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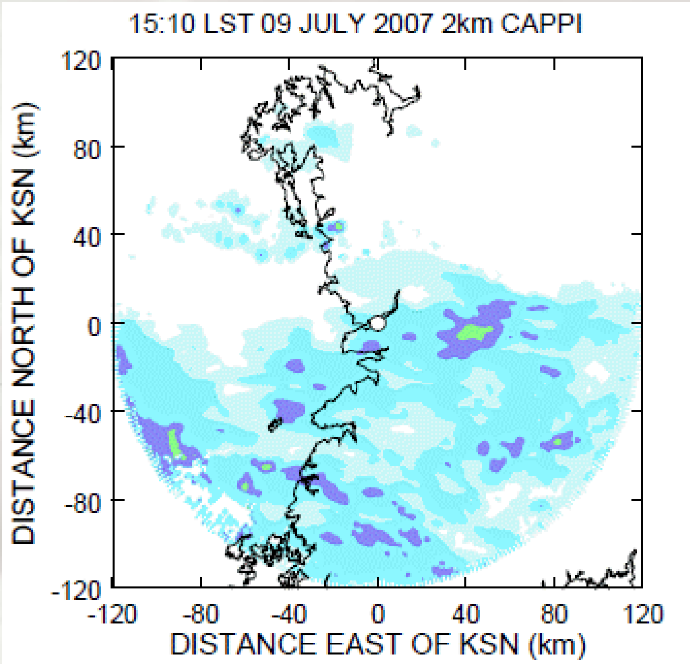

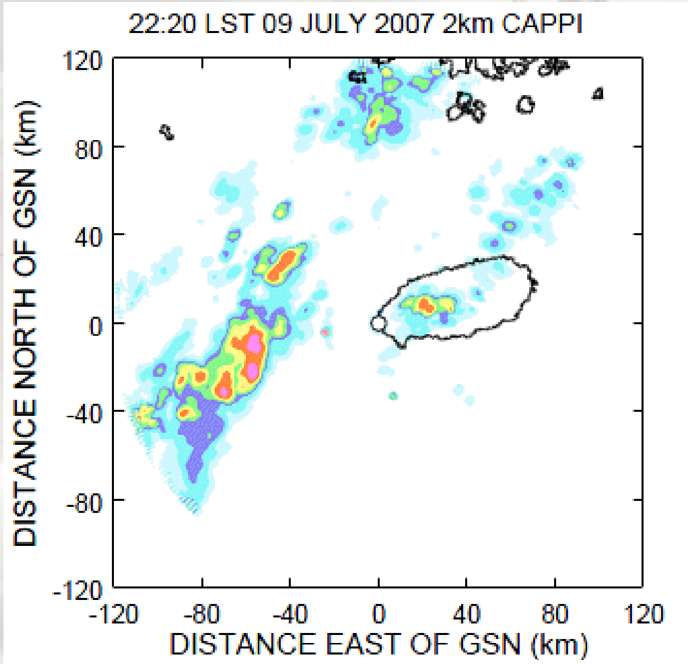

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Outline

- Introduction
- Data and Methodology
- A case study of mesoscale convective systems in Changma front
  - Sub-synoptic conditions
  - Dual Doppler radar analysis
  - Upper air sounding analysis
- Summary

Introduction

- **Mesoscale convective systems** (MCSs) are **significant rain-producing weather system** during summer season (Zipser 1982).
- **Mesoscale convective systems** in a moist environment around the East China Sea, which produces **heavy rainfalls** to Korean peninsula, Japan, Taiwan and China.

- **Previous studies,**
- There were many studies about heavy precipitation system in **Baiu/Meiyu season and region** (Ninomiya, 1978; Ninomiya and Akiyama, 1992; Chen et a.; 2003; Ding and Johnny, 2005).
- There were almost studies about favorable synoptic conditions for heavy rainfall in **Changma season** (Lee et al, 1998; Sun and Lee, 2002; Shin and Lee, 2005; Kim and Lee; 2006).
- **The study about MCSs over Korea is generally insufficient using observational data.**
- **Especially, the studies about MCSs with Changma front accompanied with surface low pressure**

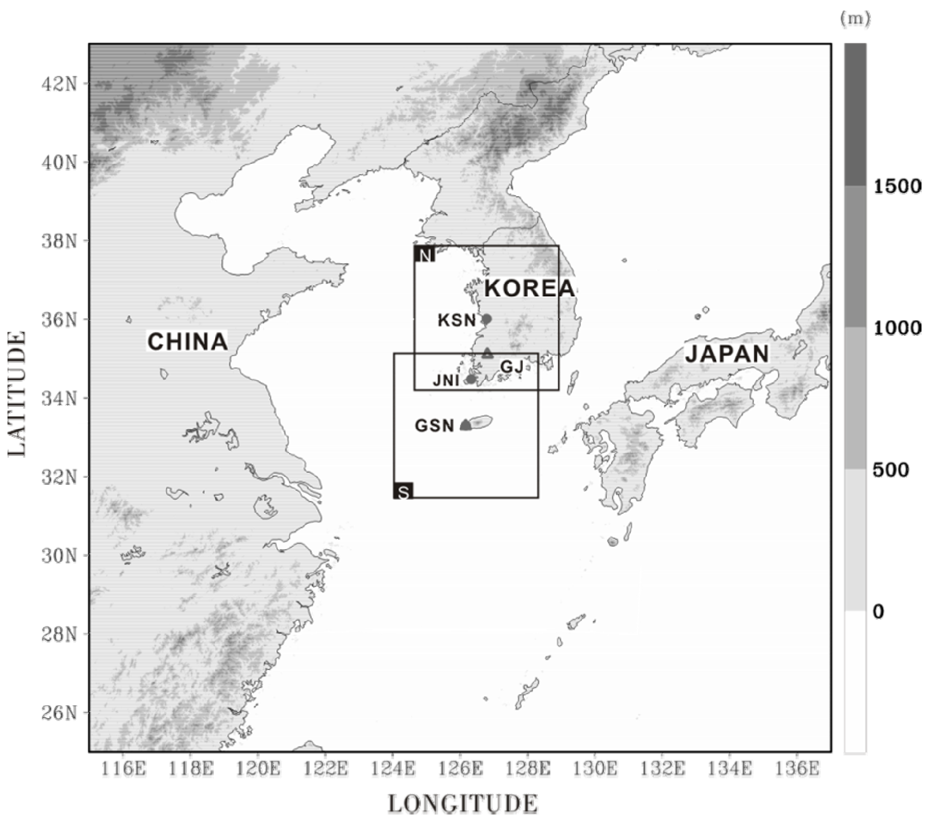
1. Purpose of this study,

- **To investigate the sub-synoptic environment, structure and evolution of Changma front with surface low pressure**

2. Purpose of this study,

- **To investigate the development mechanisms of two different types of MCSs accompanied with Changma front using dual Doppler radar analysis.**

Data and Methodology



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❖ **MTSAT – IR**

❖ **JMA MANAL (meso-scale analysis)**

❖ **Upper air sounding**

➢ Gwangju (GJ), Gosan (GSN)

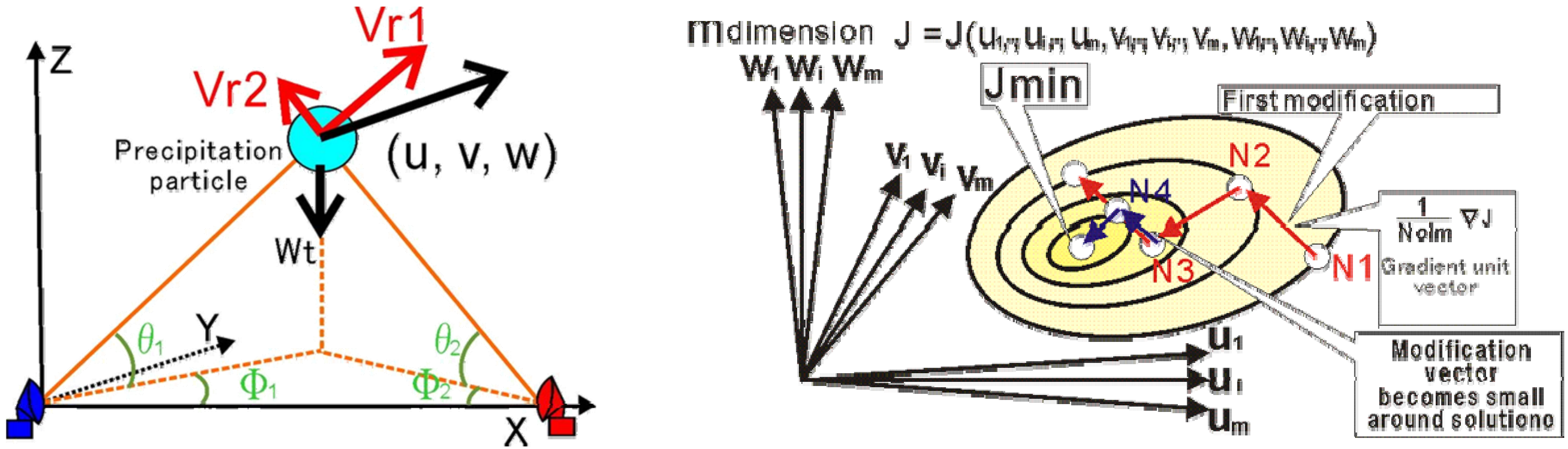
❖ **Doppler Radar**

➢ Gunsan (KSN), Gosan (GSN), Jindo (JNI)

Wdeoh#41Vshflilfdwlrqv#ri#udgduv

Radar site	KSN	GSN	JNI
Type (wavelength)	S-band(10cm)	S-band(10cm)	S-band(10cm)
Range (km)	240	250	240
Nyquist Velocity (ms^{-1})	33	63	31
Number of Elevation Angle	15 (0.4°~ 25°)	15 (0.5°~ 24°)	12 (0.2°~ 20°)
Scan interval (min.)	2.5	2.3	2
Location	36.01°N, 126.79°E	33.29°N, 126.16°E	34.47°N, 126.33°E

Variational analysis using dual Doppler radars (Gao et al., 1999)



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$$J = J_o + J_d + J_s + J_b \quad (1)$$

$$J_o = \frac{1}{2}\sum_{i,j,k,m} \lambda_o (Vr_m - u\cos A - v\cos B - (w+w_t)\cos C)^2 \quad (2)$$

$$J_d = \frac{1}{2}\sum_{i,j,k} \lambda_d D^2 \quad (3)$$

$$J_s = \frac{1}{2}\Big[\sum_{i,j,k} \lambda_s (\nabla^2 u)^2 + \sum_{i,j,k} \lambda_s (\nabla^2 v)^2 + \sum_{i,j,k} \lambda_s (\nabla^2 w)^2\Big] \quad (4)$$

$$J_b = \frac{1}{2}\Big[\sum_{i,j,k} \lambda_{ub} (u-u_b)^2 + \sum_{i,j,k} \lambda_{vb} (v-v_b)^2 + \sum_{i,j,k} \lambda_{wb} (w-w_b)^2\Big] \quad (5)$$

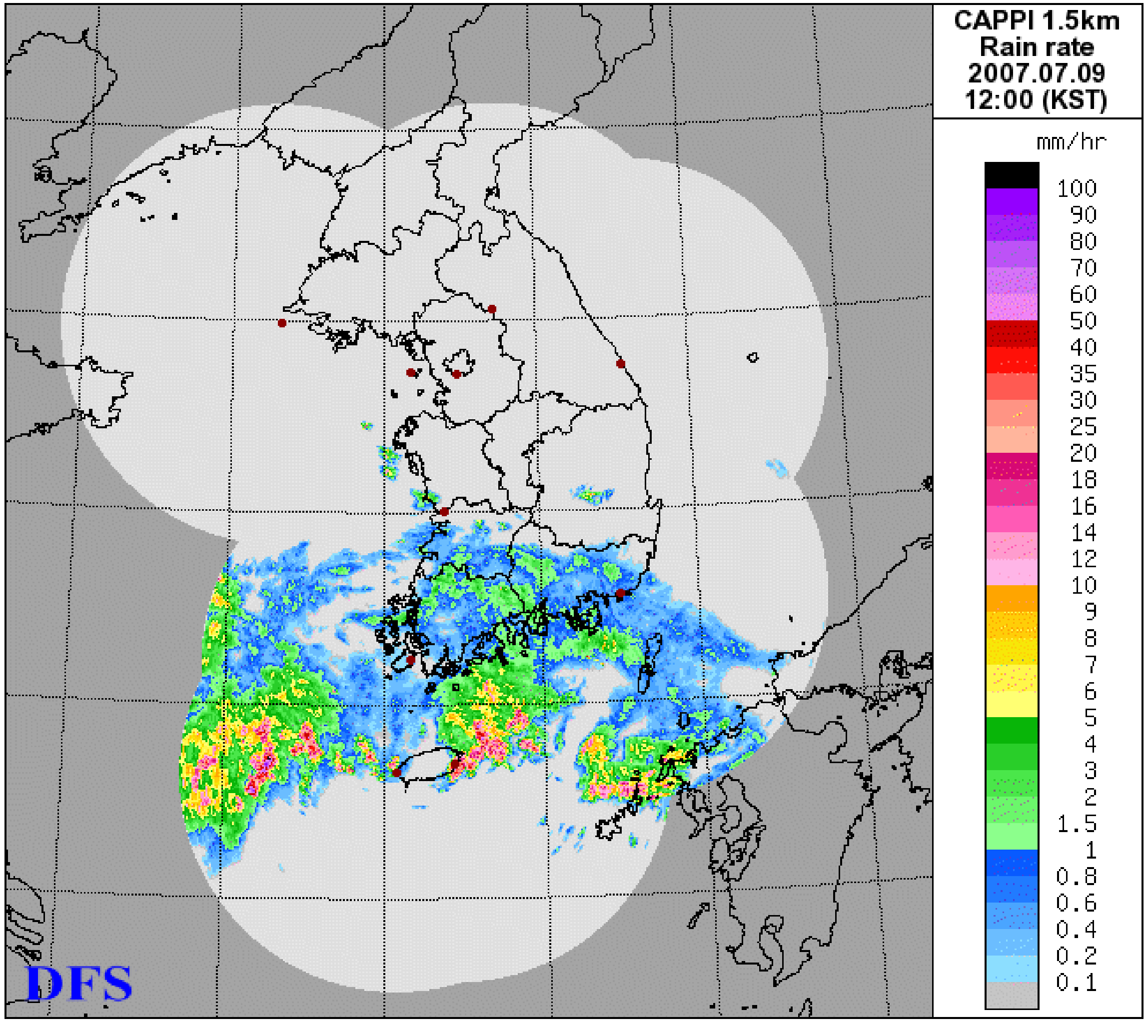
$$D = \frac{\partial \bar{\rho} u}{\partial x} + \frac{\partial \bar{\rho} v}{\partial y} + \frac{\partial \bar{\rho} w}{\partial z} \quad (6)$$

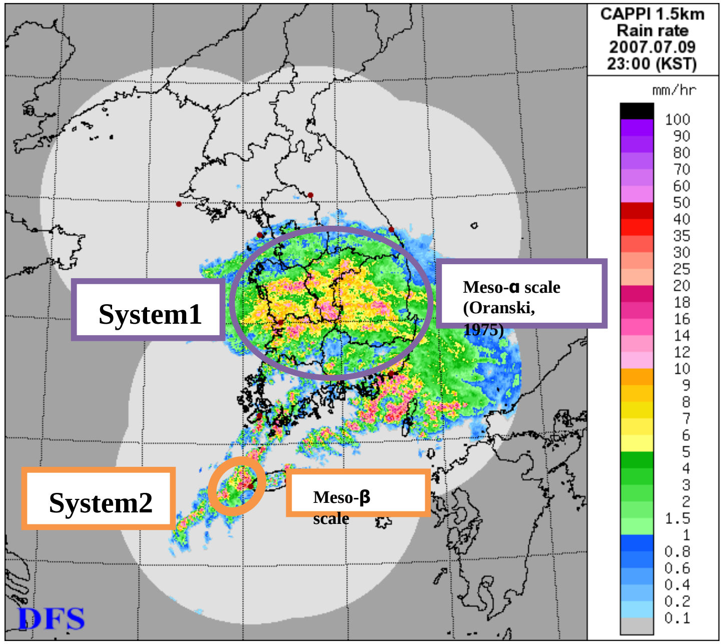
$$\frac{\partial J}{\partial u} = \lambda_o(-\cos A)*(Vr_m - u\cos A - v\cos B - (w+w_t)\cos C) + \lambda_b*(u-u_b) - \lambda_d \bar{\rho}\frac{\partial D}{\partial x} + \lambda_{su}\nabla^2(\nabla^2 u) \quad (7)$$

$$\frac{\partial J}{\partial v} = \lambda_o(-\cos B)*(Vr_m - u\cos A - v\cos B - (w+w_t)\cos C) + \lambda_b*(v-v_b) - \lambda_d \bar{\rho}\frac{\partial D}{\partial y} + \lambda_{sv}\nabla^2(\nabla^2 v) \quad (8)$$

$$\frac{\partial J}{\partial w} = \lambda_o(-\cos C)*(Vr_m - u\cos A - v\cos B - (w+w_t)\cos C) + \lambda_b*(w-w_b) - \lambda_d \bar{\rho}\frac{\partial D}{\partial z} + \lambda_{sw}\nabla^2(\nabla^2 w) \quad (9)$$

The different types of MCSs





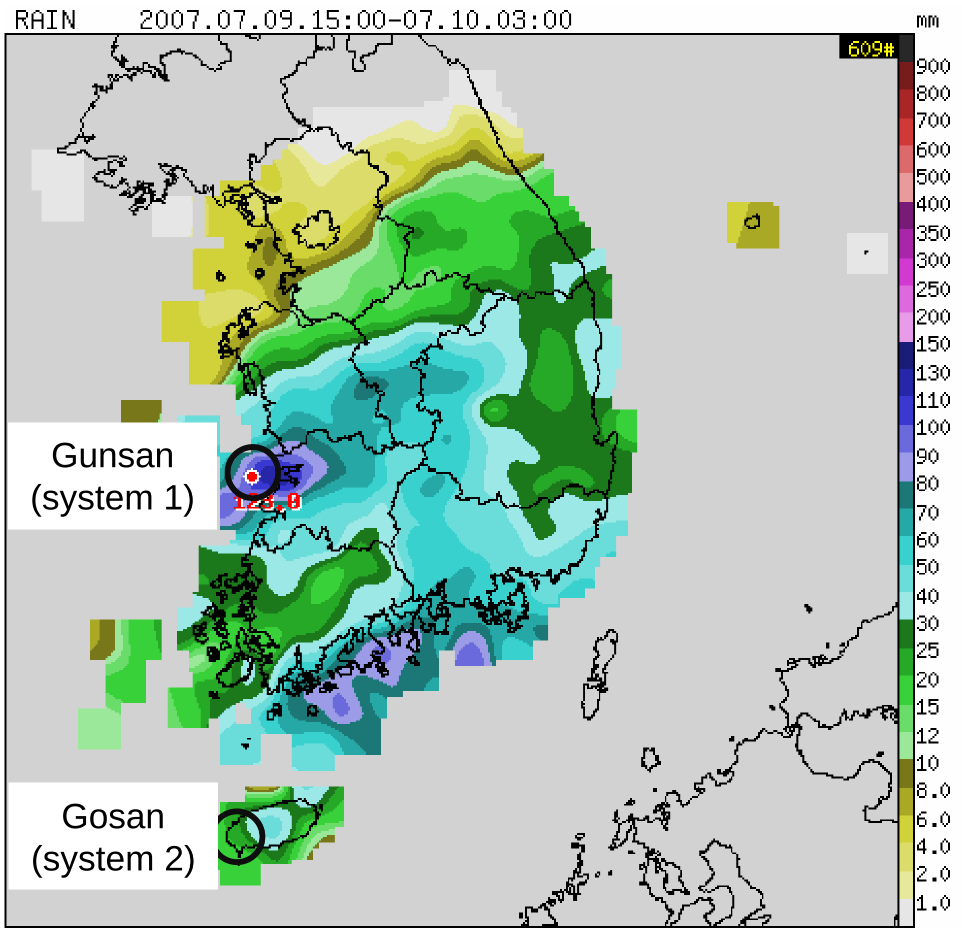
The two different types of MCSs passed and occurred accompanied with **Changma front** over **middle and south part** of Korean peninsula.

Rainfall amount and rainrate

❖ Rainfall amount and maximum rain intensity

➢ System1: 15 ~ 24 LST 09 July 2007

➢ System2: 22 LST 09 ~ 4 LST 10 July 2007



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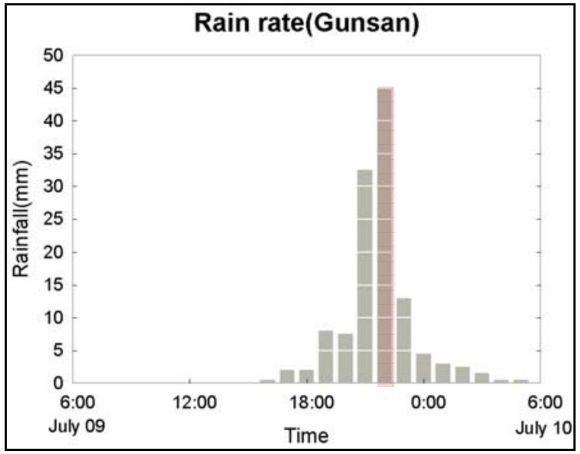
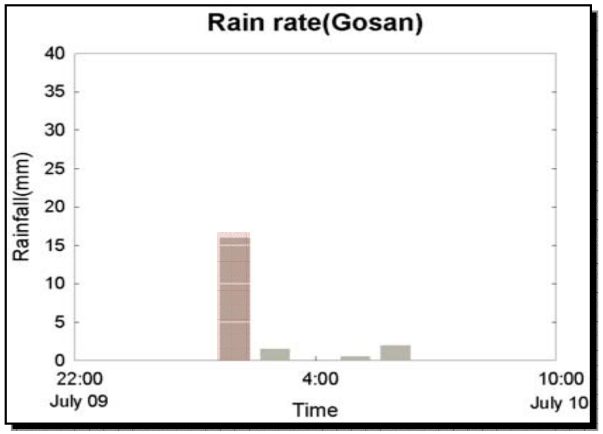
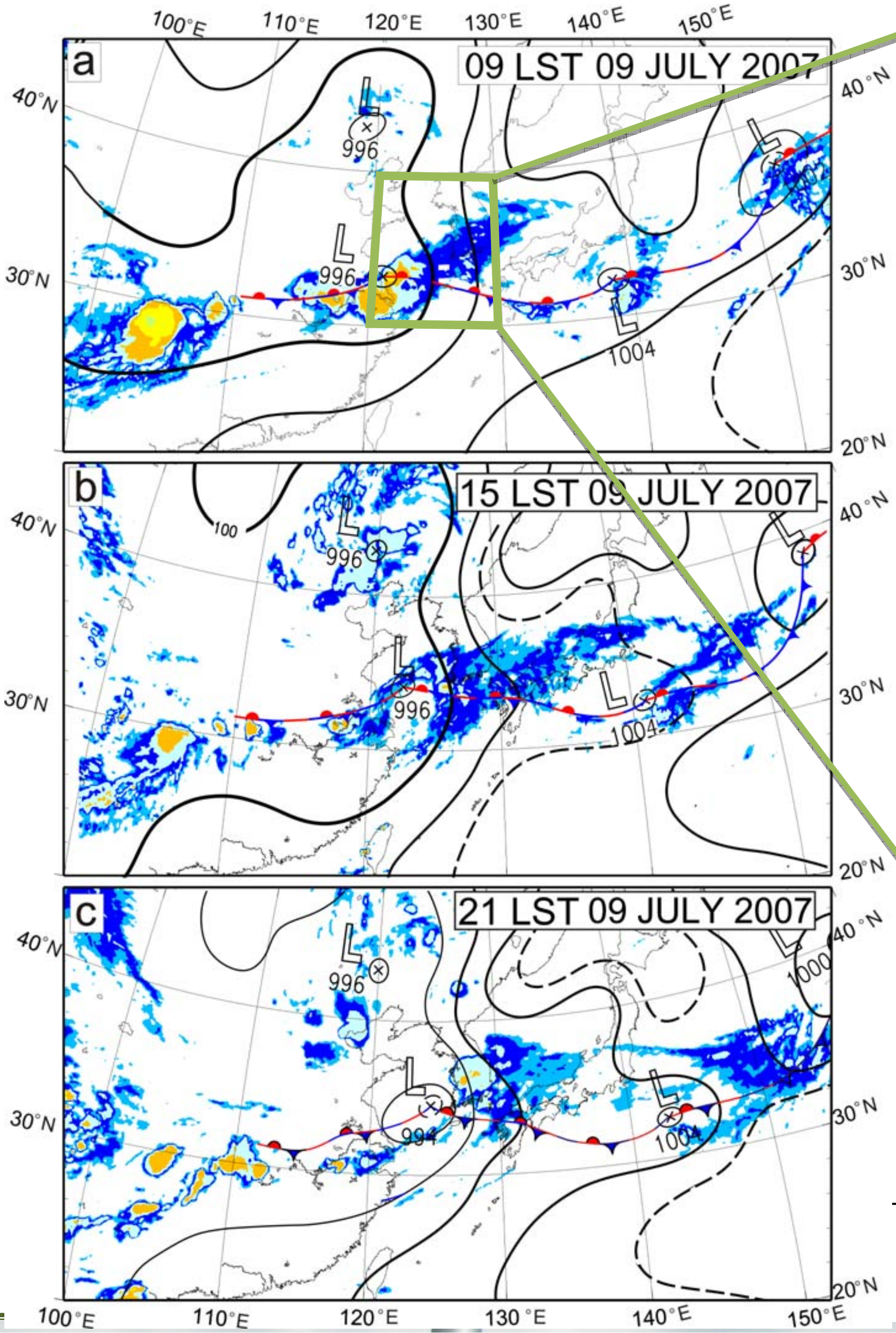


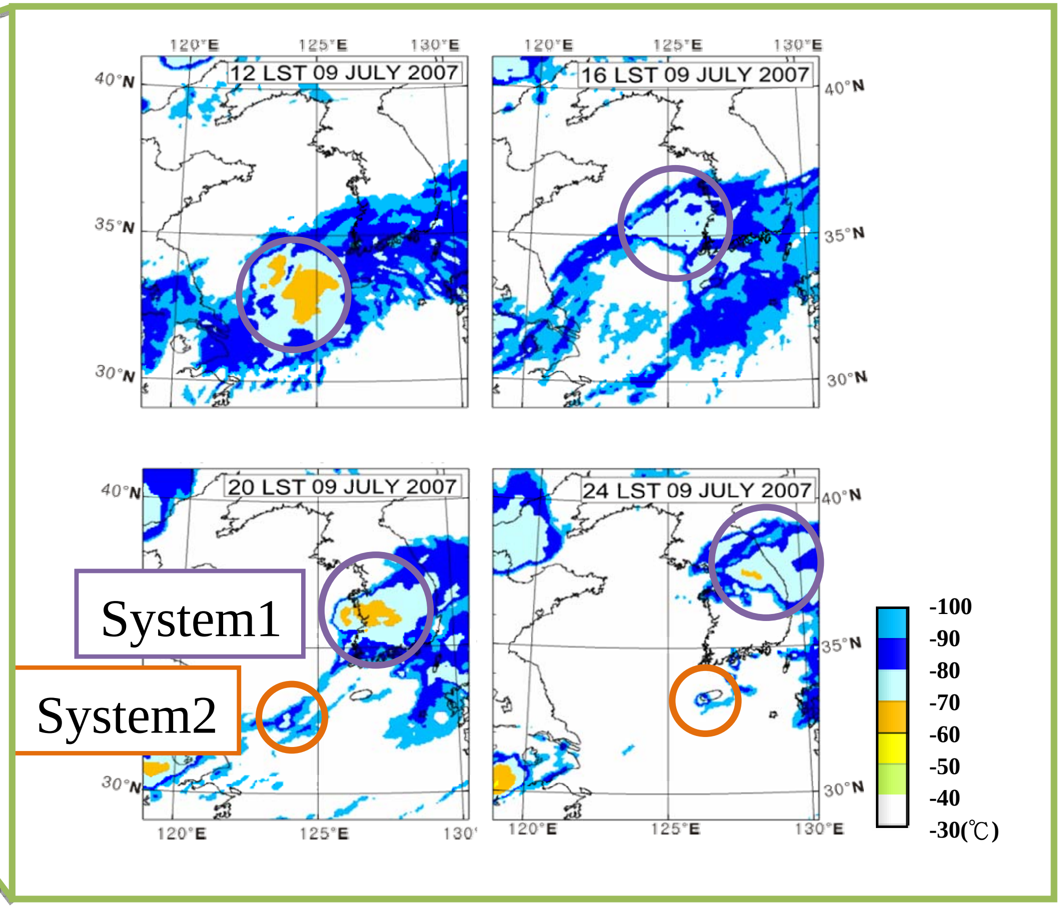
✓ Gunsan
Rainfall amount : **123 mm/12h**
Max. rain intensity : **45 mm/h**



✓ Gosan
Rainfall amount : **20 mm/12h**
Max. rain intensity : **16 mm/h**

MTSAT-IR satellite image

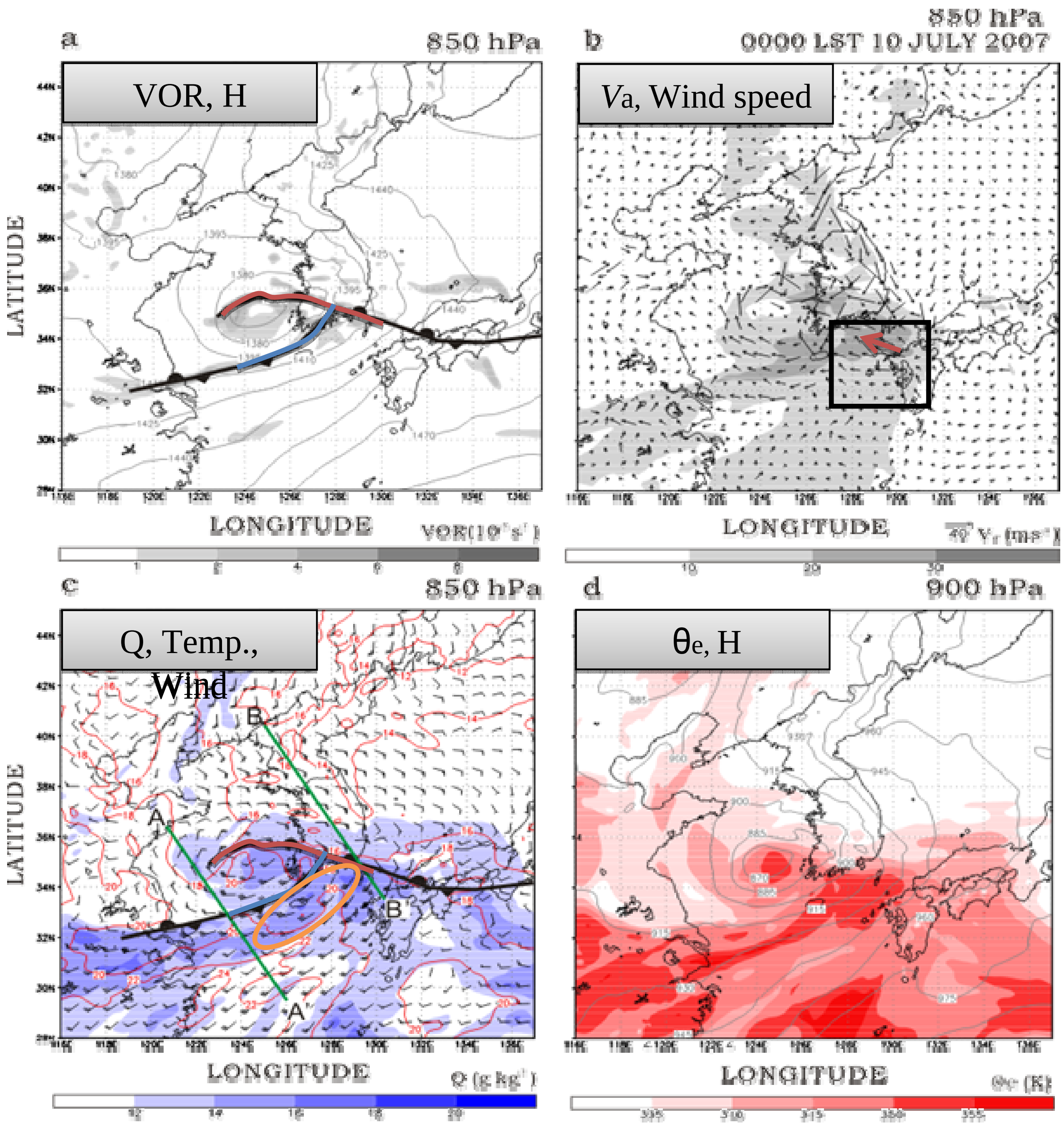




- ❖ Developed MCSs moved forward along the Changma front that moved quasi-stationary to northeastward.

I lj1#7 1#Vhulhv#ri#vxuidfh#z hdwkhu#p ds#dqg#glvwulexwlrq#ri#
forxg#wrs#whp shudwxuh1#

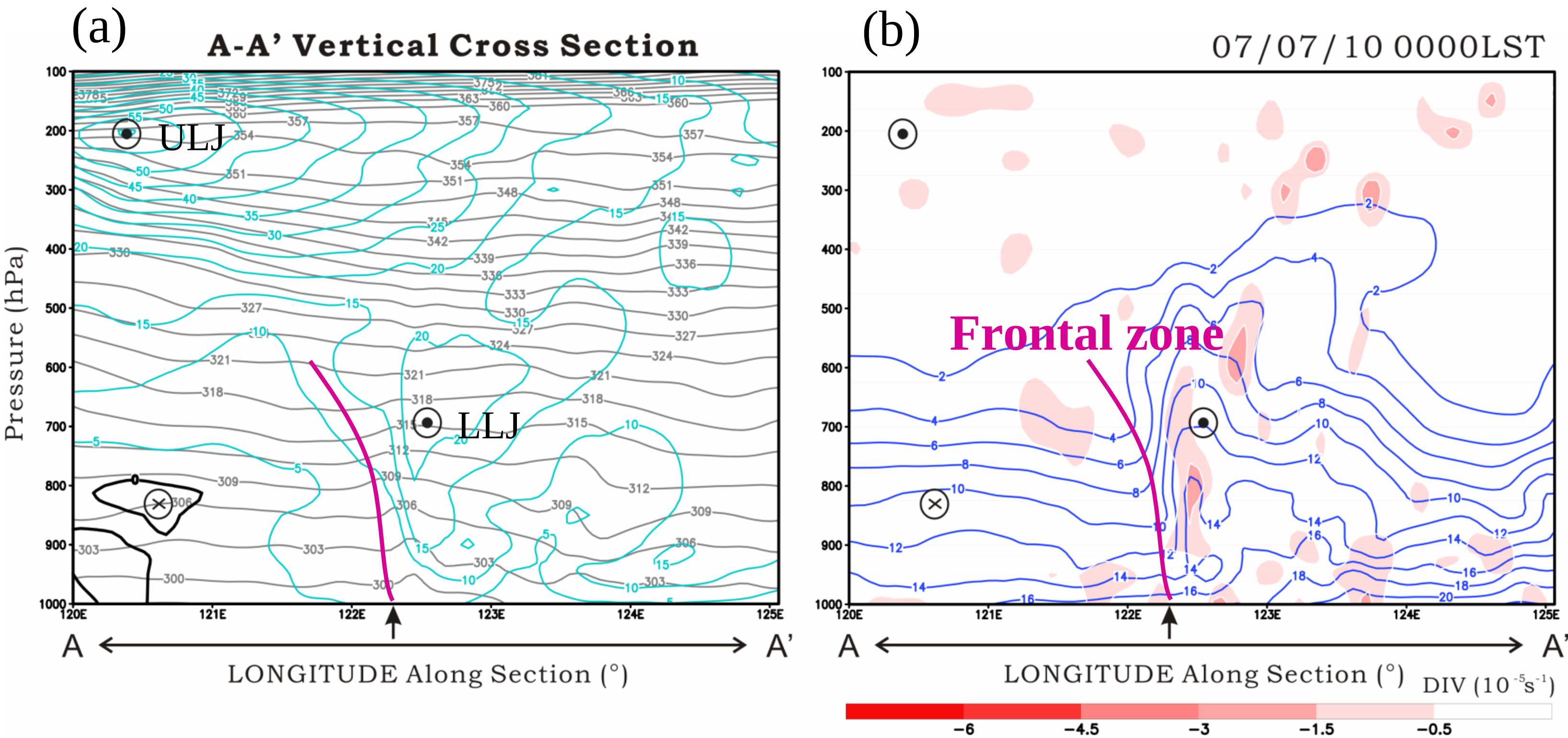
Sub-synoptic environment



- **The horizontal gradient of geopotential height** and **relative vorticity** were **intense** near surface low pressure.
- The enhanced **low pressure** induced **southeasterly ageostrophic wind** and **intensified southwesterly LLJ** at the ahead of cold front.
- **Low level jet (LLJ)** transported warm and moist air.
- **High equivalent potential temperature** (θ_e) toward System2

I lj1#81#Wkh#vlp xodwhg#ilhog#d,#krul}rqwdo#yruwlflw|# +vkdghg#,#dqg#jhrsrwhqwldo#khljkw#+frqwrxuhg/#e,# krul}rqwdo#z lqg#vshhg#+vkdghg,/#djhrwurslf# z lqgv#+durz ,/#+f,#vshflilf#kxp lglw|#+vkdghg,/# krul}rqwdo#z lqgv#+eduev,#dqg#whp shudwxuh#+°C ,#dw# ;83#kSd#dqg#+g,#htxlydohqw#srwhqwldo#whp shudwxuh# +vkdghg,/#jhrsrwhqwldo#khljkw#+jsp ,#dw#<33#kSd#iru# 3333#OVW#43#Mxo|#533:1#Iru#z lqgv/#ixoo#kdoi,#eduev# duh#8#+518,#p v⁻¹1#Wkh#olqh#D D Údqg#E E Úxvhg#wr# frqwuxfw#I lj1#9/:1

Vertical cross section (A-A’)



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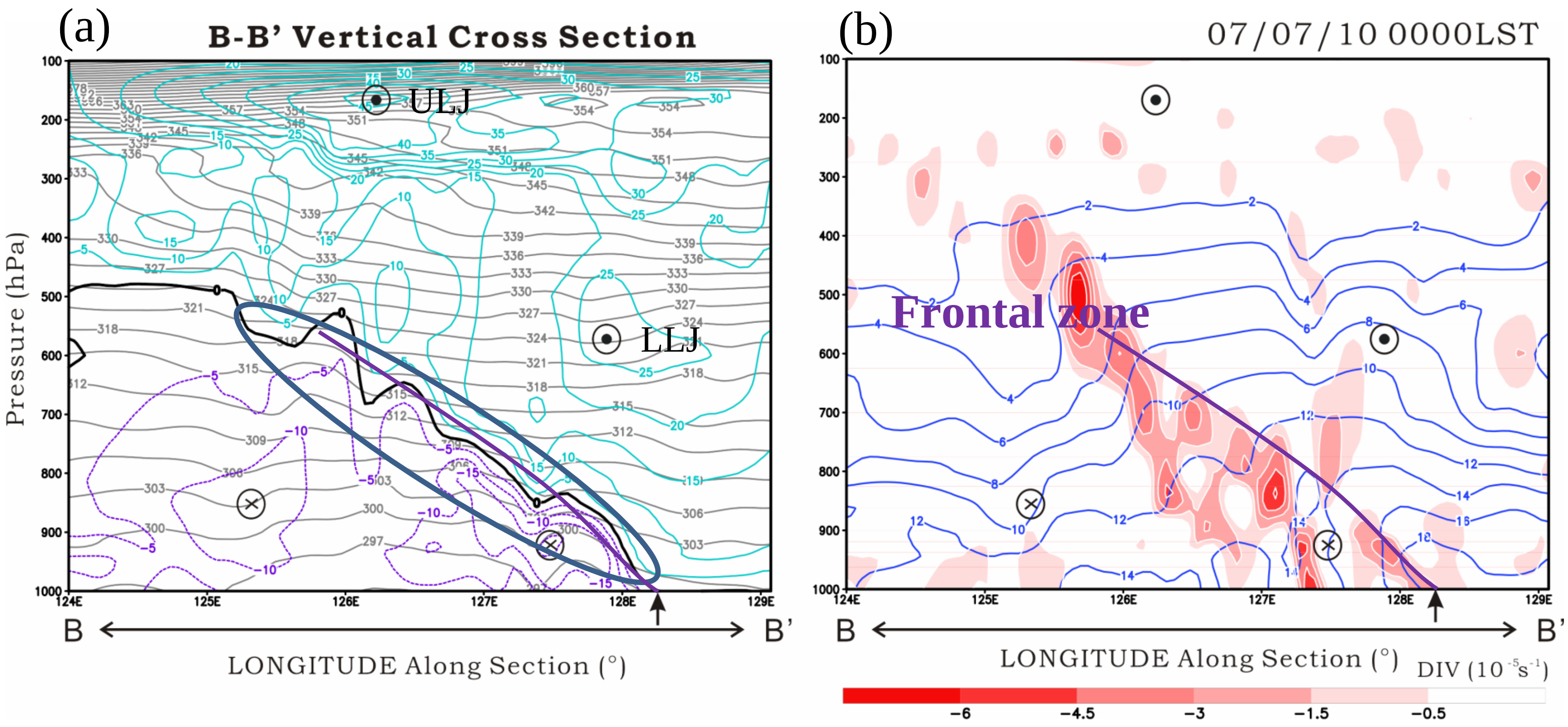
frp srqhqw#qrup do#wr#wkh#vhfwlrq#sodqh/#dqg#e,#glyhujhqfh#vkdghg,/#vshflilf#kxp lglw|#t/#j2nj,#ehwz hhq#4333#kSd#dqg#433#kSd1

- ❖ **Vertical cross section across to surface cold front**
- ❖ **Strong west-southwesterly wind ahead of cold front associated with LLJ**, ULJ around 200 hPa
- ❖ A convergence zone appeared and straightened with height below 600 hPa, corresponding to sloping frontal zone .
- ❖ **Moisture advected largely and deeply on sloping frontal zone.**

Vertical cross section (B-B')



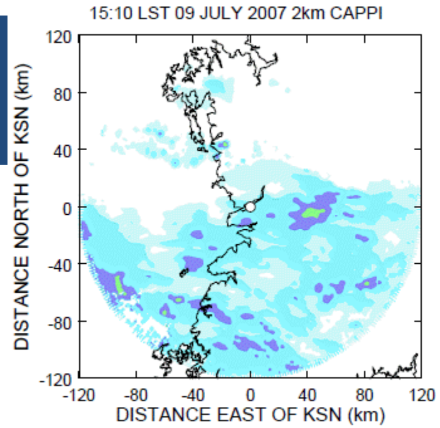
Ilj1#:1#Vdp h#dv#Ilj1#:/#h{fhsw#iru#dorqj#olqh#EŒÚlq#Ilj1#9#

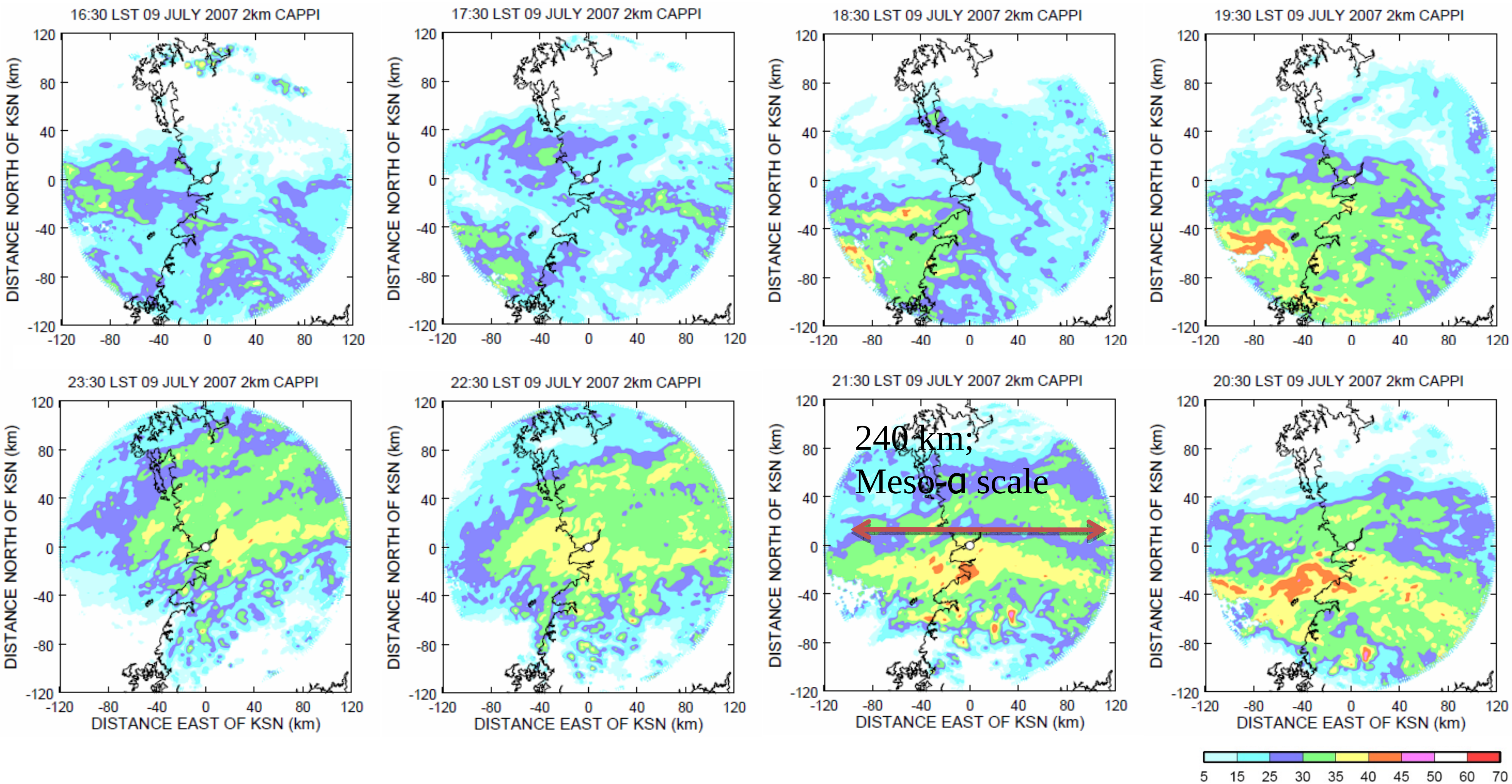
- ❖ **Vertical cross section across to surface warm front**
- ❖ **The strong cross prefrontal horizontal wind shear below 500 hPa.**
- ❖ A convergence zone appeared and sloped with height below 350 hPa, corresponding to sloping frontal zone.
- ❖ **Less steeped sloping frontal zone and advected moist air compare with cold front.**

Radar analysis (System 1)

❖ System1

- ➢The convective systems (meso-ɑ scale) were scattered within an area of stratiform clouds to the north of the warm front.
- ➢ Convective cells developed as a line shape





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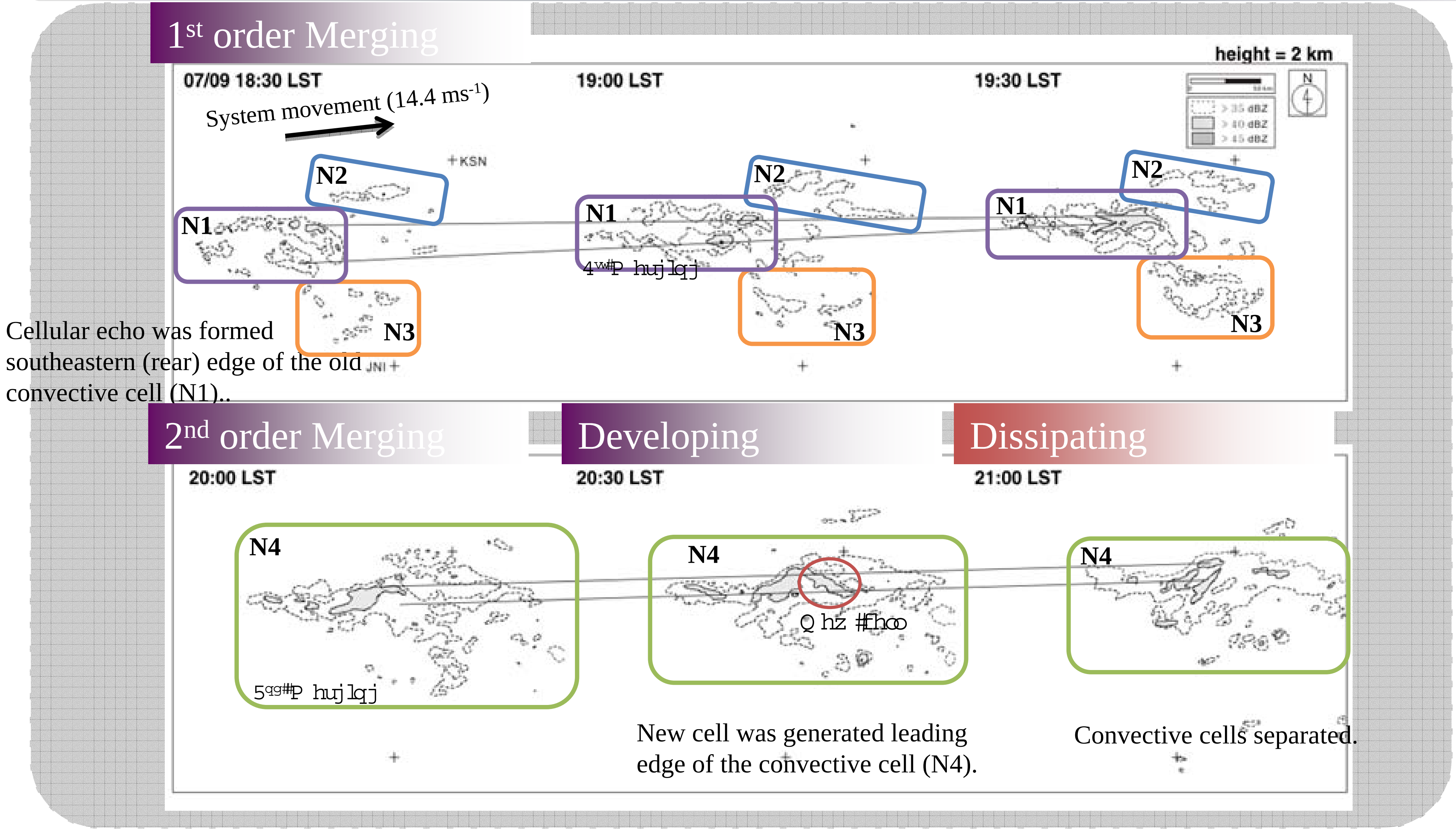
Series of horizontal reflectivity (System 1)

2nd order Merging → Developing → Dissipating



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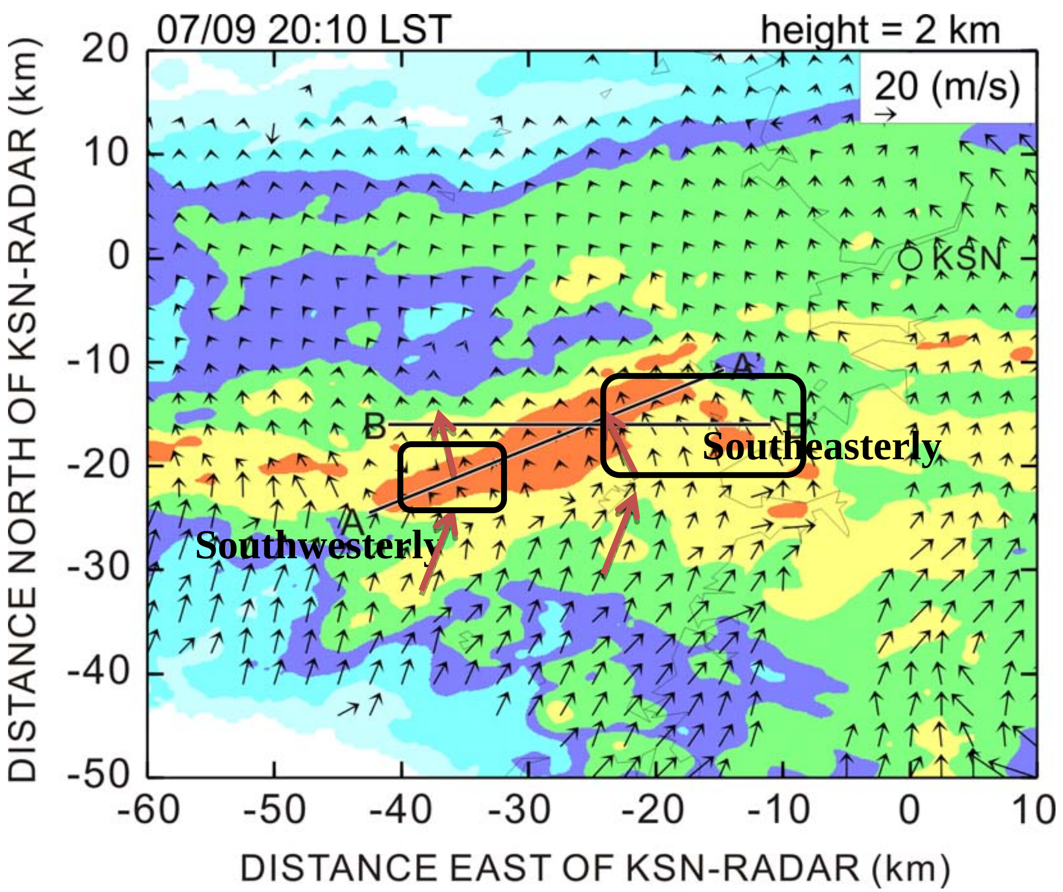
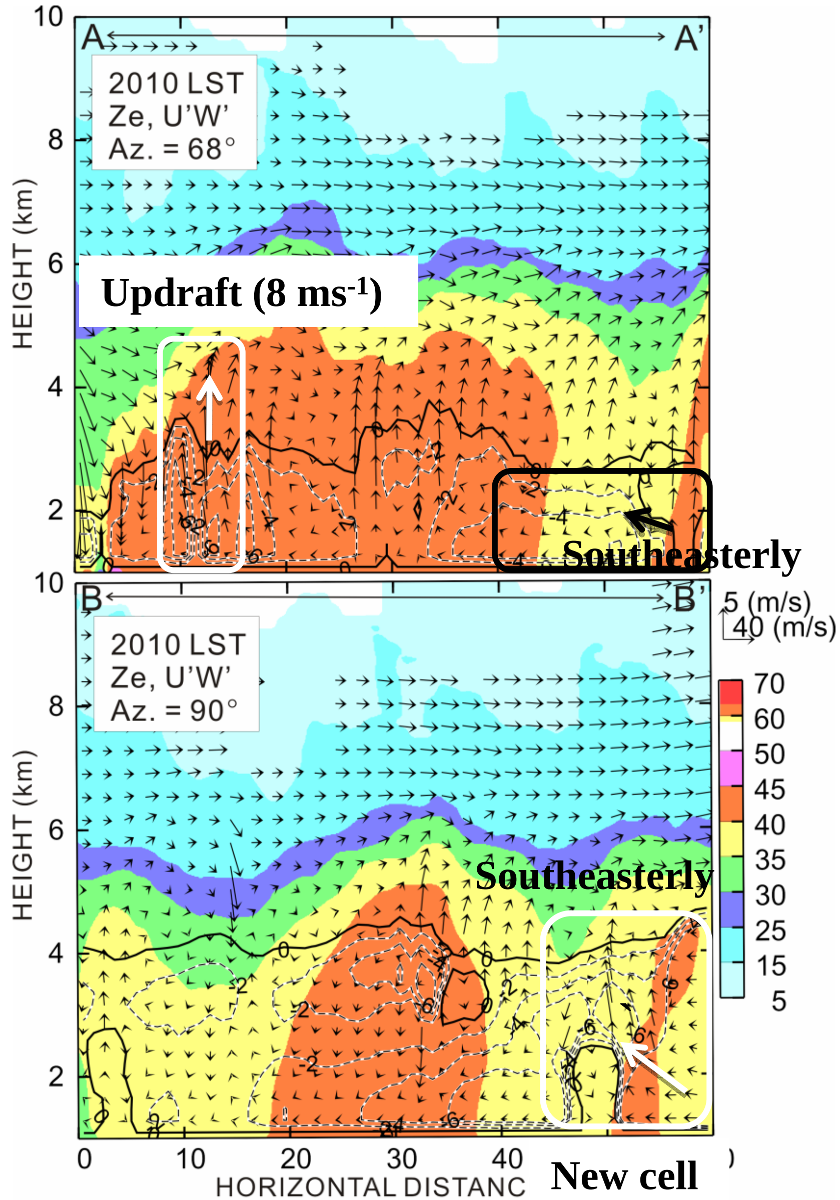
Dual Doppler analysis (System 1) – Developing stage





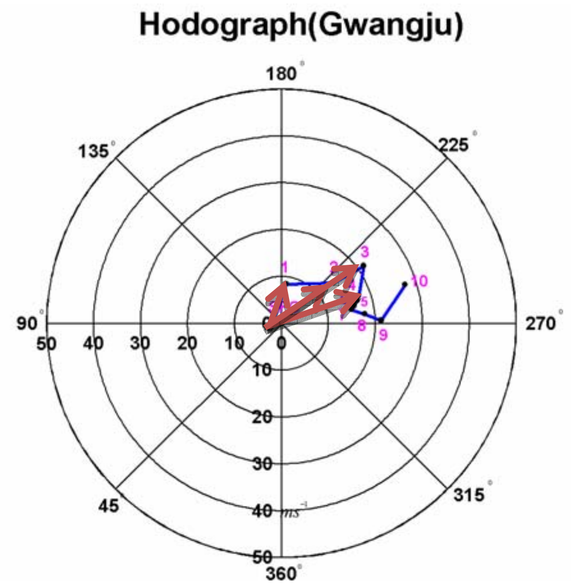
- ❖ System 1
- ➢ Strong convective region (≥40 dBZ) up to 5 km
- ➢ **Convective cells were affected by wind shear.**
- ✓Strong southeasterly winds was shown near the strong convective cells and they are merged with southwesterly winds near convective cell band.

I lj1#431#K rul}rqwdo#glvwulexwlrqv#ri#uhiohfwlylw|#dqg#v|vwhp #uhodwlyh#z lqg#yhfwru#dw#5#np # D VO#dw#5343#OVW#rq#3<#Mxo|#533:1#Wkh#erog#olqh#lqglfdwh#yhuwlfdo#furvv#vhfwlrqv# lq#I lj1#461

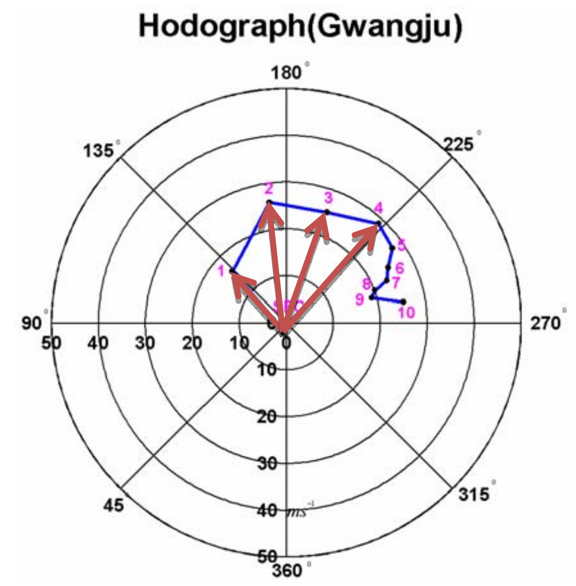
I lj1#441#Uhiohfwlylw|#dqg#z lqg#iorz #sdwwhuq#lq#wkh#yhuwlfdo#furvv#vhfwlrq +D 0D Ú,dqg#E 0E Ú,#dw#5343#OVW#rq#3<#Mxo|#533:1#Erog#olqh#lqglfdwhv# lqwhuidfhv#ri#srvlwlyh#dqg#qhjdwlyh#yhorflwlhv#ri#krul}rqwdo#z lqgv# dorqj#wkh#vhfwlrq#sodqh1#Eurnhq#olqhv#lqglfdwh#wkh#qhjdwlyh#z lqgv# dorqj#wkh#vhfwlrq#sodqh1

Upper air sounding analysis (System 1)

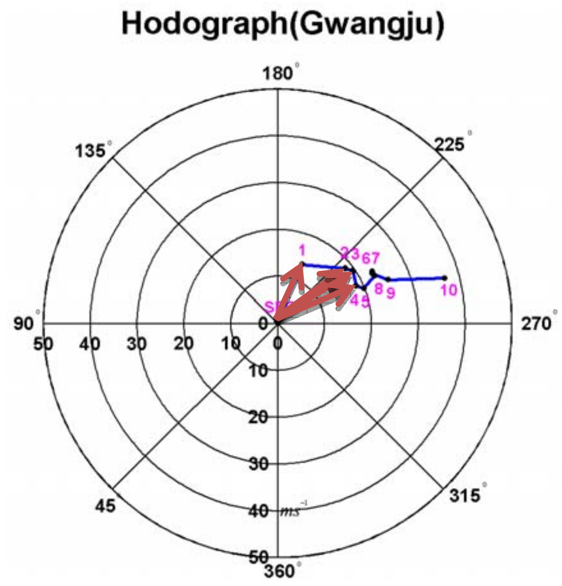
15 LST 09 Jul.



21 LST 09 Jul.

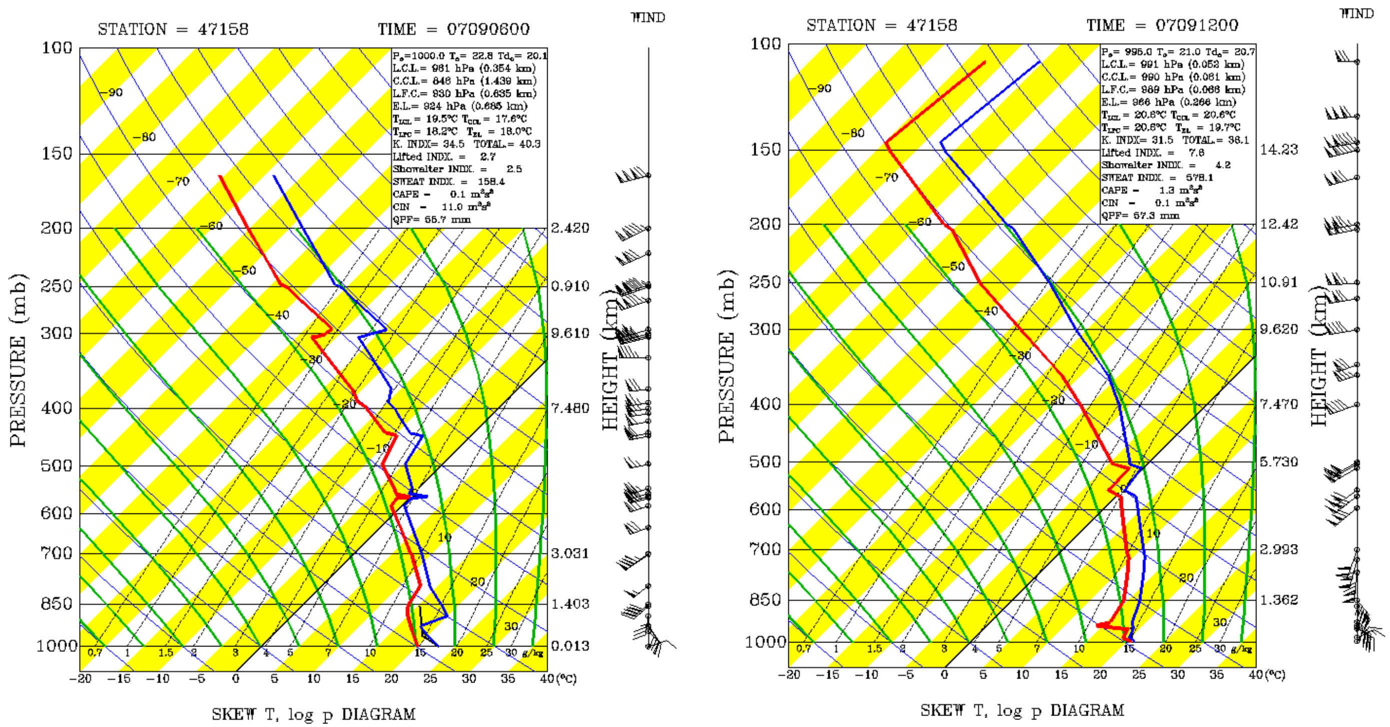


03 LST 10 Jul.



	15 LST 09 Jul.			21 LST 09 Jul.			03 LST 10 Jul.		
Height (km)	Bulk Shear ($10^{-3}s^{-1}$)	Directional Shear (10^{-3} degree/m)	Speed Shear ($10^{-3}s^{-1}$)	Bulk Shear ($10^{-3}s^{-1}$)	Directional Shear (10^{-3} degree/m)	Speed Shear ($10^{-3}s^{-1}$)	Bulk Shear ($10^{-3}s^{-1}$)	Directional Shear (10^{-3} degree/m)	Speed Shear ($10^{-3}s^{-1}$)
Surface ~ 3	**4.15**	**23.026**	2.294	**6.041**	**11.796**	3.592	**2.926**	**9.629**	1.698
3 ~ 6	**0.785**	**3.811**	0.973	**2.542**	**6.382**	1.282	**1.024**	**2.86**	1.075
6 ~ 12	1.739	3.440	1.529	1.379	2.012	1.504	2.001	2.01	2.201

Upper air sounding analysis (System 1)



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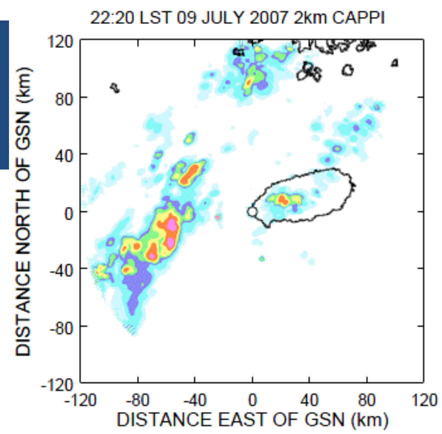
iurp#48#wr#54#OVW#3<#rq#Mxo|#533:#

Table 2. Environmental parameters by upper-air sounding

Parameters	15 LST 09 JULY 07.	21 LST 09 JULY 07.
CAPE (JKg^{-1})	0.1	1.3
CIN (JKg^{-1})	11.0	0.1
BRN	-	-
LCL Height (hPa)	940.94	952.37

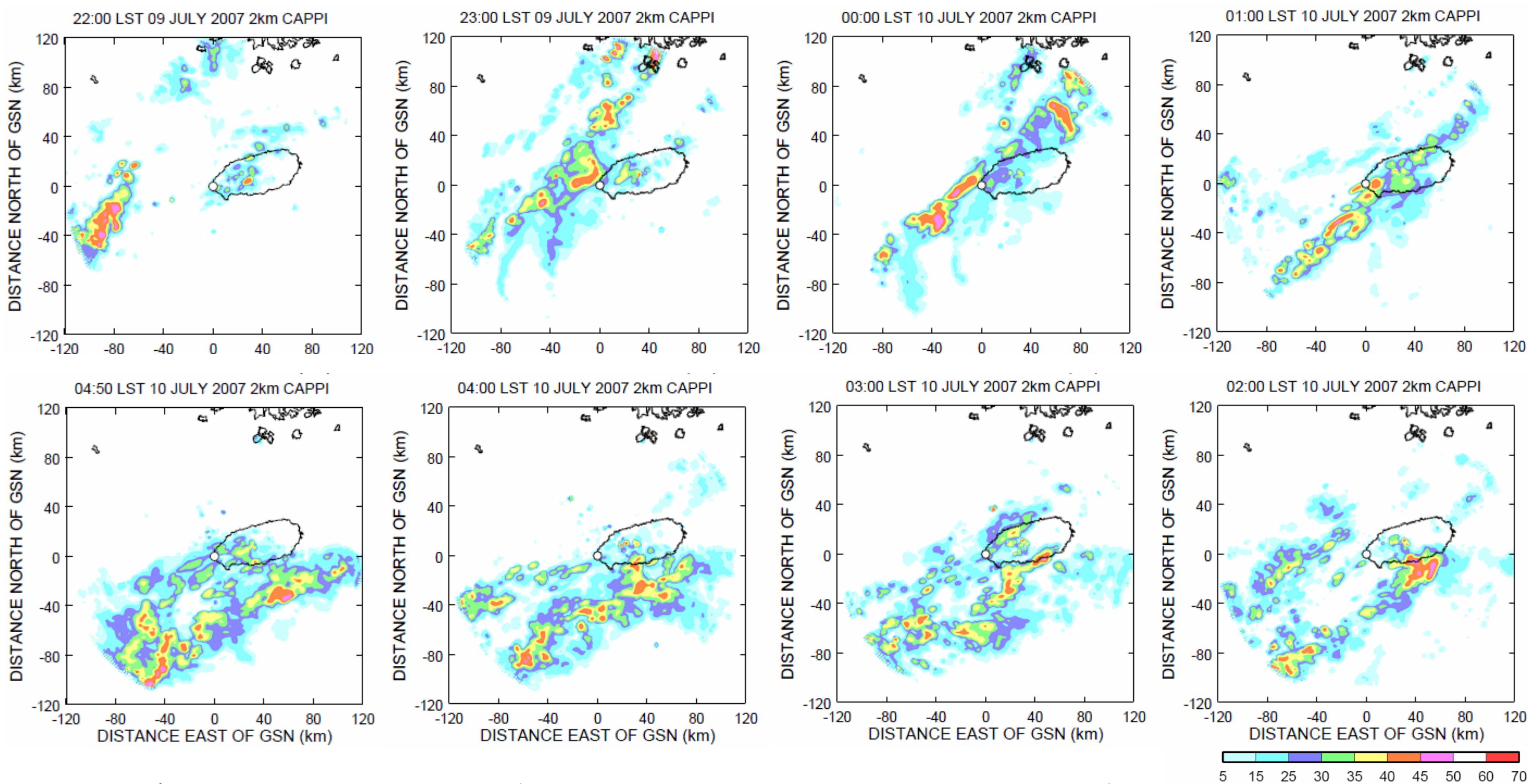
- ❖ Convective parameters did **not provide favorable condition** for convective cells.
- ➢ **Unstable layer** located below 920hPa (15 LST).

Radar analysis(System 2)



❖ System 2

➢Each of convective cells (meso-β scale) moved along the line ahead of cold front within the prefrontal warm sector.



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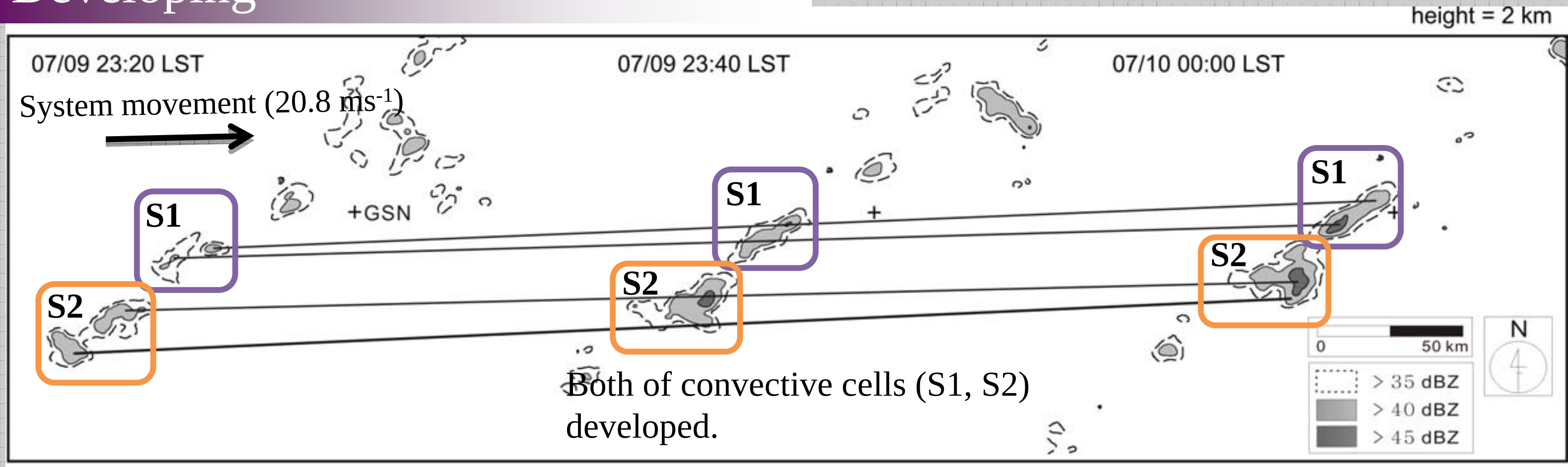
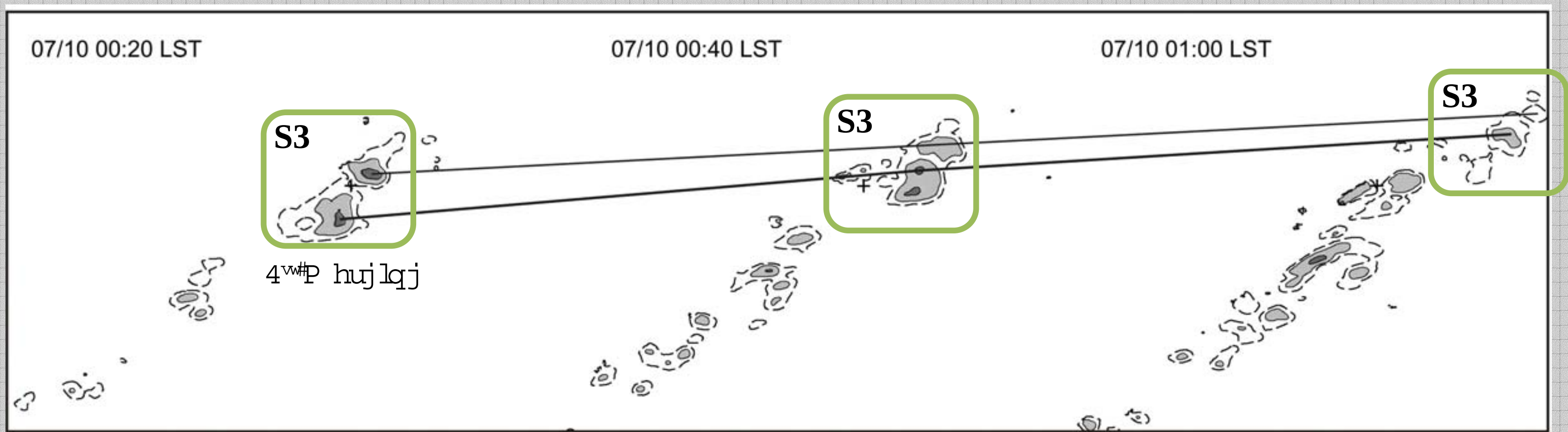
Series of horizontal reflectivity (System 2)

Developing → 1st order Merging → Dissipating

Developing



1st order Merging



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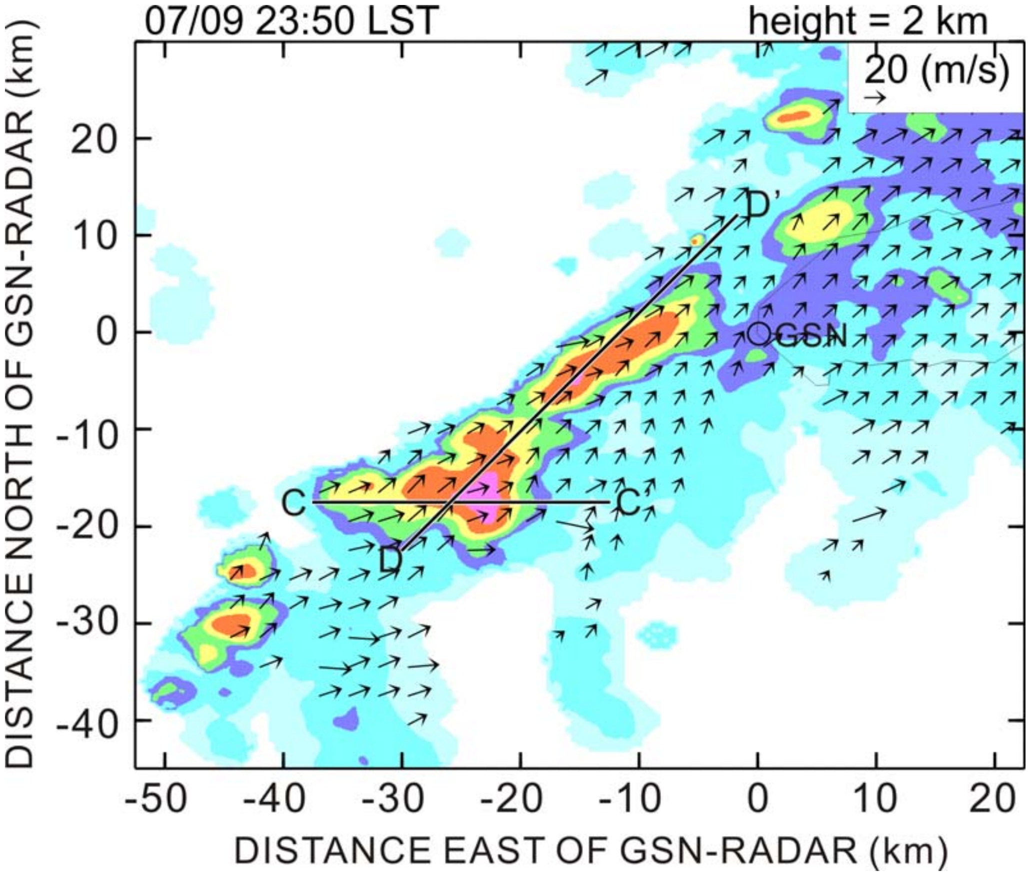
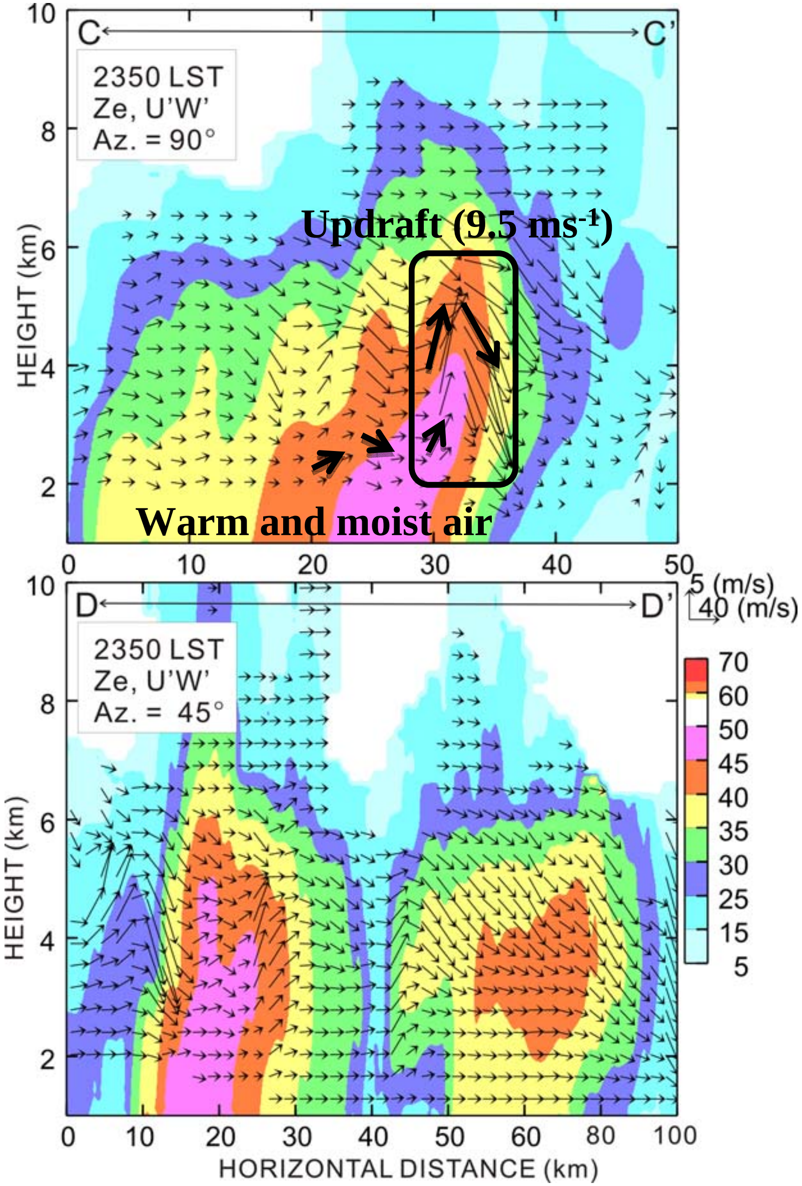
34330VW#rq#43#Mxo|#533:1#

Dual Doppler analysis (System 2) – Developing stage





❖ System 2

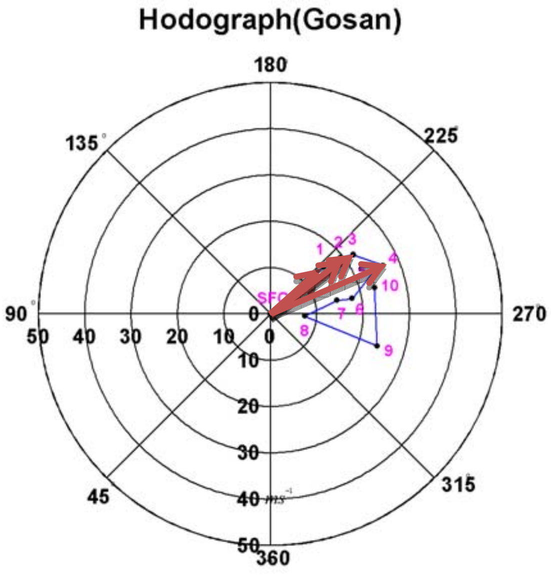
- ➢Strong convective region (≥40 dBZ) up to 6 km.
- ➢**Mainly southwesterly wind flow showed around the convective cells with warm and moist air.**
- ➢Strong updraft (9.5 ms^{-1}) and downdraft (11 ms^{-1}) intensified at the core of strong reflectivity region.

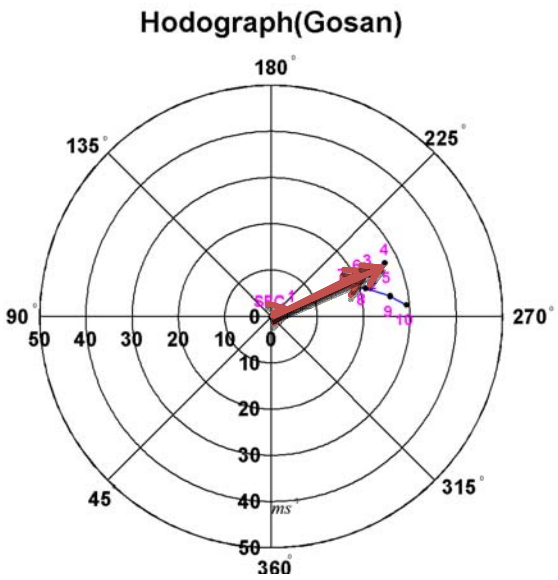
I lj1#491#K rul}rqwdo#glvwulexwlrqv#ri#uhiohfwlylw|#dqg#z lqg#yhfwru#dw#5#np DVO#dw#5683#OVW# rq#3<#Mxo|#533:1#Wkh#erog#olqhv#lqglfdwh#yhuwlfdo#furvv#vhfwlrqv#lq#I lj1#461

I lj1#4:1#Uhiohfwlylw|#dqg#z lqg#iorz#sdwwhuq#lq#wkh#yhuwlfdo#furvv# vhfwlrq#dw#5683#OVW#rq#3<#Mxo|#533:1

Upper air sounding analysis (System 2)

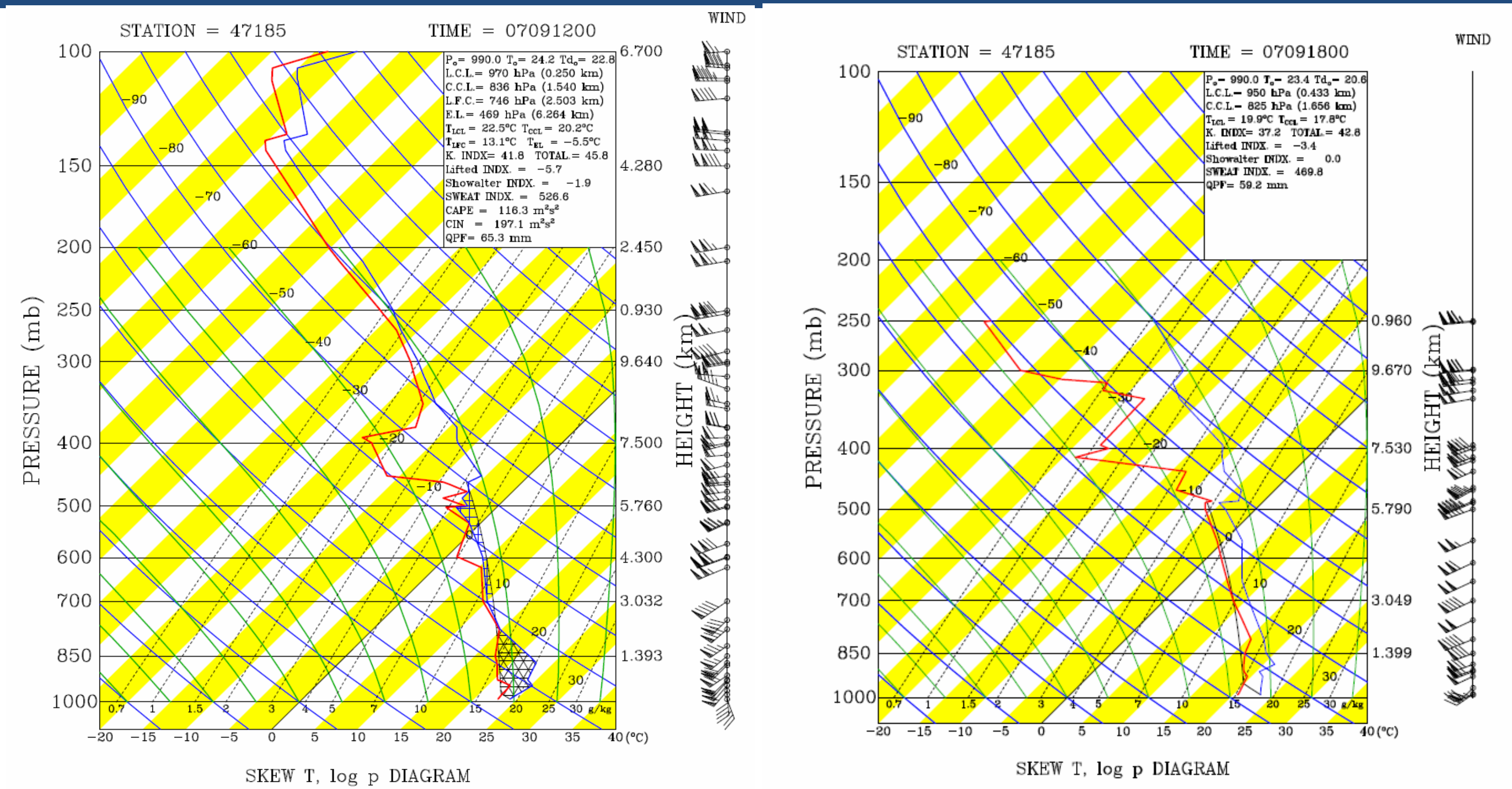
21 LST 09 Jul.	03 LST 10 Jul.





Height (km)	Bulk Shear ($10^{-3}s^{-1}$)	Directional Shear (10^{-3} degree/m)	Speed Shear ($10^{-3}s^{-1}$)	Bulk Shear ($10^{-3}s^{-1}$)	Directional Shear (10^{-3} degree/m)	Speed Shear ($10^{-3}s^{-1}$)
Surface ~ 3	**2.076**	4.734	1.378	**2.435**	4.772	2.029
3 ~ 6	2.506	4.72	2.803	1.241	1.143	1.443
6 ~ 12	5.061	8.041	5.404	1.473	2.803	1.485

Upper air sounding analysis (System 2)



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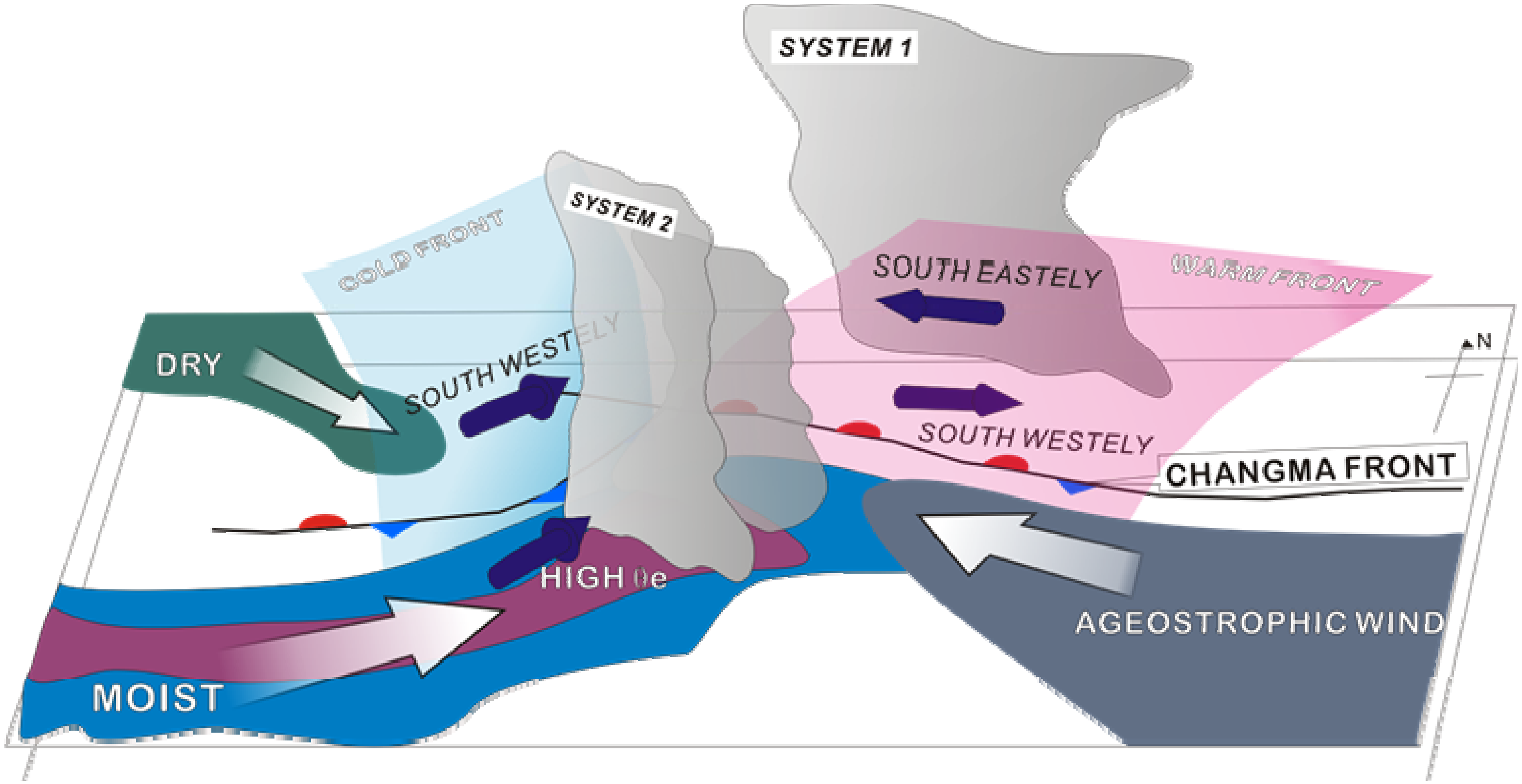
533:1#K qlw#ri#krul}rqwdo#z lqgv#lv#wkh#uljkw#duh#nqrw1

Table 3. Environmental parameters by upper-air sounding

Parameters	21 LST 09 JULY 07.	03 LST 10 JULY 07.
CAPE (JKg^{-1})	**408.94**	-
CIN (JKg^{-1})	**-101.26**	-
BRN	**5.67**	-
LCL Height (hPa)	932.65	928.66

- **CAPE (≒408.94)** value showed little instability.
- **Stable layer** located below 930hPa (21 LST).

Summary (sub-synoptic condition)



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duhdv#lqglfdwh#wkh#zdup#dqg#frog#iurqwdo#}rqh/#uhvshfwlyho|

❖ **In sub-synoptic conditions,**

➢**The enhanced low pressure** induced **southeasterly ageostrophic wind.**

➢**Southwesterly LLJ** intensified with warm and moist air.

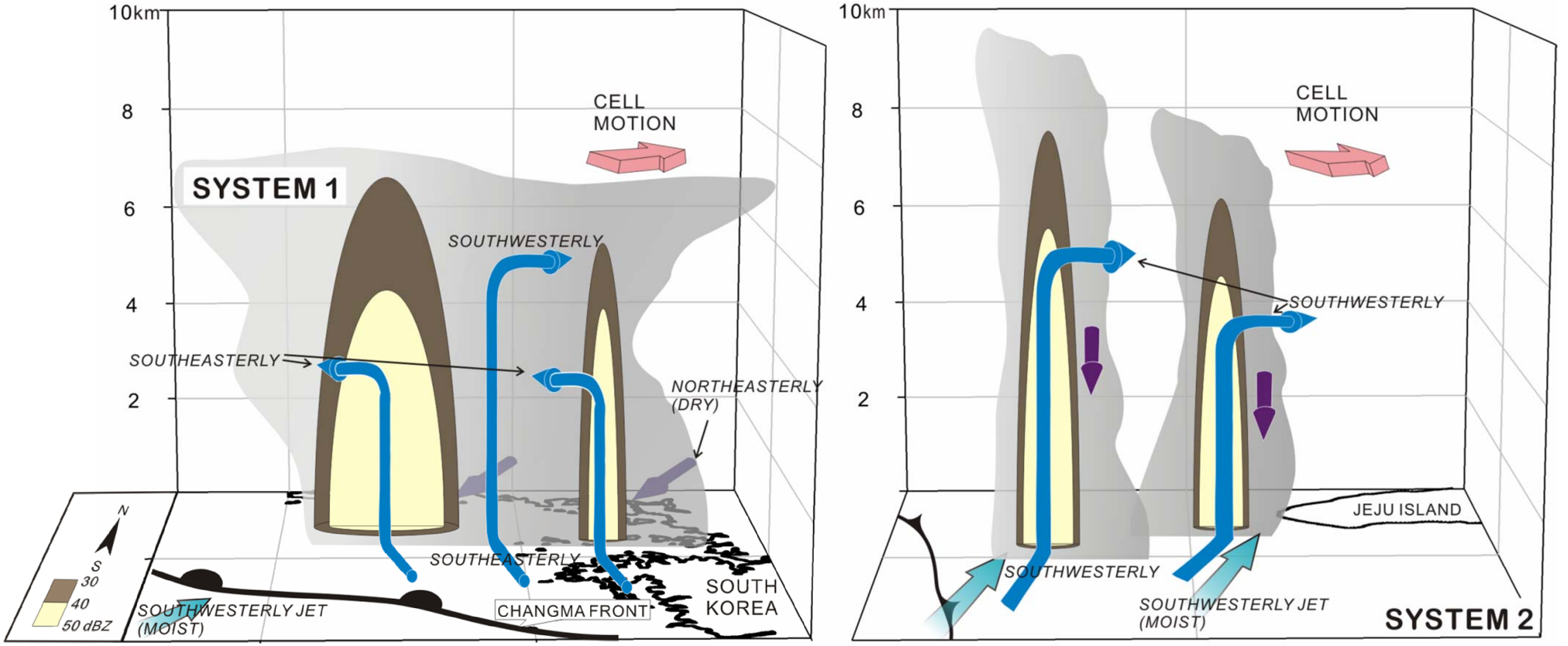
❖ **In vertical cross section across the Changma front,**

➢Consistent **southwesterly wind blew with moist air** ahead of cold front

➢Strong cross prefrontal **horizontal wind shear** and **convergence zone** across warm front

Summary (Radar analysis)

System 1 System 2



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lox wudwhg#iurp #gliihuhqw#uhjlrqv1

❖ **In radar analysis (System2),**

- **Single convective cells** developed ahead of cold front into prefrontal warm sector
- **Strong southwesterly** wind blew with warm and moist air in the ocean.

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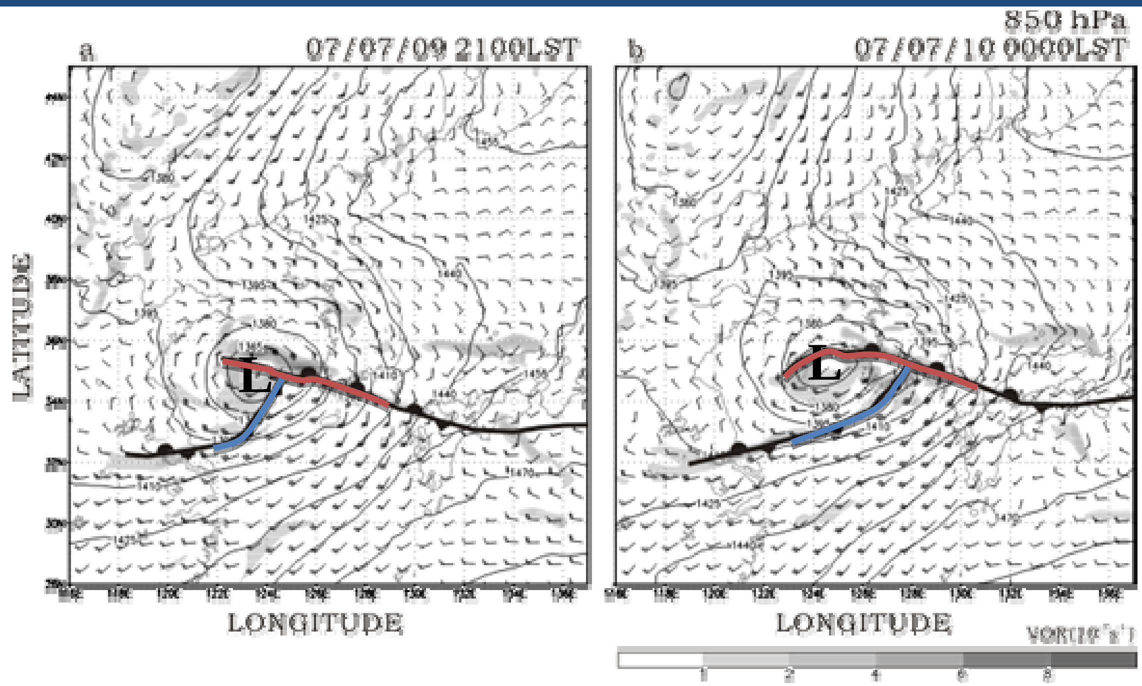
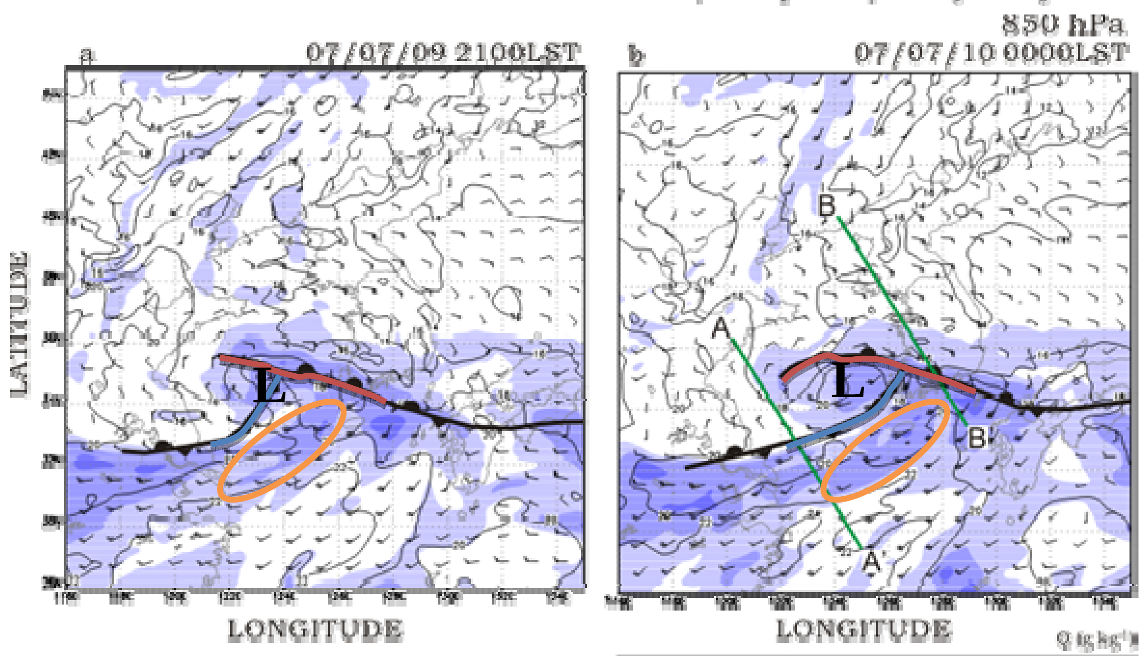
Thank you for listening !!

The structure and evolution of Changma front



850 hPa

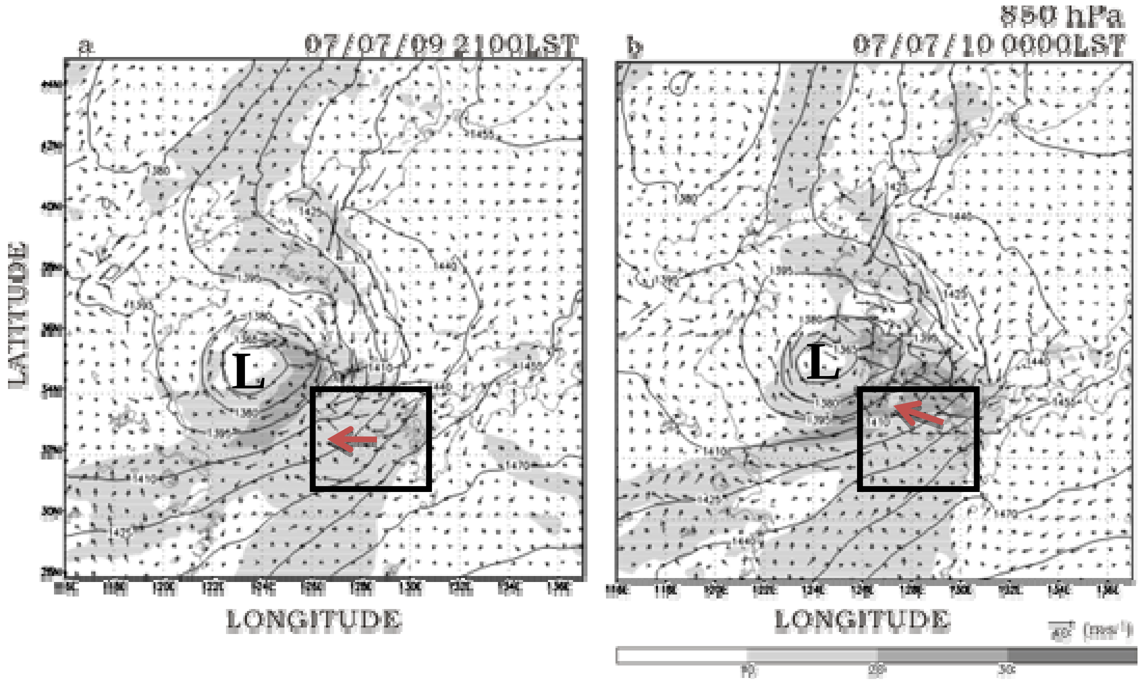
- ❖**The horizontal gradient of geopotential height** and **relative vorticity** were **intense** near surface low pressure.
- ❖ A low-level **warm front** gradually formed with an east-west orientation.
- ❖ The **cold front** near the low pressure was aligned from northeast to southwest.

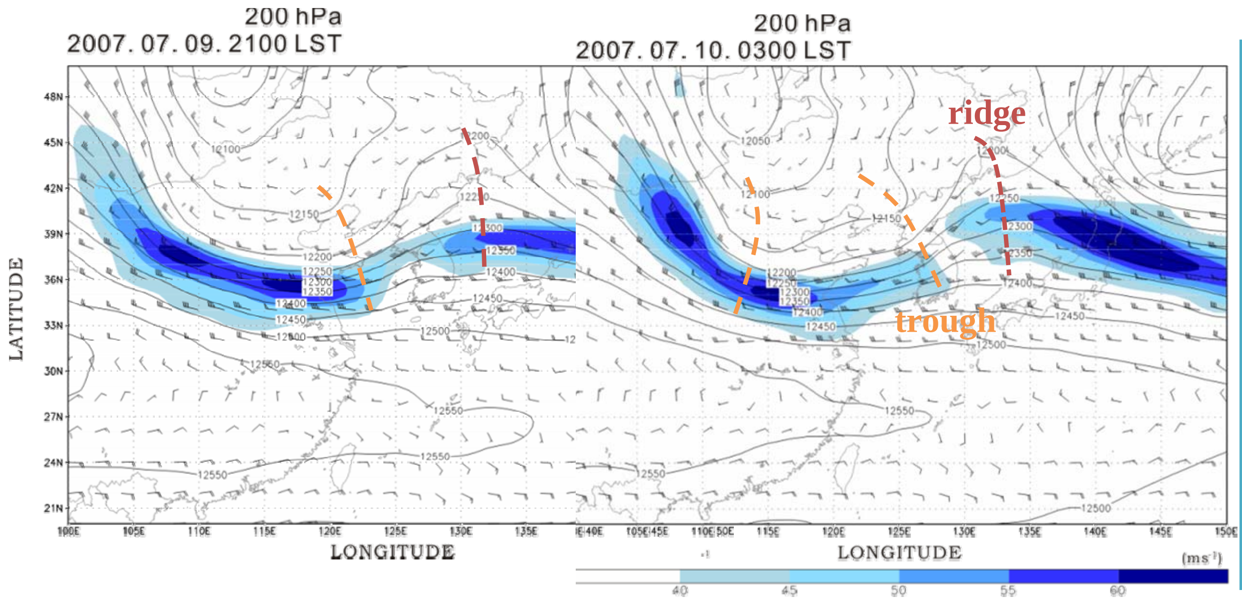


850 hPa

- ❖ **Low level jet (LLJ) transported warm and moist air.** (mainly 850 hPa)
- ❖ Warm and moist conveyor belt indicated ahead of cold front.
- ❖ Thermal gradient over south Korea was strong at 2°- 4℃ (100 km^{-1})

The structure and evolution of Changma front





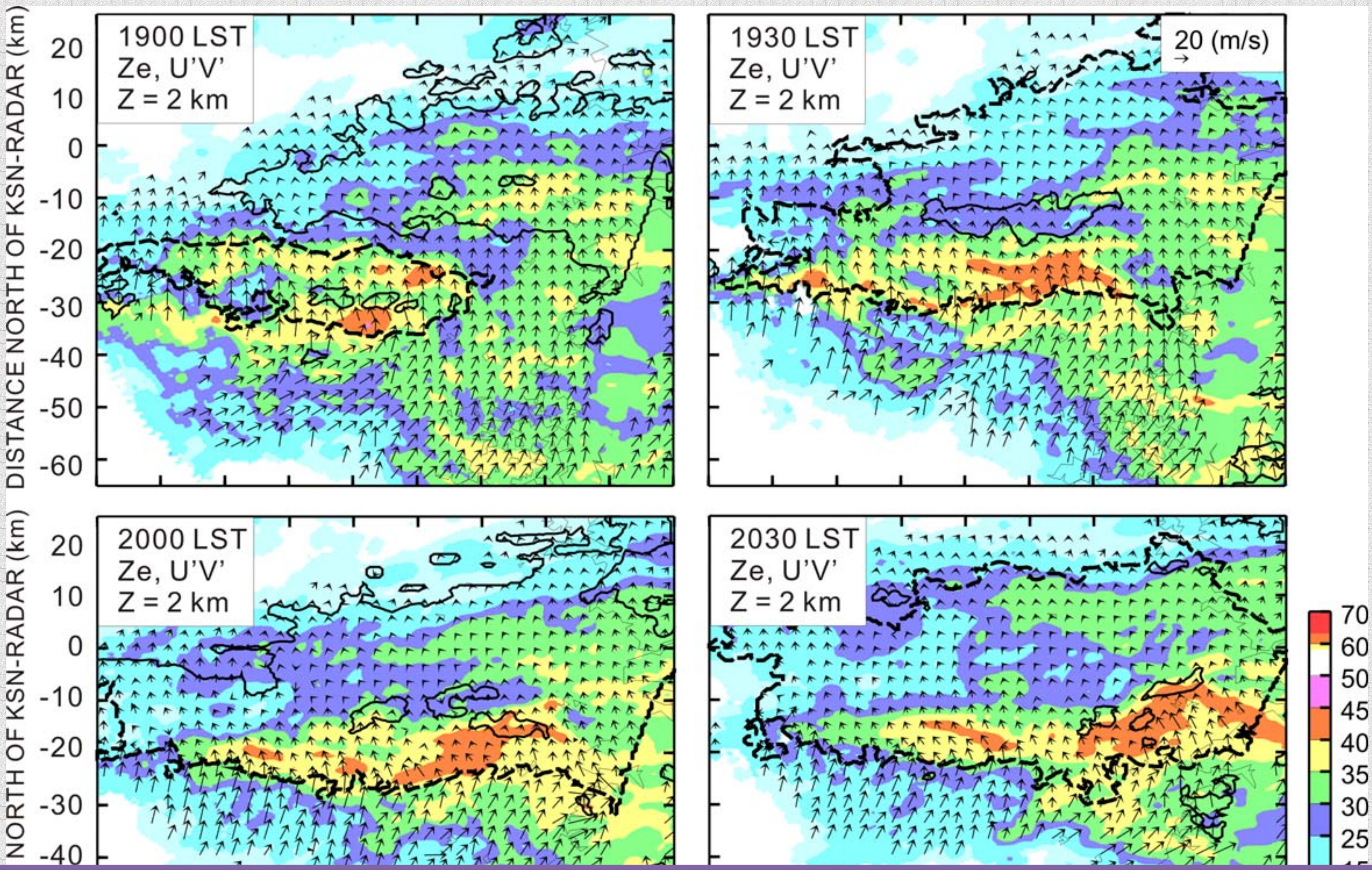
850 hPa

- ❖ The accompanied height fall appeared to be responsible for generation of ageostrophic winds.
- ➢ South-easterly ageostrophic winds blew into the LLJ core exit.
- ➢ The enhanced low pressure induced southeasterly ageostrophic wind and intensified southwesterly LLJ at the ahead of cold front.

200 hPa

- ❖ **Both trough and ridge in upper troposphere amplified.**
- ❖ Accompanying the amplification of this trough and ridge system, the baroclinic zone, characterized by a large geopotential height gradient and upper-level jet (ULJ), migrated westward.

Horizontal wind flow (System 1)



❖ System 1

➢**Wind shift line** shown at the rear edge of the strong convective cells **(≥40 dBZ).**

➢Wind was **shifted** to the easterly in the strong convective cells.

➢**Thus, southeasterly winds play important role in System 1.**

Surface wind (0000LST 10 July)