdong
Beibu Gulf
Hainan
45°N
35°N
25°N
110°E
120°E
>8
7-8
5-6
3-4
1-2
0
>4
4
3
2
1
0
>5
5
4
3
1-2
0

LS

PS



(a)
41.5N
41N
40.5N
40N
39.5N
39N
93.5W
93W
92.5W
92W
91.5W
91W
(b)
41N
40.5N
40N
39.5N
39N
38.5N
38N
37.5N
37N
36.5N
36N
35.5N
35N
100W
99.5W
99W
98.5W
98W
97.5W
97W
96.5W
96W
95.5W
95W
94.5W
94W

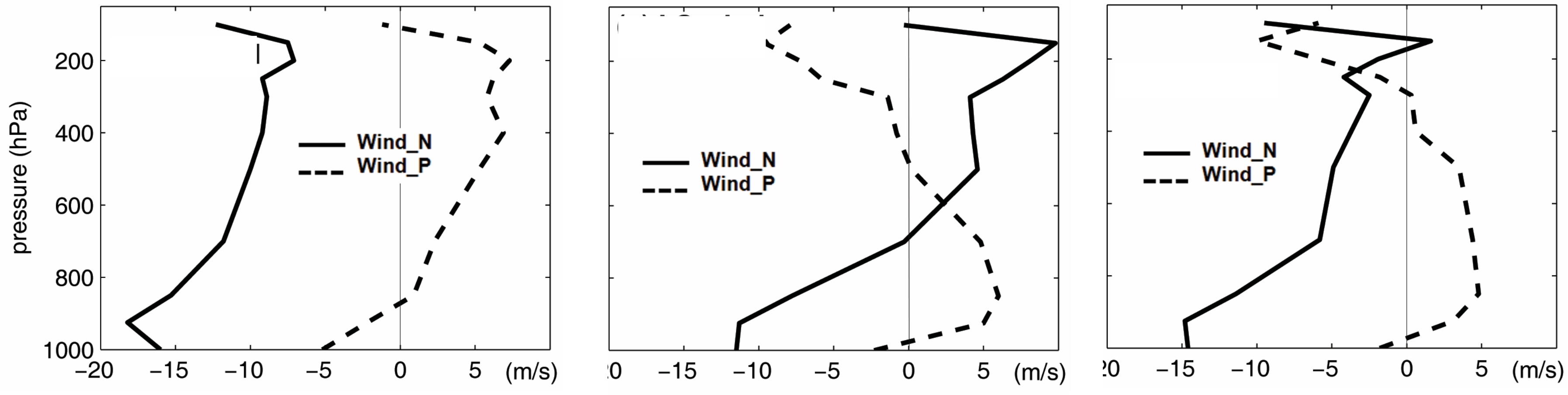


Meng et al. 2013

Composite rawinsonde for Different Organization Modes

Based on Squall Line in East China

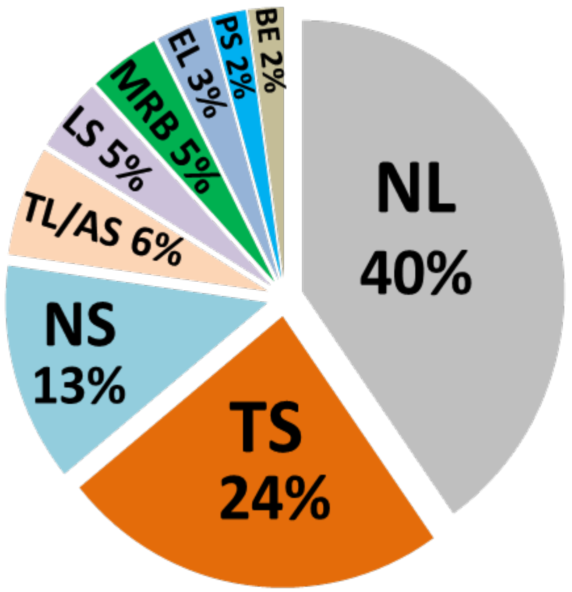
Guess which is which? LS, TS, PS



Meng et al. 2013

华南暖区暴雨MCS组织形态

- The top 3 modes of the target MCSs are the nonlinear (NL) mode and two dominant linear modes: trailing (TS) and no (NS) stratiform rain.
- NL systems develop faster, move more slowly, have shorter lifespans, and produce stronger 3-h and 6-h rainfalls than TS and NS systems.
- The Total Totals index is significantly different among the top three modes of the target MCSs.



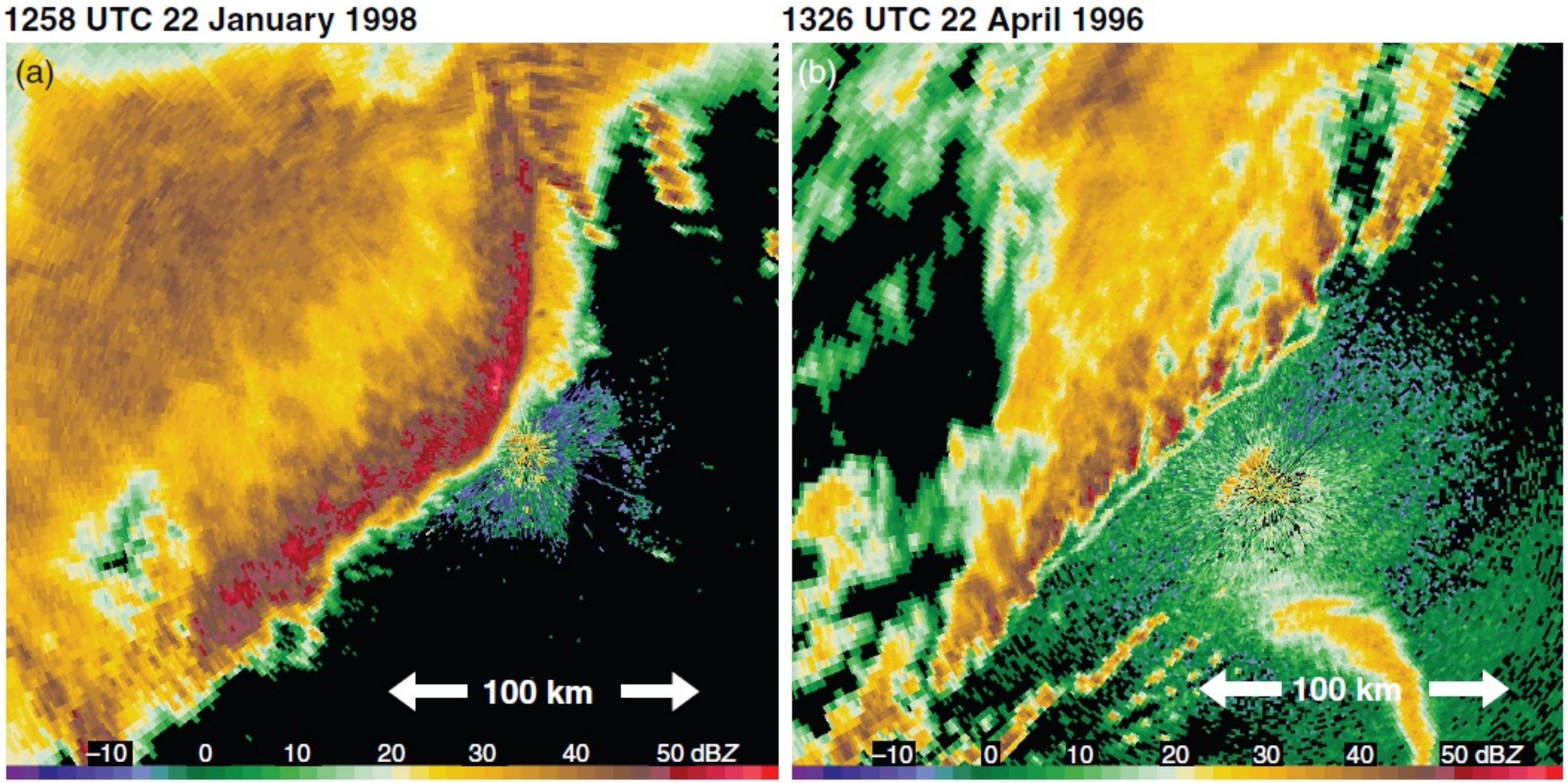
(Li and Meng 2021 JGR)

$$\mathrm{TT} = T_{850} - T_{500} + T_{\mathrm{d}\,850} - T_{500}$$

Linear vs Cellular

Unbroken

Cellular

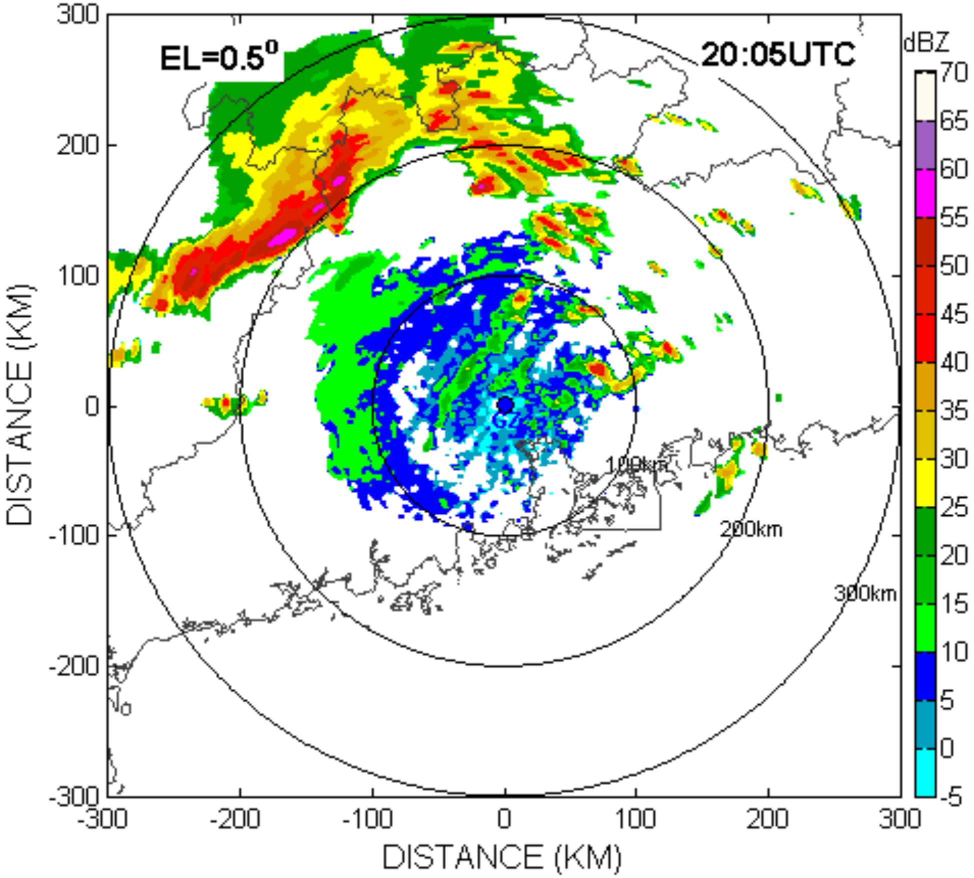


Closely related to low-level relatively humidity (RH)

Squall Line

Squall line: structure

GZ Radar Reflectivity at 0.5 Elevation



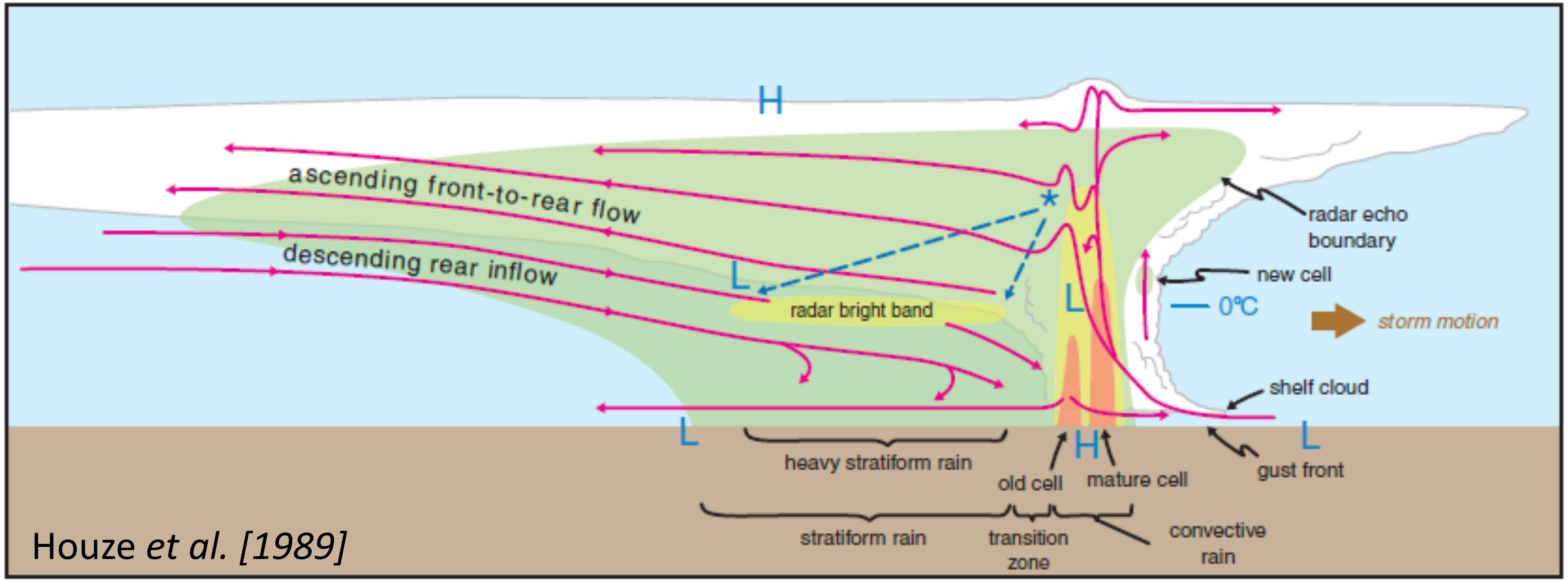
特点: 移速快,45 km / h,
持续时间长， 约11 h,
范围广， 横跨广东全省.

灾害: 23日至24日， 广东遭遇大范围暴雨和雷雨大风天气， 全省大部分地区普降强降水。47个市县出现暴雨， 局部出现大暴雨， 全省最大降雨量186.3毫米。曲江的沙溪镇出现了冰雹。出现了8级至9级的大风， 花都大风30米 / 秒 （１１级） 。

（Zhao kun 2007）

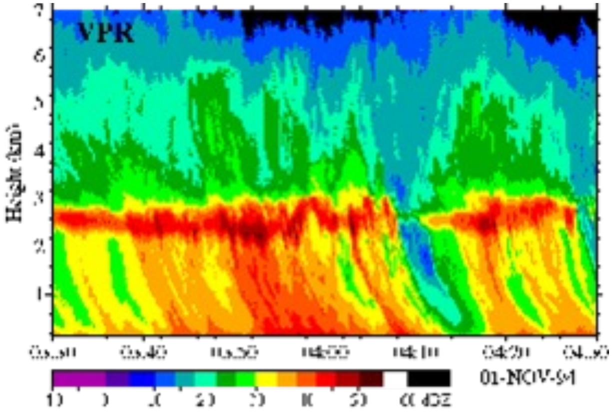
An example of squall line

Squall Line Structure

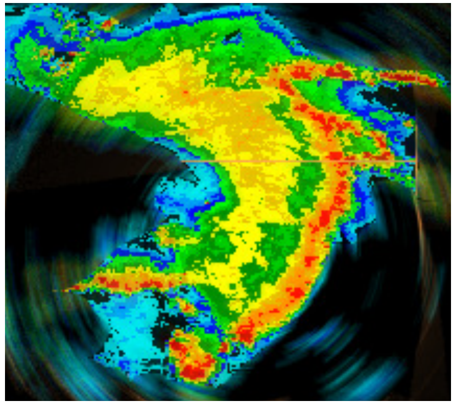


Houze *et al. [1989]*

Cloud
Radar
Flow
Pressure

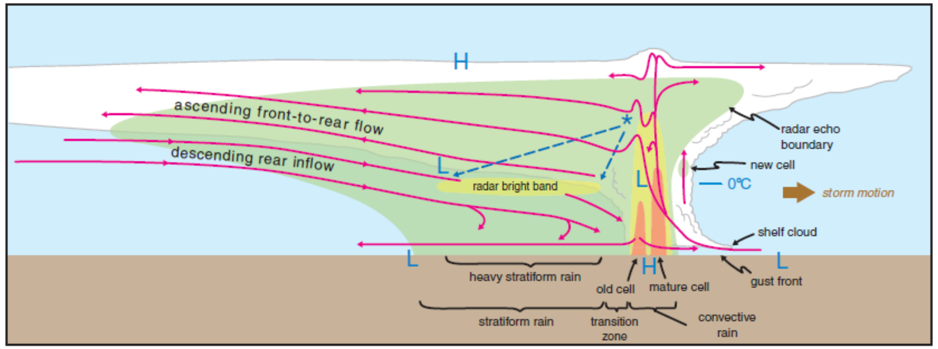


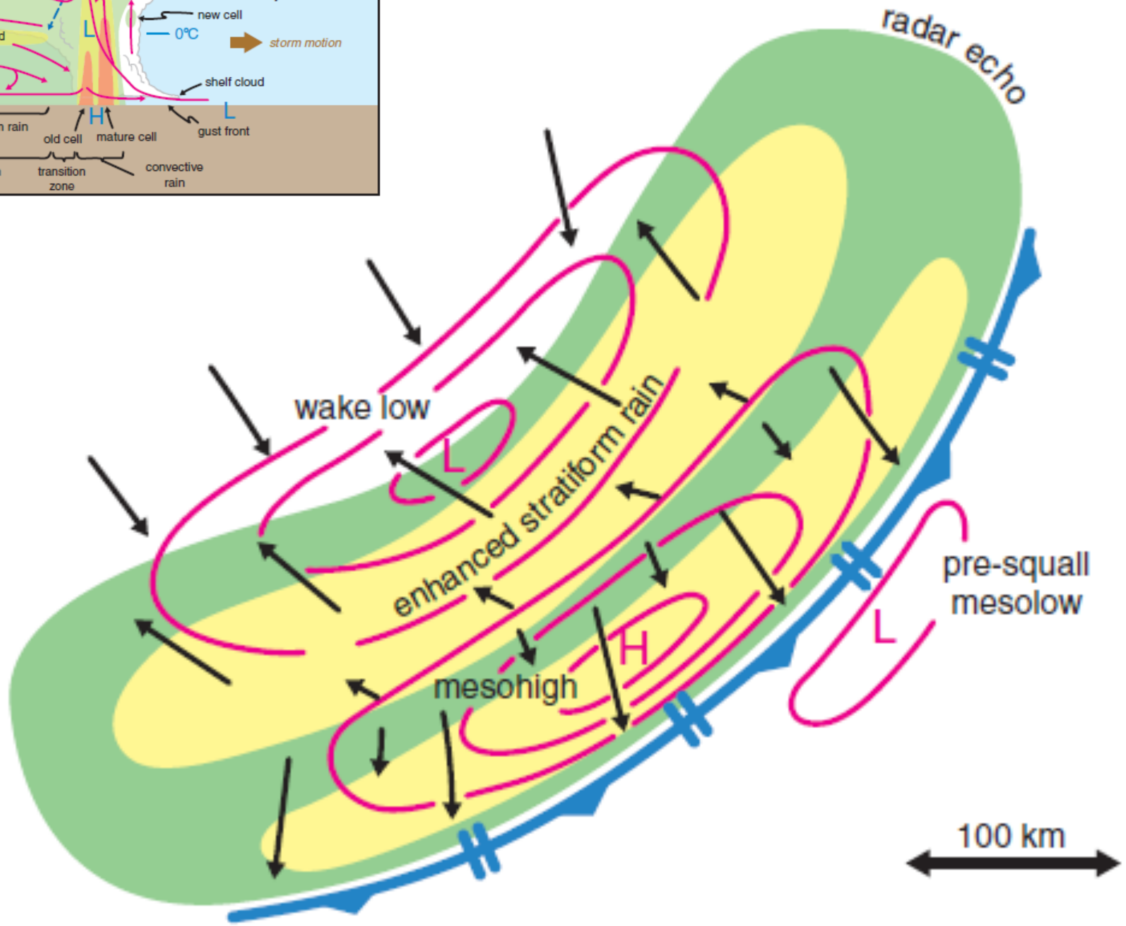
Courtesy of Dr. Weiss



Courtesy of Comet

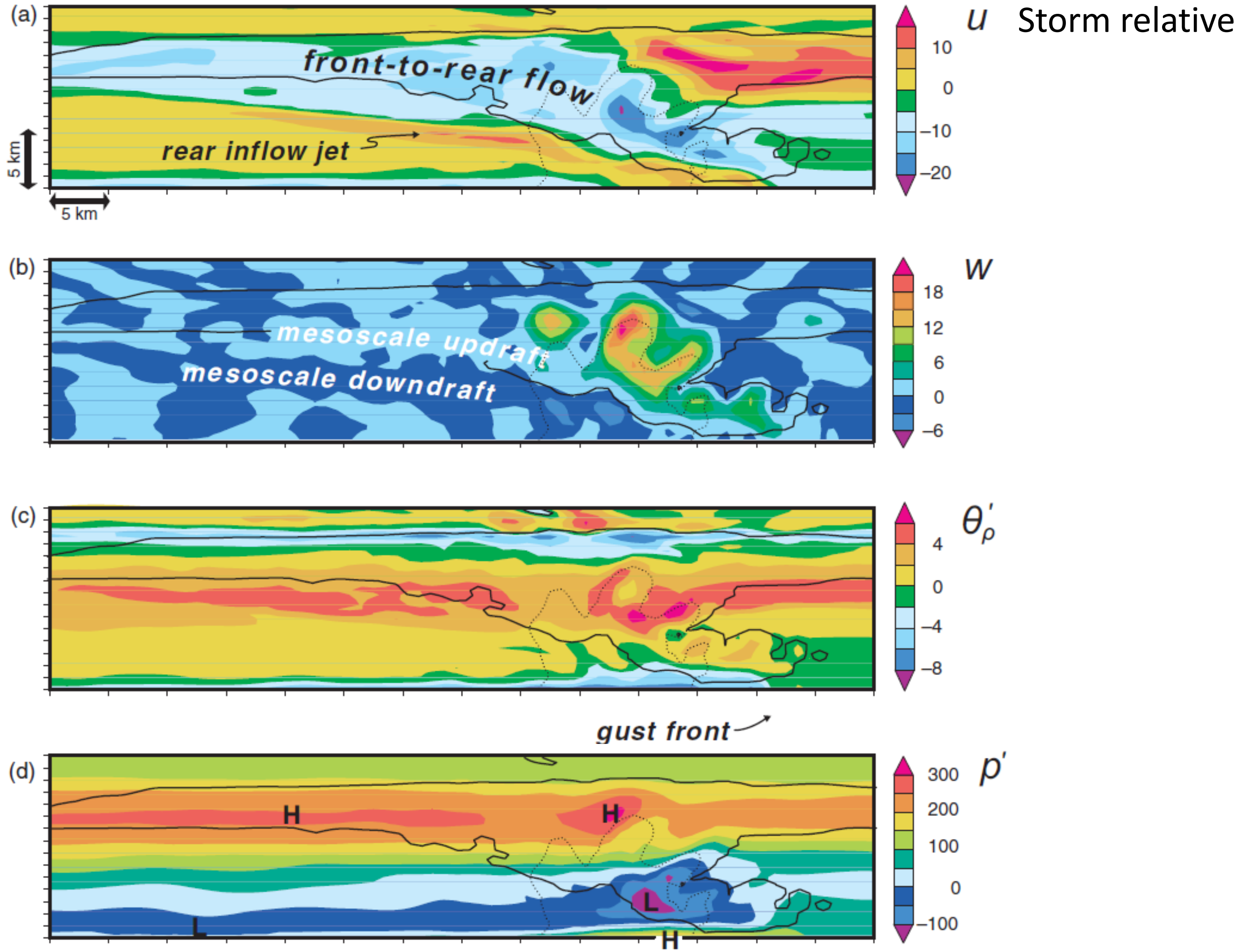
Surface pressure features



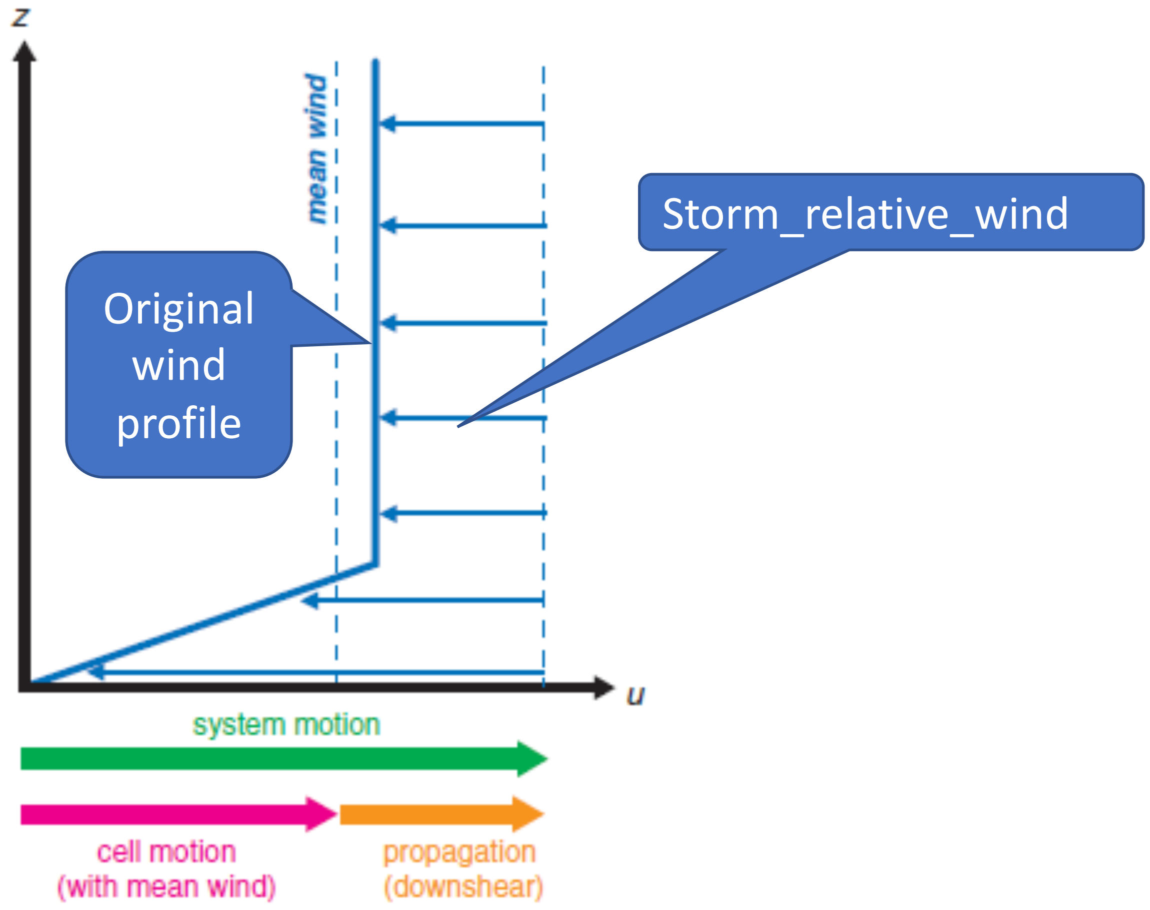


A Numerical Simulation of Squall Line

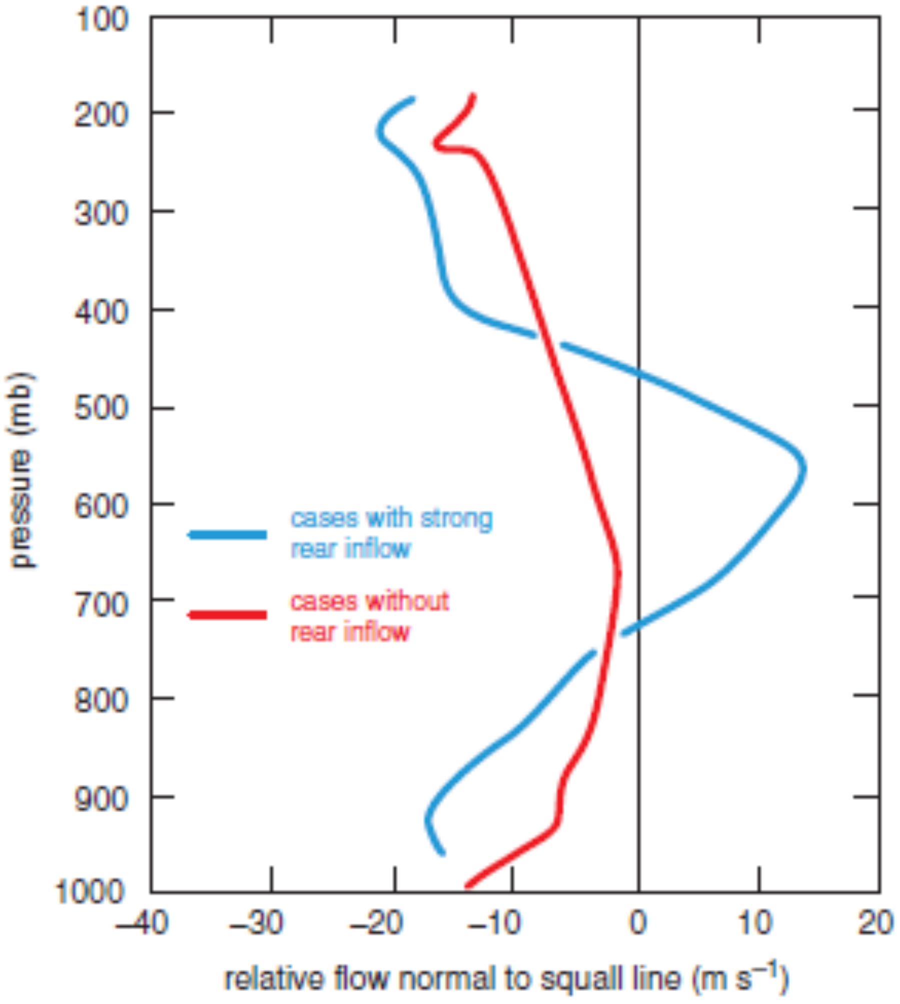
CAPE ~ 2000 J kg^{-1} and the unidirectional, westerly wind shear of 10 m/s in the lowest 2.5 km



System-relative flow: front-to-rear flow



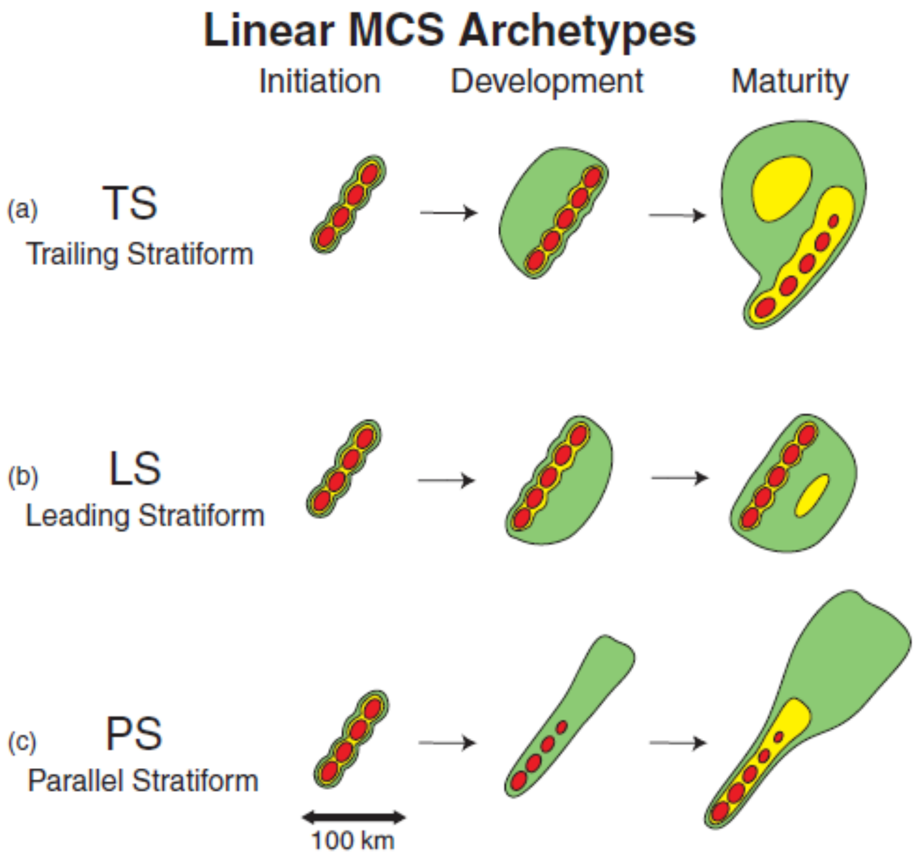
Composite of Rear Inflow



Smull and Houze 1987

Strong squall lines tend to have strong rear inflow

Squall line organization mode



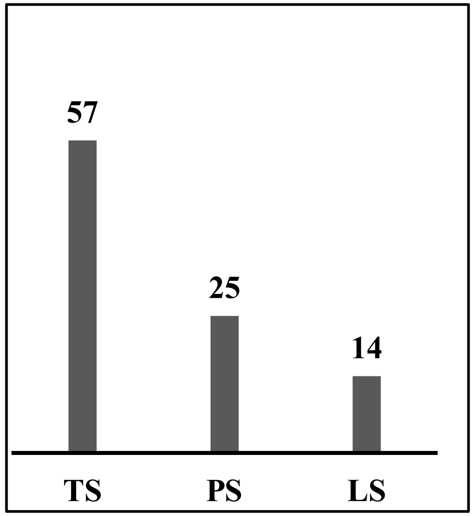
(Parker and Johnson 2000)

60-80%

Rear-to-front shear at high levels
10-20%

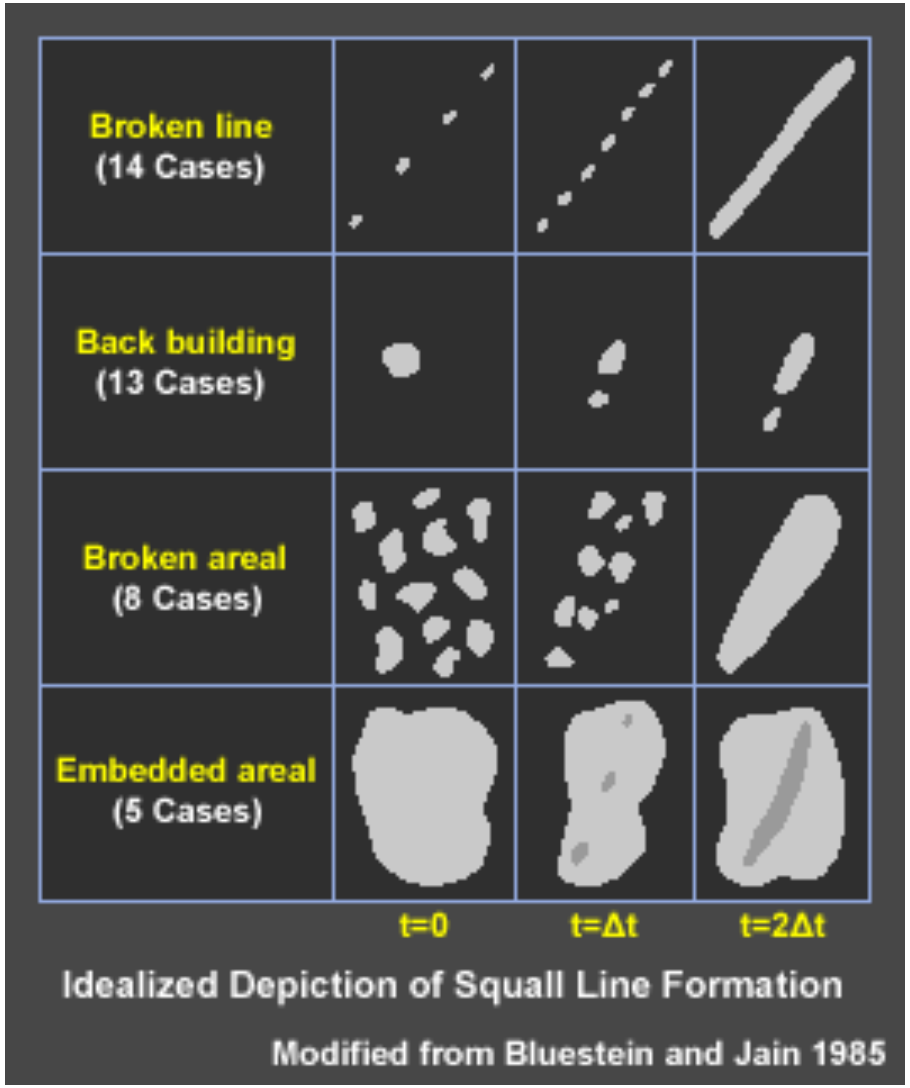
Strong along line deep-layer shear
10-20%

In east China

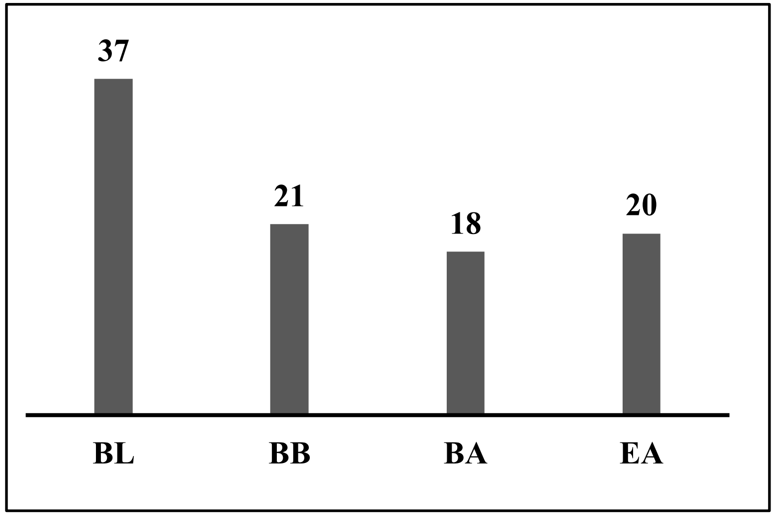


Meng et al. 2013

Squall line: formation

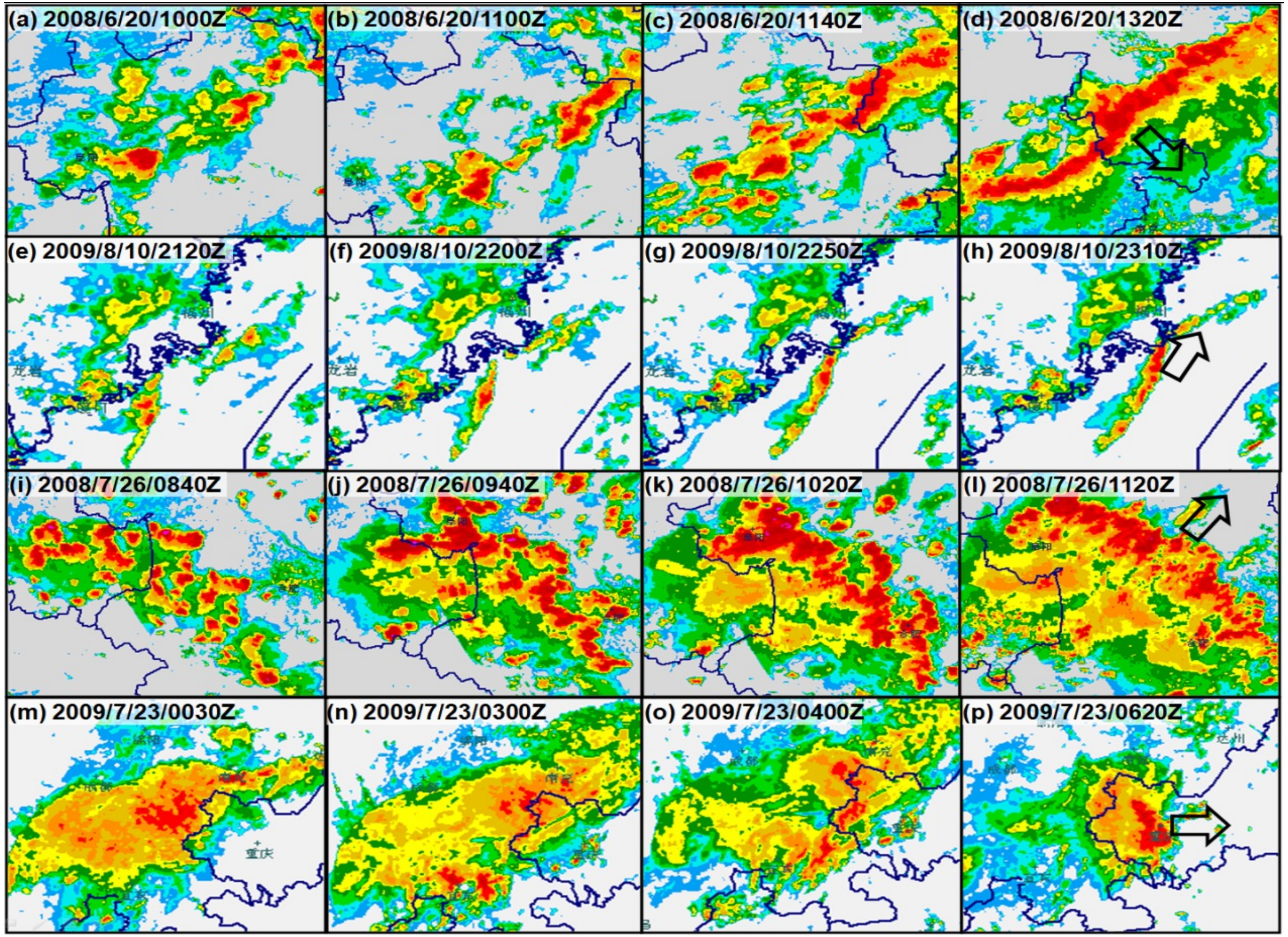


In east China



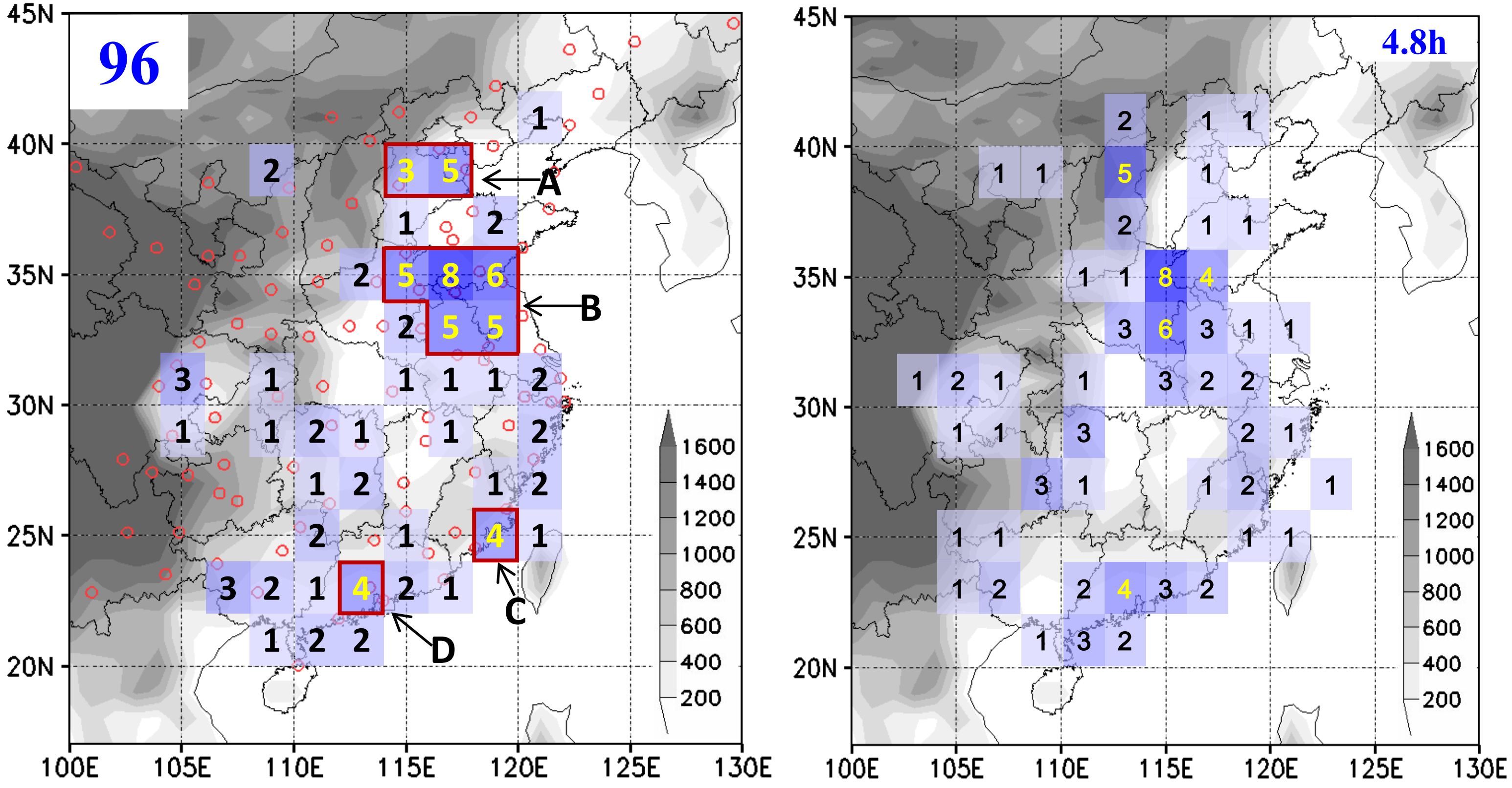
Meng et al. 2013

Examples from China



Squall line in East China

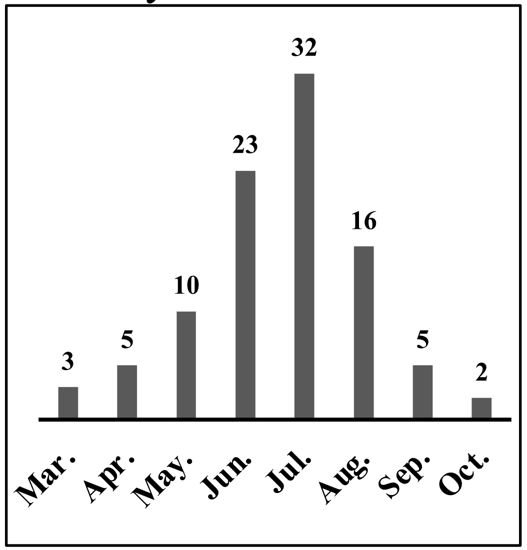
Formation frequency of squall line | Formation frequency of the first echo

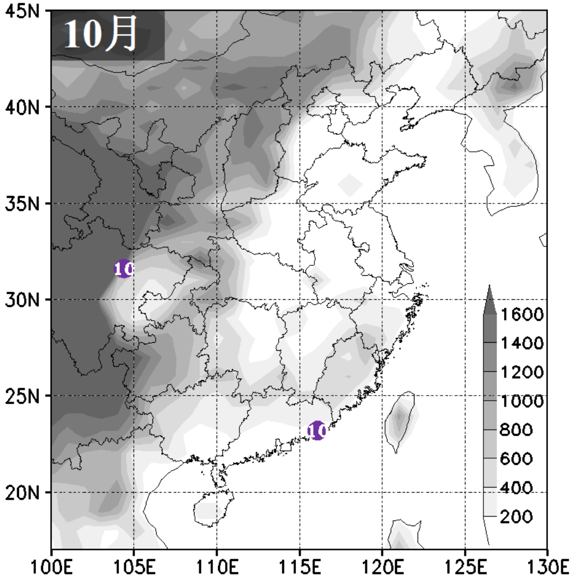


Meng et al. 2013

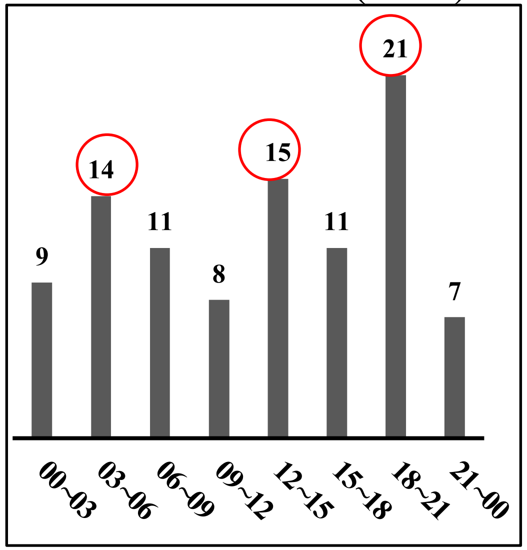
Temporal distribution

Monthly variation



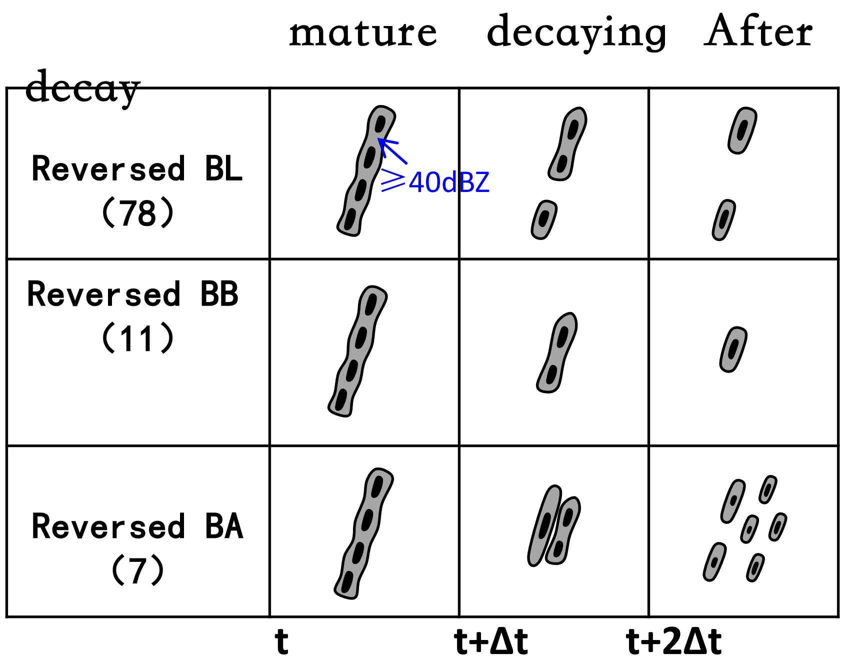


Diurnal Variation (LST)

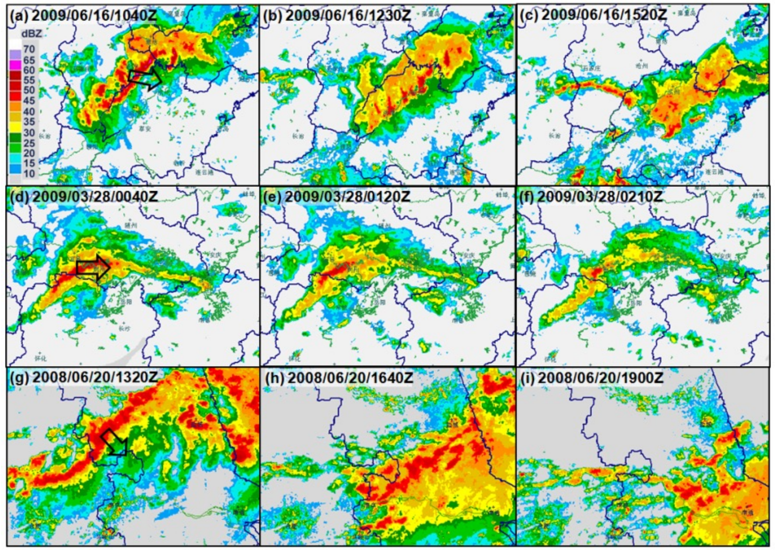


Meng et al. 2013

Dissipation mode

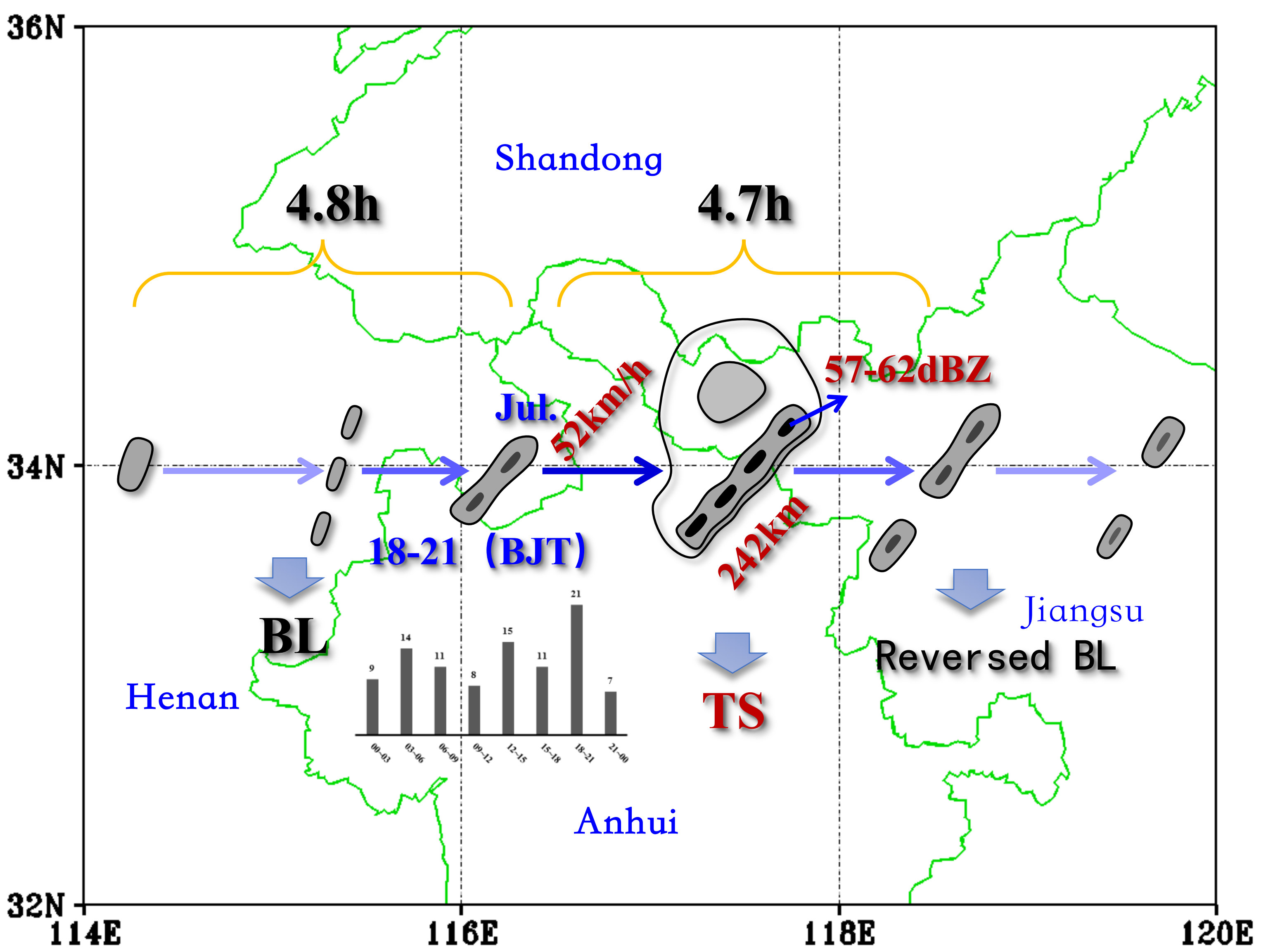


Typical examples



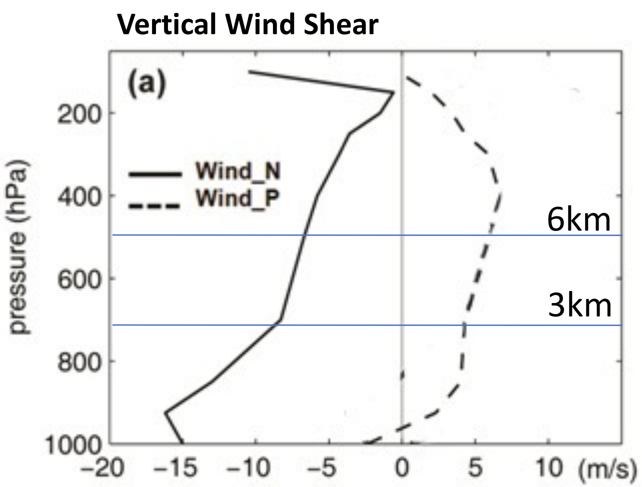
Meng et al. 2013

A Schematic model of squall lines in East China



Composite Radiosonde

Averages of derived properties	CAPE (J/kg^{-1})	CIN (J/kg^{-1})	LI (K)	LCL (hPa)	PW (cm)
Bluestein & Jain(1985)	2260	33			2.8
Wyss & Emanuel (1988)	1208	76			
Parker & Johnson (2000)	1605		-5.4	831	3.4
Squall lines in East China	**1480**	**77**	**-4.3**	**909**	**5.6**



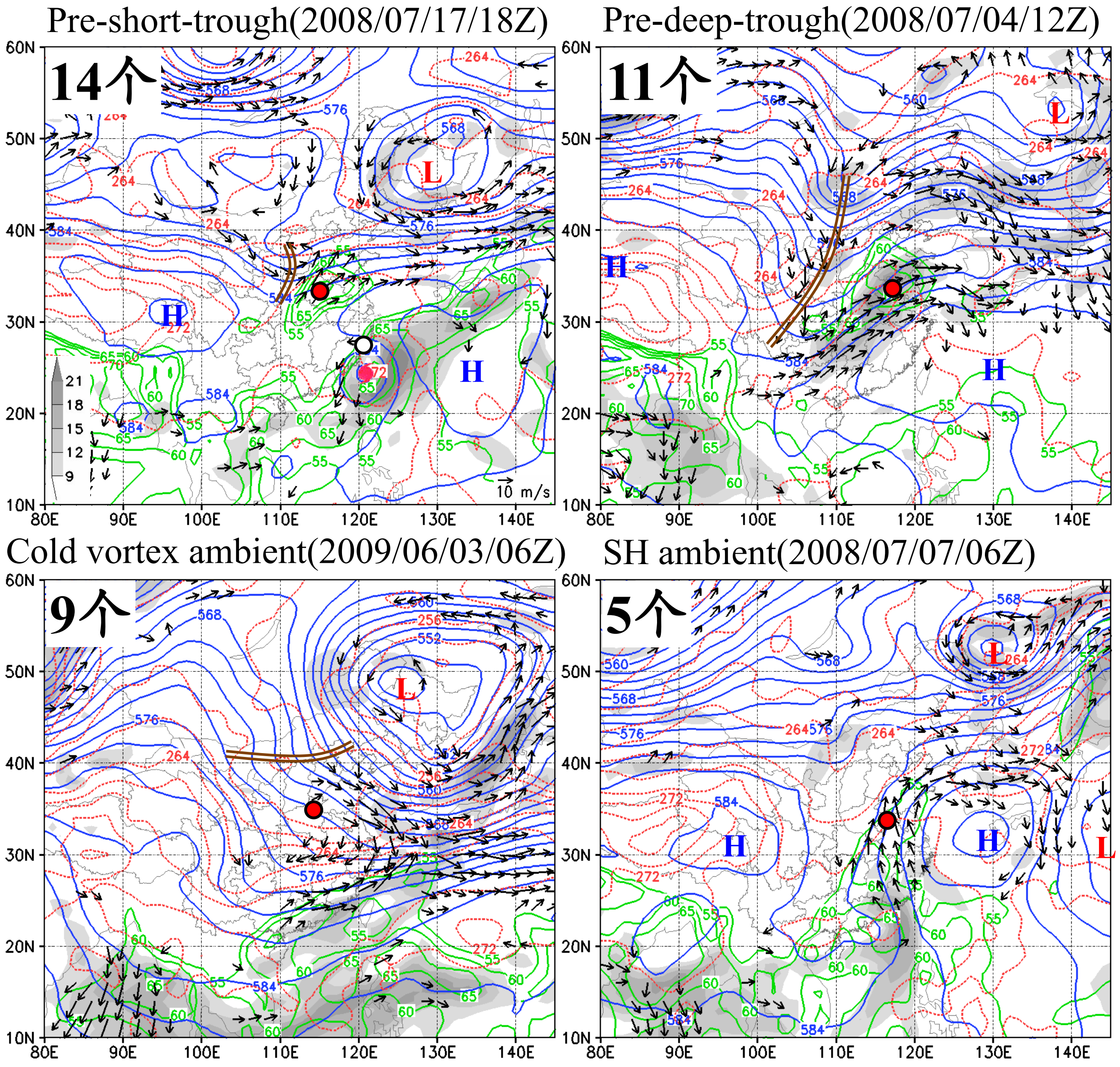
Squall lines in east China vs. U.S.

- moister environment
- similar background instability
- weaker low-level vertical wind shear

(Meng et al. MWR, 2013)

Class break 2023 11 13

Typical weather pattern (for the 45 cases in area A,B,C,D)



蓝线: 500hPa H

红线: 850hPa 温度

绿线: 可降水量

阴影: 850hPa 风速

箭头: 700-1000hPa 垂直风切变