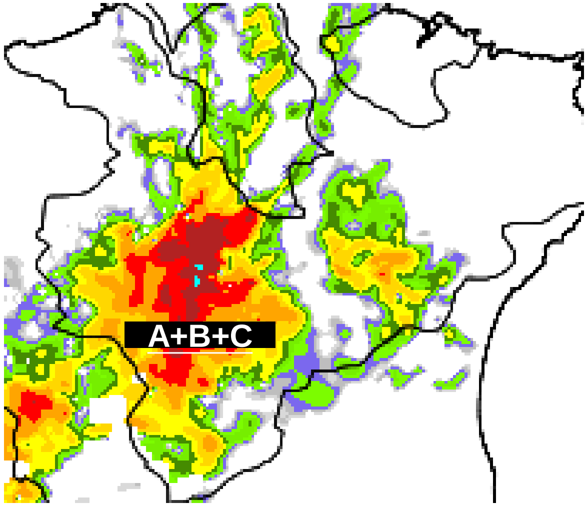
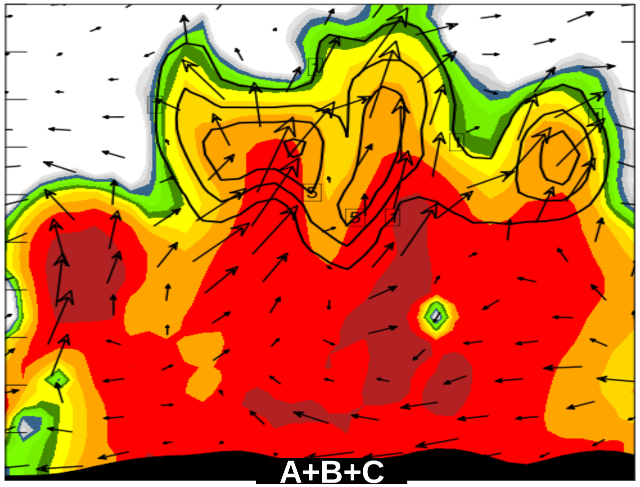
A 0.5-kilometer Modeling Study of the Severe Thunderstorm Event with Urban Flooding at Taipei on 14 June 2015





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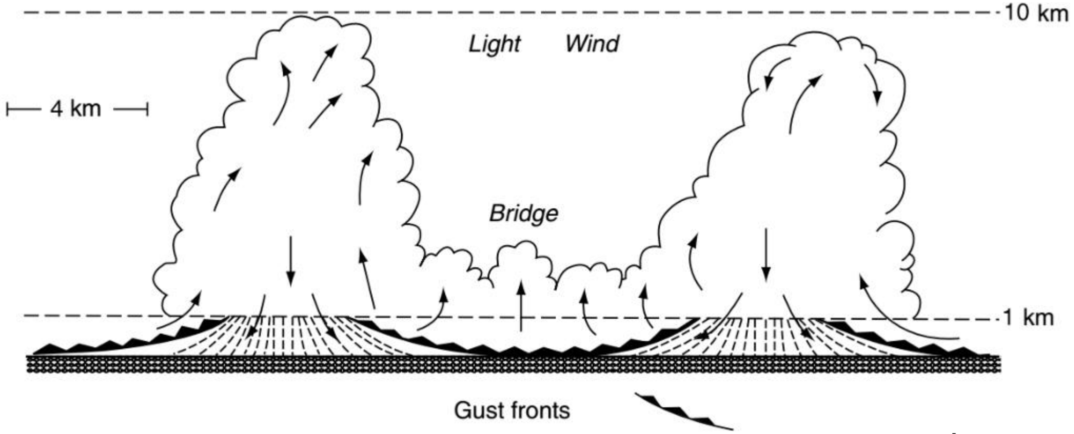
Introduction

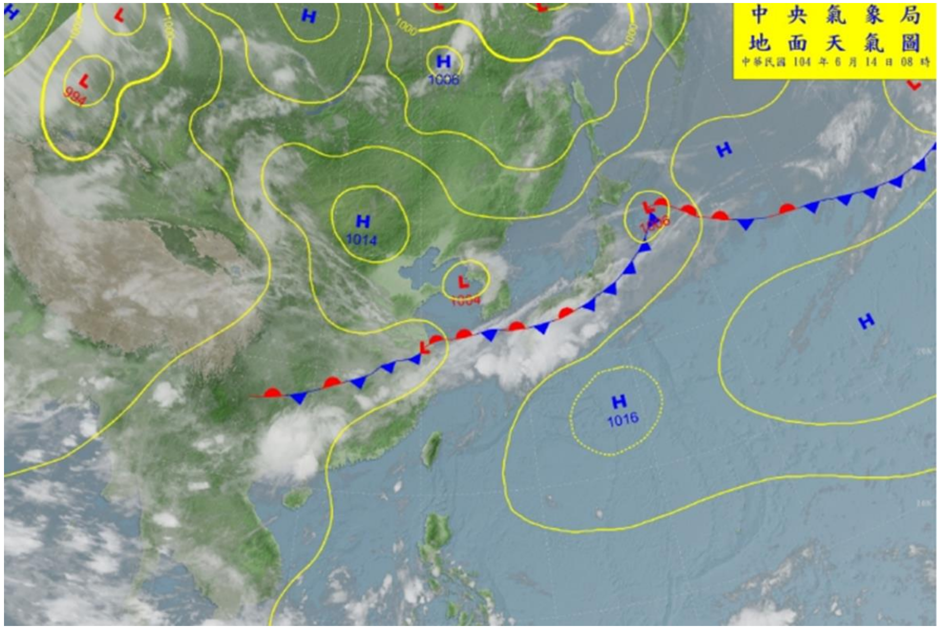
- Jou et al. (2016) performed the observation study of this afternoon thunderstorm (TS_A) event => (1) the merge of several convective cells; (2) enhanced low-level convergence produced by the sea-breeze circulation and thunderstorm coldair outflow

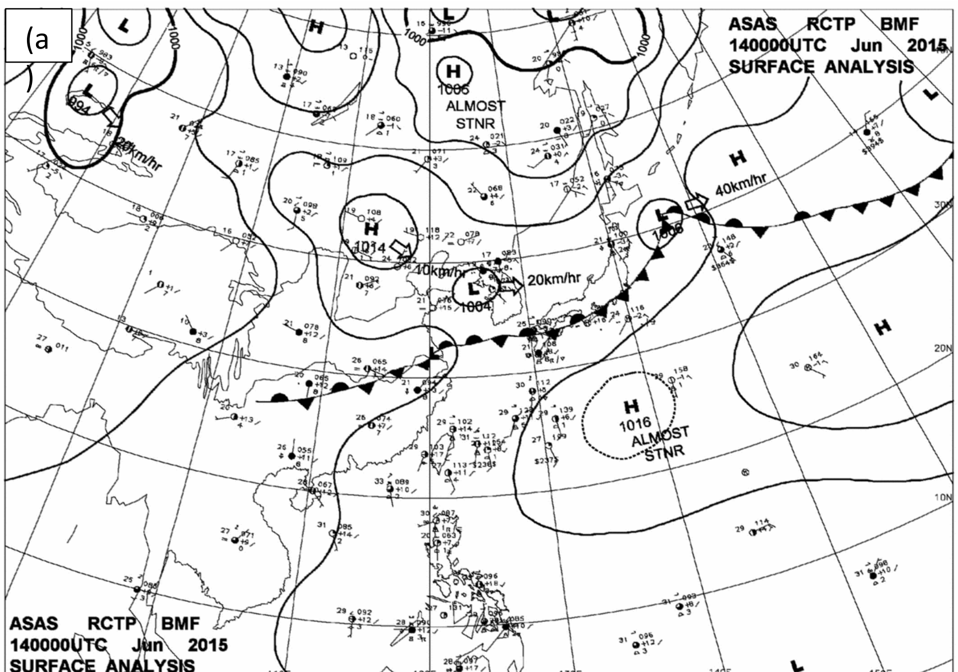
- The proposed mechanisms for cloud merging may be due to:

(i) low-level convergence (Tao and Simpson 1989)
(ii) cold pool interaction (Tao and Simpson 1989)
(iii) different propagation speeds of two cells (Lin and Joyce 2001)



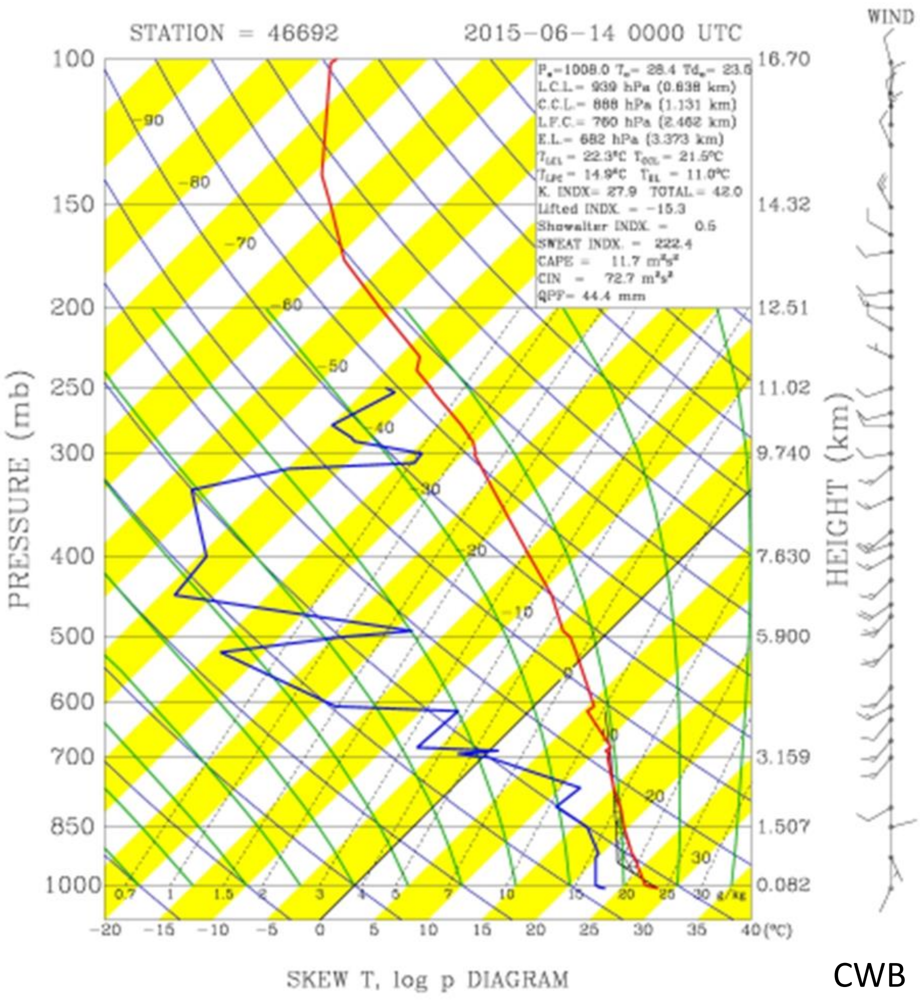
Simpson et al. (1980)





No significant synoptic forcing for this afternoon thunderstorm (TS_A) event!

From CWB



CWB

Weak thermodynamic instability (with an CAPE of 11.7 J/kg) for the 08LST sounding at Panchiao
=> Weak inversion at 700 hPa

表 5　臺北市於 2015 年 6 月 14 日是否發生午後雷雨之評估檢查表（林等 2012），使用包括淡水、基隆、臺北三個地面觀測站 0800-1300 LST 之觀測數據及板橋站 0800 LST 探空觀測數據。

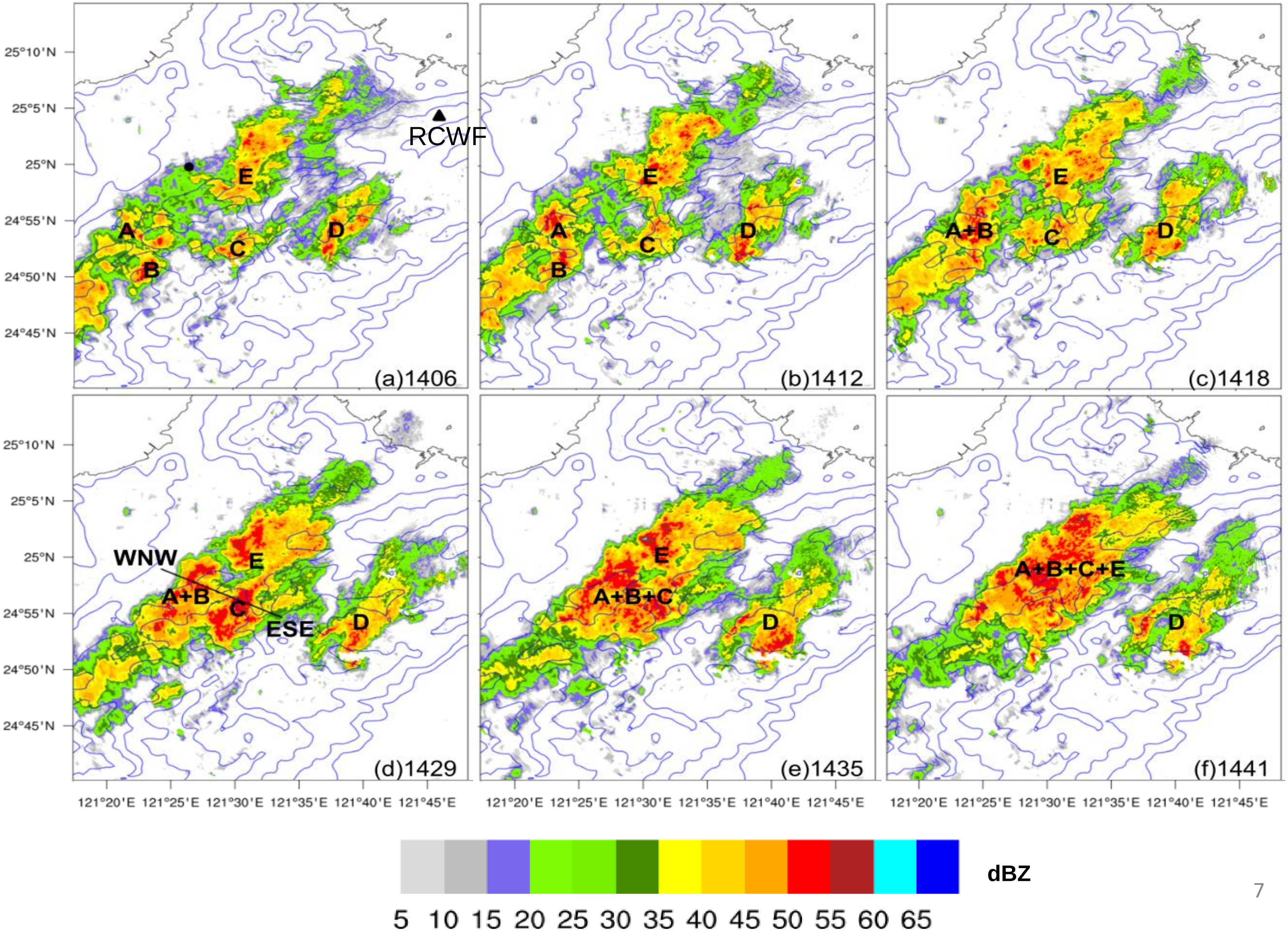
STATION	Hour	8	9	10	11	12	13
淡水 (46990)	VPRE(hpa)	29	30.5	31	31.5	31	31
		V	FALSE	FALSE	FALSE	FALSE	V
	HUMD(%)	74	70.5	69	67.5	67	67.5
		V	FALSE	FALSE	FALSE	FALSE	V
	WDIR(degree)	160	250	240	270	280	280
		190	310	310	310	320	320
		V	V	V	FALSE	V	V
	WDSD(m/s)	1.5	2	2	3.5	4.5	4.5
		V	V	FALSE	V	V	V
基隆 (46694)	VPRE(hpa)	28.5	28	28.5	28.5	28.5	28.5
		V	V	V	V	V	V
	HUMD(%)	68	61	61.5	59	62	60
		V	V	V	V	V	V
	WDIR(degree)	170	30	10	20	0	0
		240	50	50	50	50	50
		FALSE	FALSE	V	FALSE	V	V
	WDSD(m/s)	3	2.5	3.5	4	4.5	5
		V	V	V	V	V	V
台北 (46692)	VPRE(hpa)	28	29	29.5	28.5	28.5	29.5
		V	V	V	V	V	V
	HUMD(%)	70.5	65.5	59	56	54	57
		V	V	V	V	V	V
	WDIR(degree)	140	180	230	230	260	280
		200	210	280	330	350	360
		V	FALSE	FALSE	FALSE	V	V
	WDSD(m/s)	1.5	1.5	2	2	2.5	3
		V	V	V	V	V	V
	符合標準項目數 (總數12項)	11	8	8	7	10	12

周等 (2016)

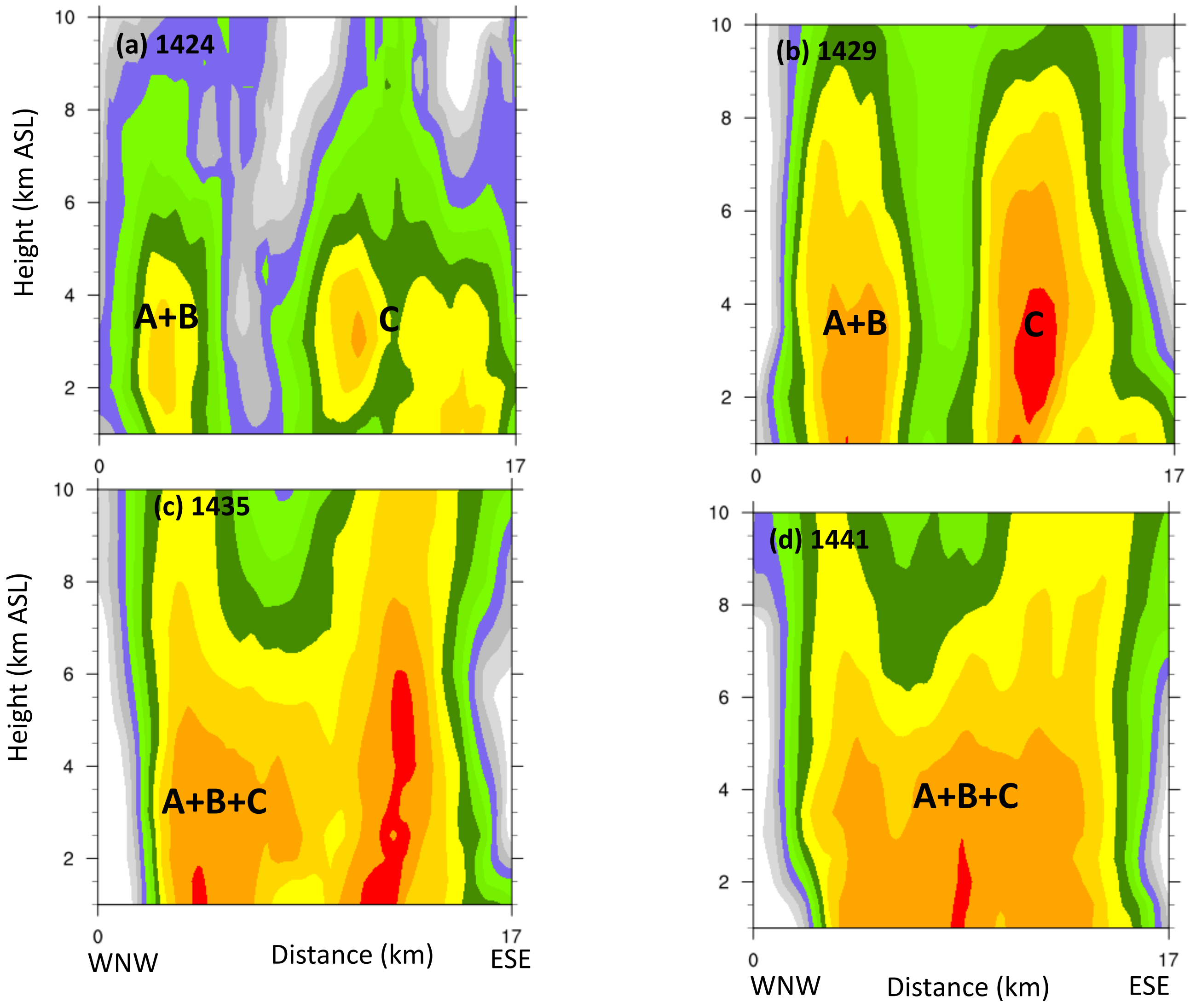
08LST	hpa	1000	925	850	700	500
板橋探空	CAPE	>500				
		X				
	T-Td	<4	<4	<6	<9.5	<11
		X	X	V	X	X
	WDIR	210	230-280	220-280	200-270	200-250
		V	X	X	V	V
	WDSD	<1.5	<4	<4.5	<6.5	<6.5
		V	V	V	V	X
		2	1	2	2	1

周等 (2016)

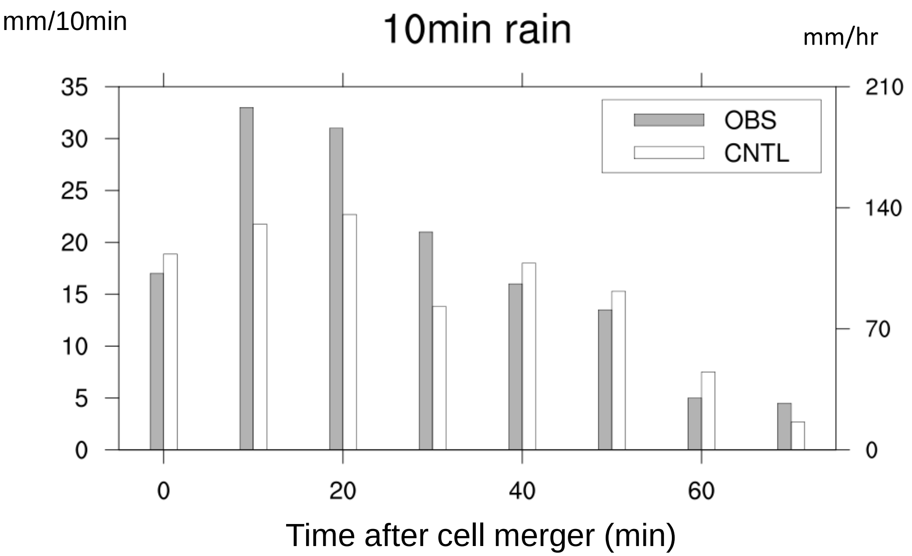
PPI Map of Radar Reflectivity at 0.5 degree elevation angle



Vertical Cross Section of Radar Reflectivity along WNW-ESE direction



Time series of rainfall rate



=> Both observation and model simulation show that rainfall rate increases significantly after cell merger!

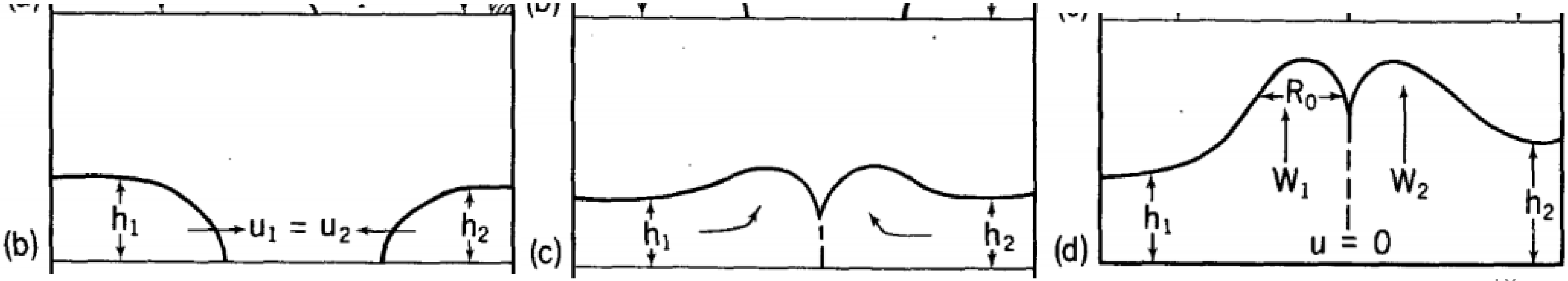
Testing Hypotheses

Hypotheses:

1) Cold pool height was elevated after the cell collision and merger.

2) Latent cooling from evaporation and melting has a significant impact on the propagation and strength of coldair outflows.

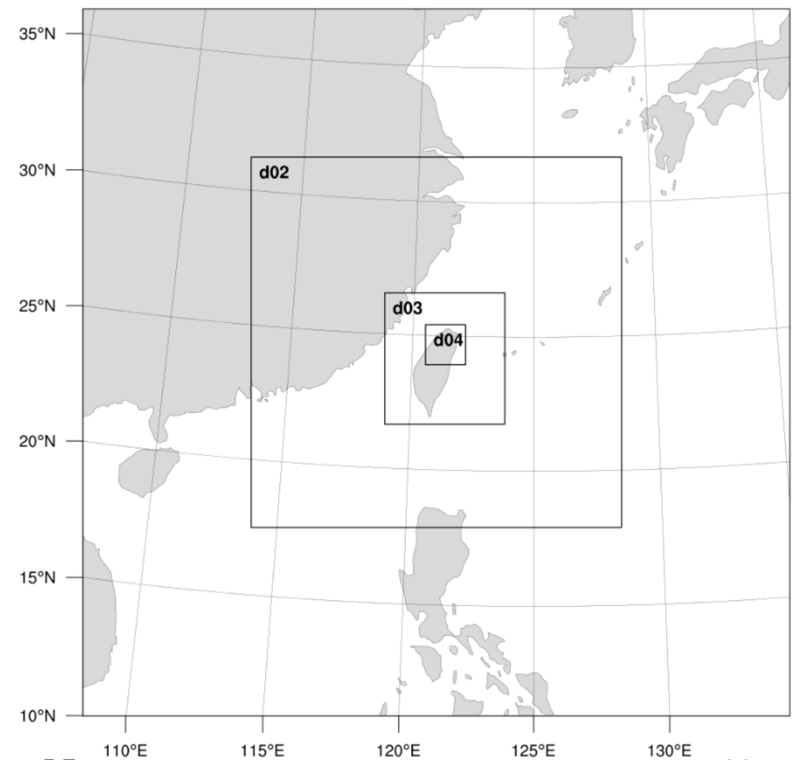
3) Mixed-phase microphysical processes were critical for the development of thunderstorm outflows and the associated intense rainfall.



Intrieri et al. (1990)

Model Configuration

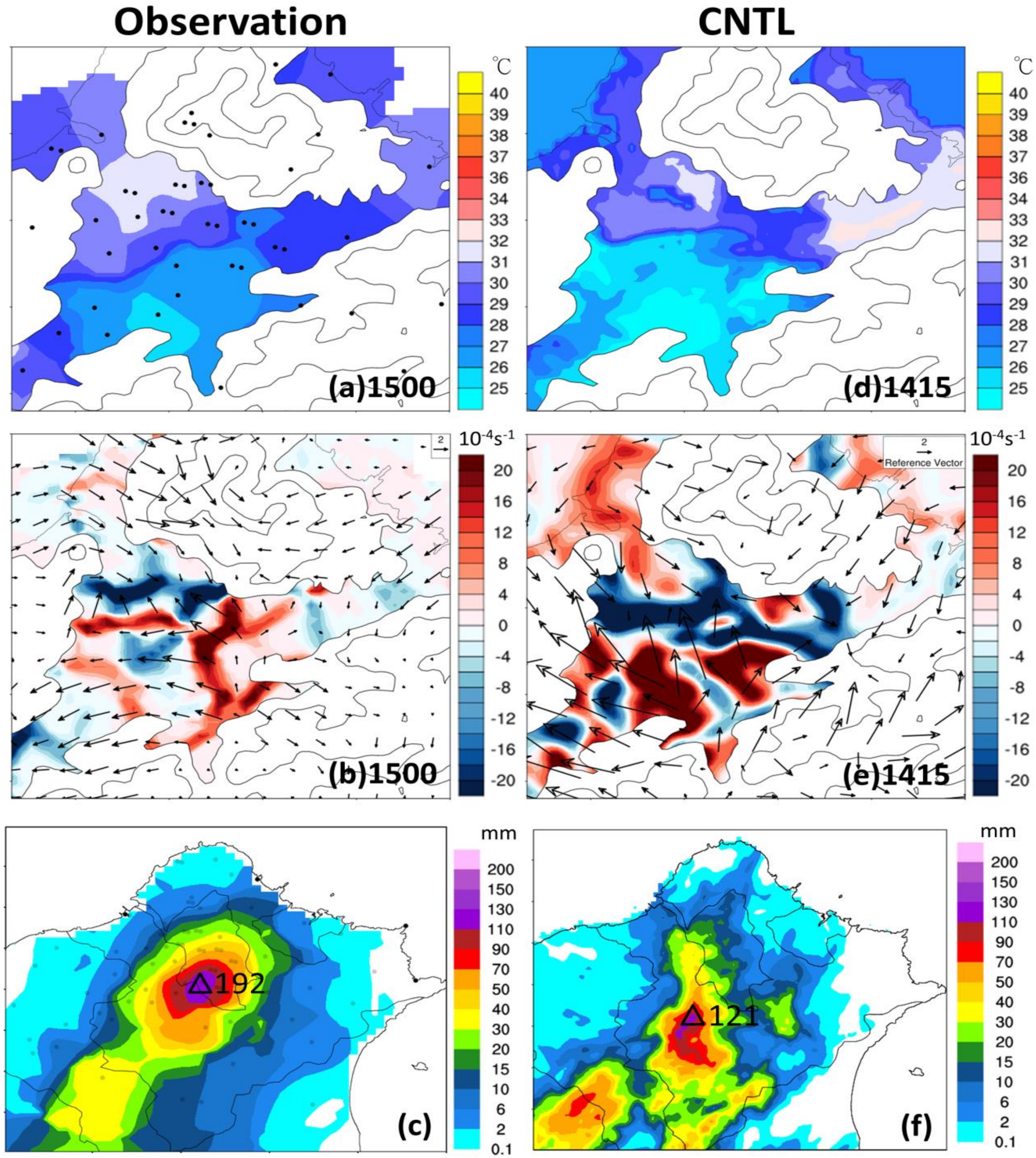
- Version 3.4 of WRF ARW
- two-way nested grid with four domains: 13.5, 4.5, 1.5 , **0.5 km**
- **55 vertical levels (8 layers within PBL)**
- WDM6 microphysics scheme
- Kain-Fritsch cumulus (only D1)
- Dudhia shortwave radiation
- RRTM longwave radiation
- Noah land surface model
- YSU PBL
- MODIS landuse data
- ECMWF ERA-Interim 0.75°x0.75°
- initial time: 6/13 12UTC
- forcast hour: 24hr ( at t = 15hr)



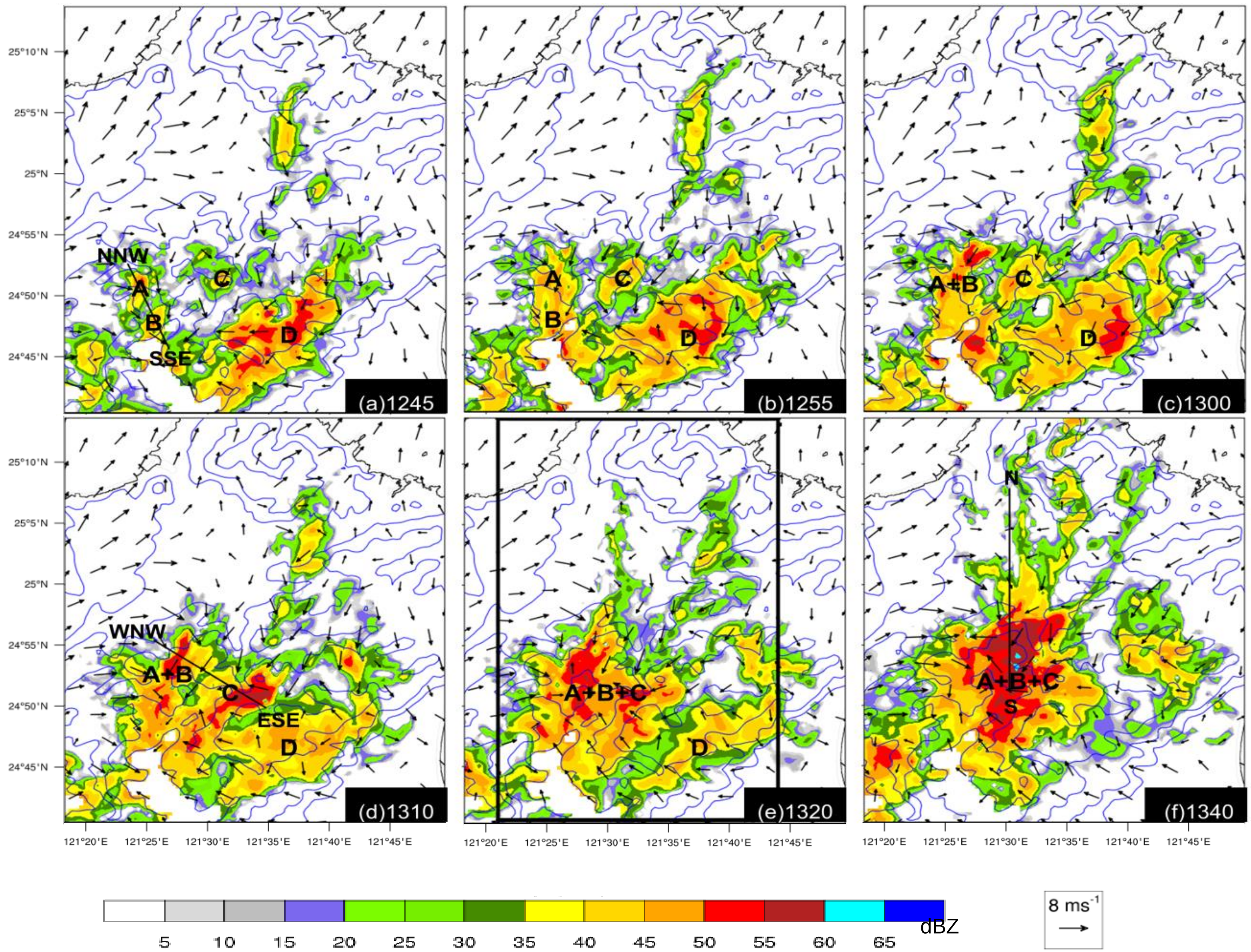
Surface Temperature

Surface Divergence

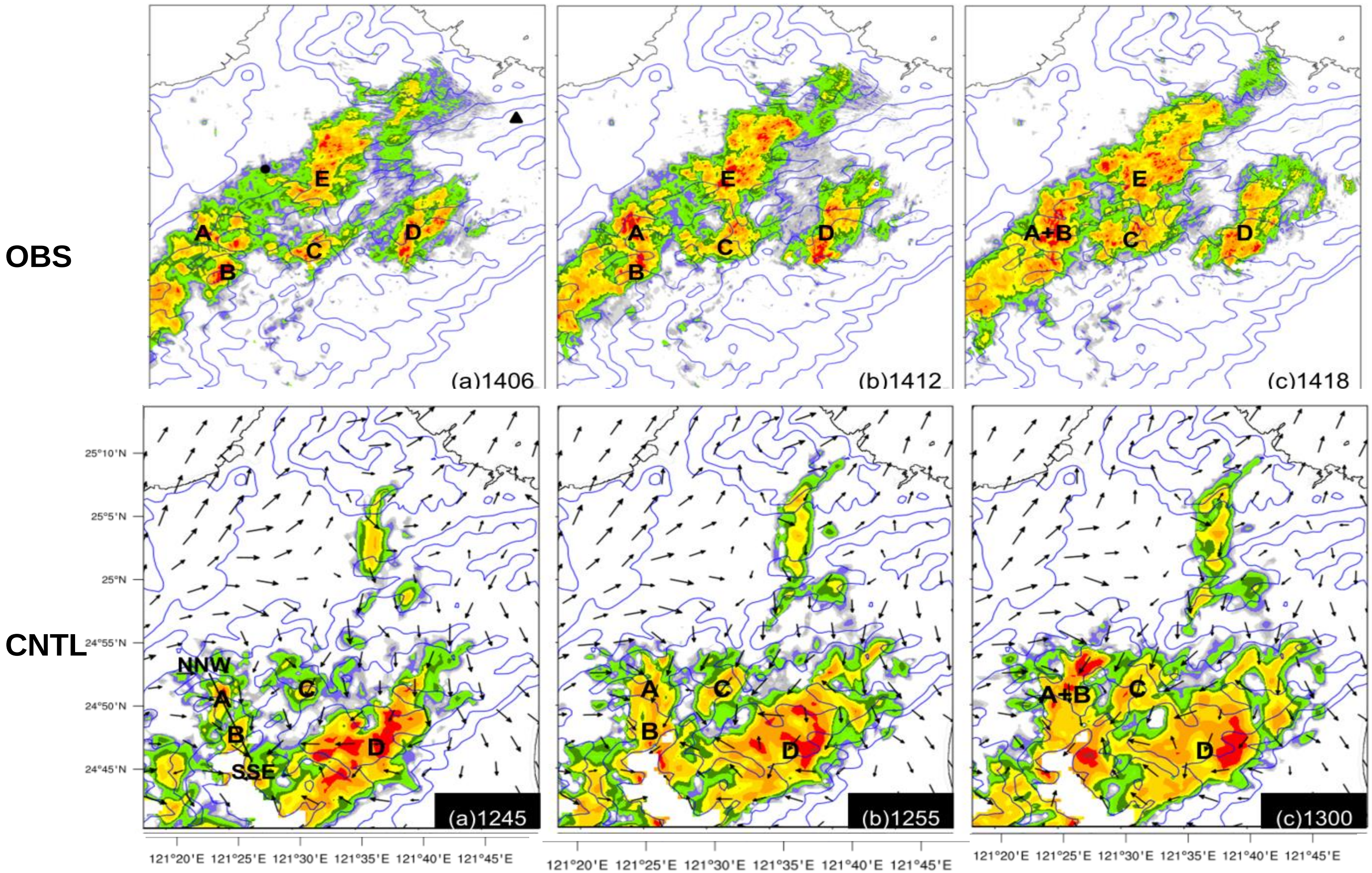
6-h Accumulated Rainfall



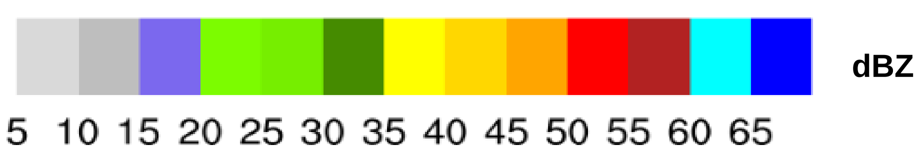
CNTL-simulated Radar Reflectivity at Z = 1.5km



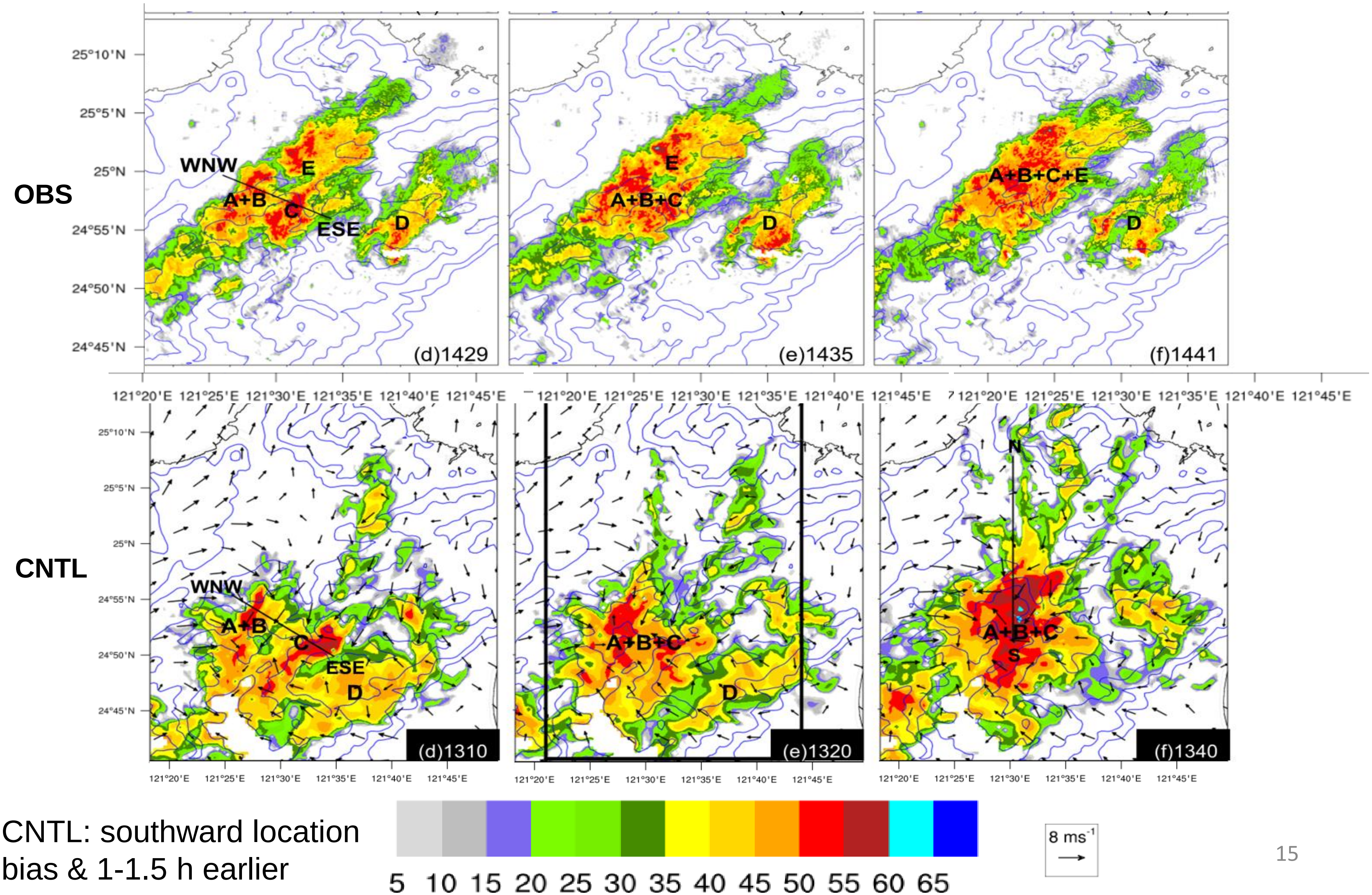
Radar Reflectivity Horizontal Map: OBS vs. CNTL



CNTL: southward location bias & 1-1.5 h earlier



Radar Reflectivity Horizontal Map: OBS vs. CNTL

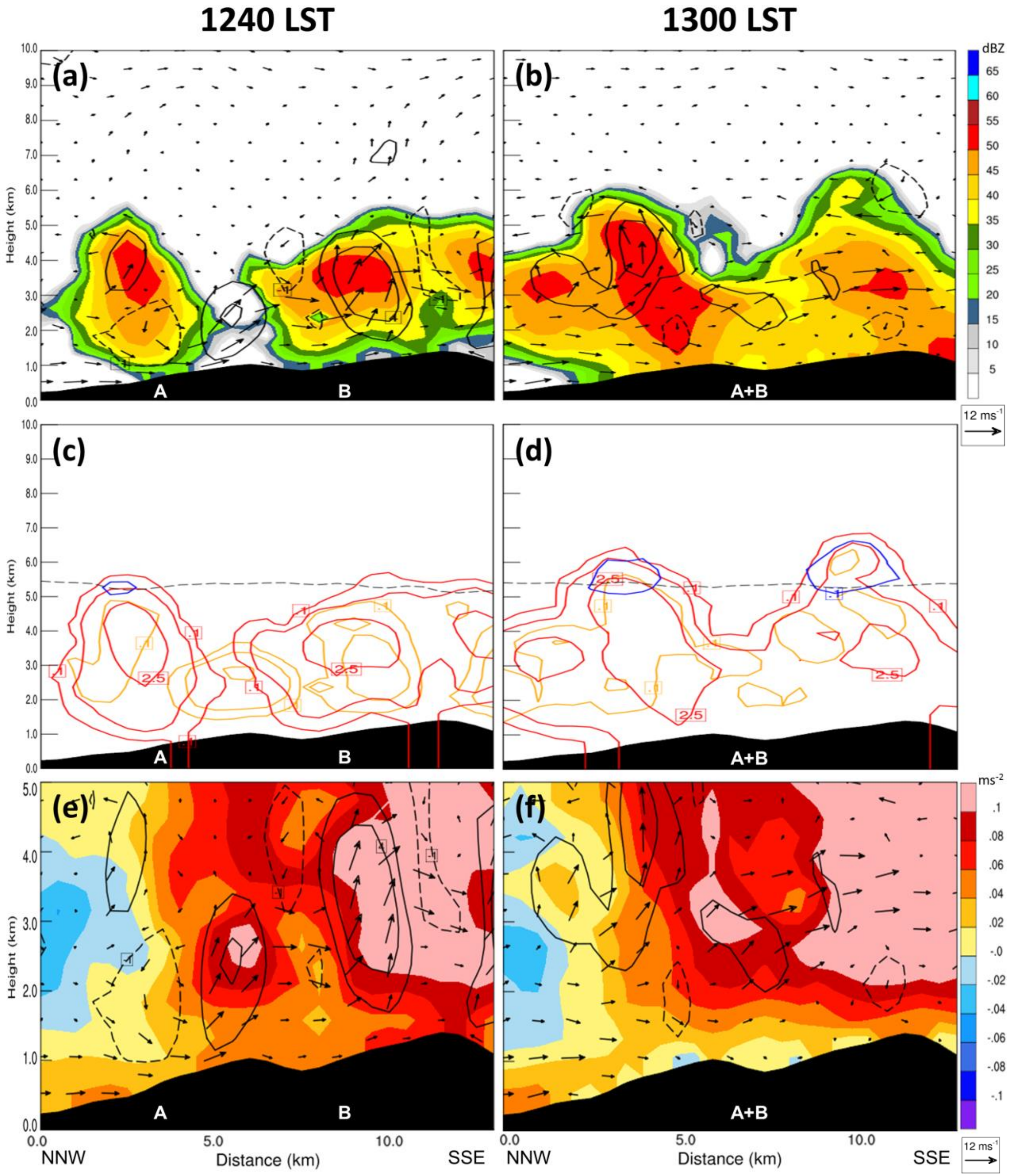


CNTL: southward location bias & 1-1.5 h earlier

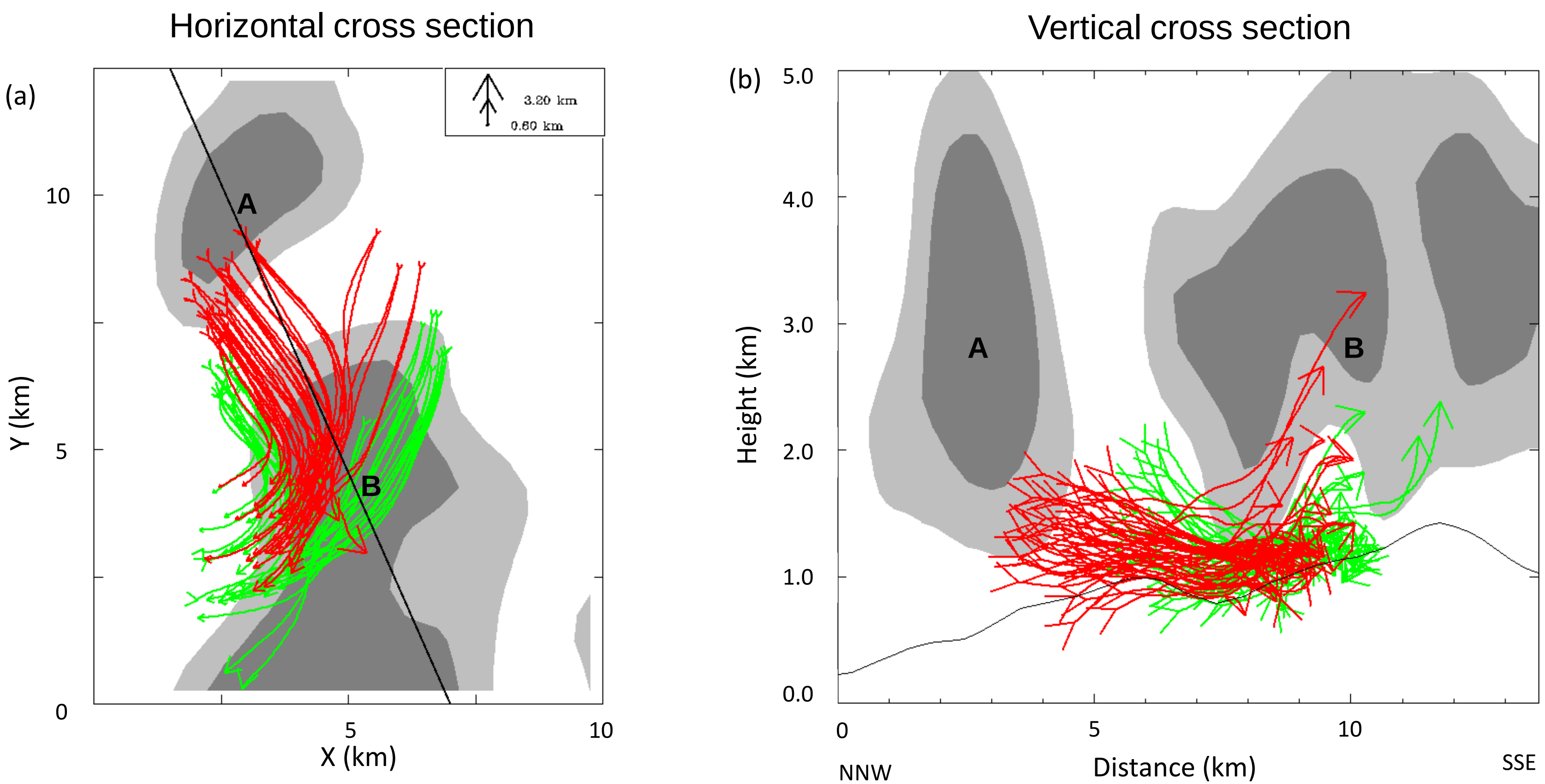
Radar Reflectivity

Mixing ratio of
Cloud water &
Rain water

Buoyancy &
Vertical velocity

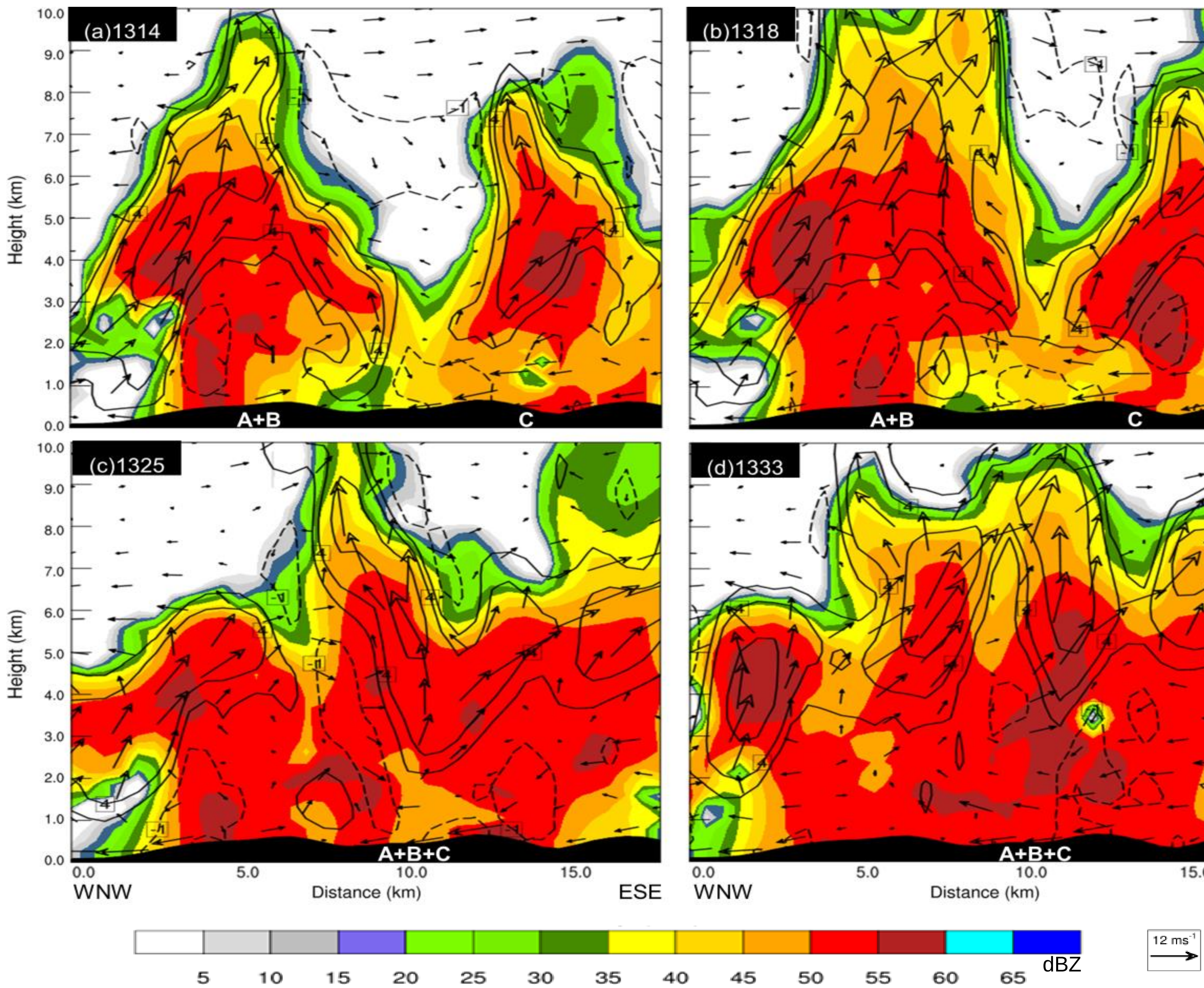


25-min forward trajectory analysis for 80 air parcels near Cell A & Cell B

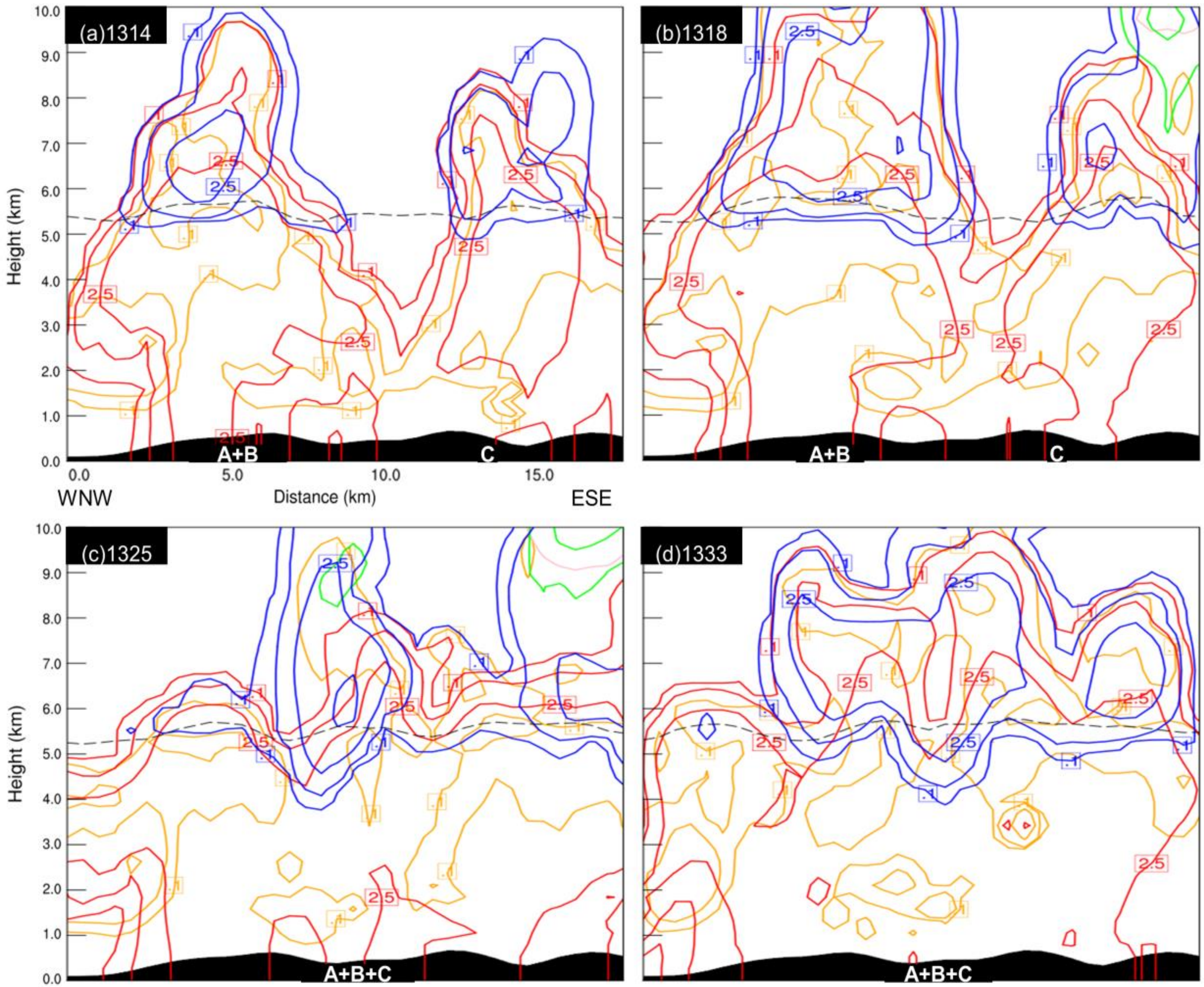


=> Rear-end collision due to different speeds of Cell A and Cell B

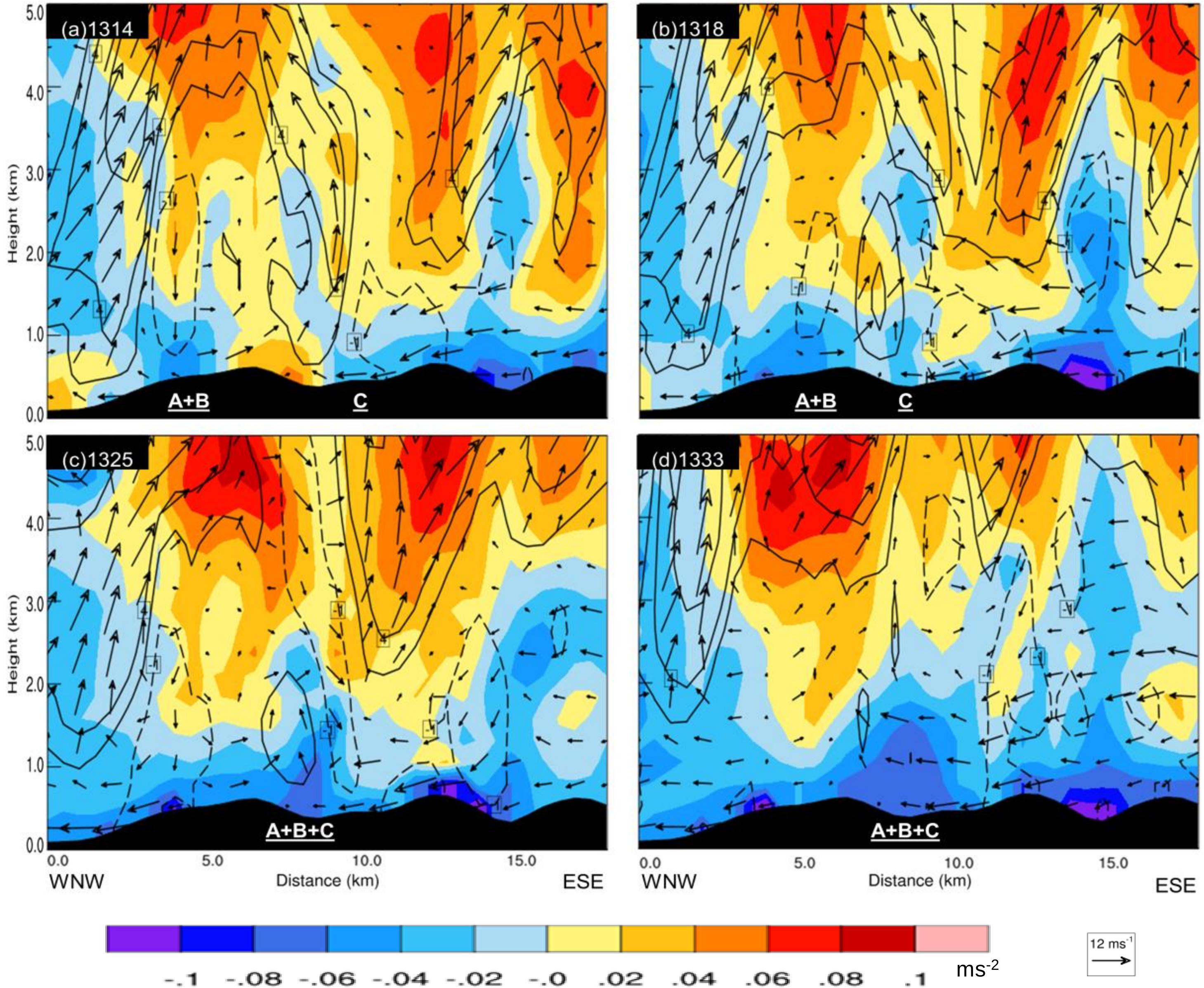
Contour: vertical velocity, Color: radar reflectivity



Contour: Mixing ratios of cloud water (orange), rain water (red), cloud ice (pink), snow (green), and graupel (blue)

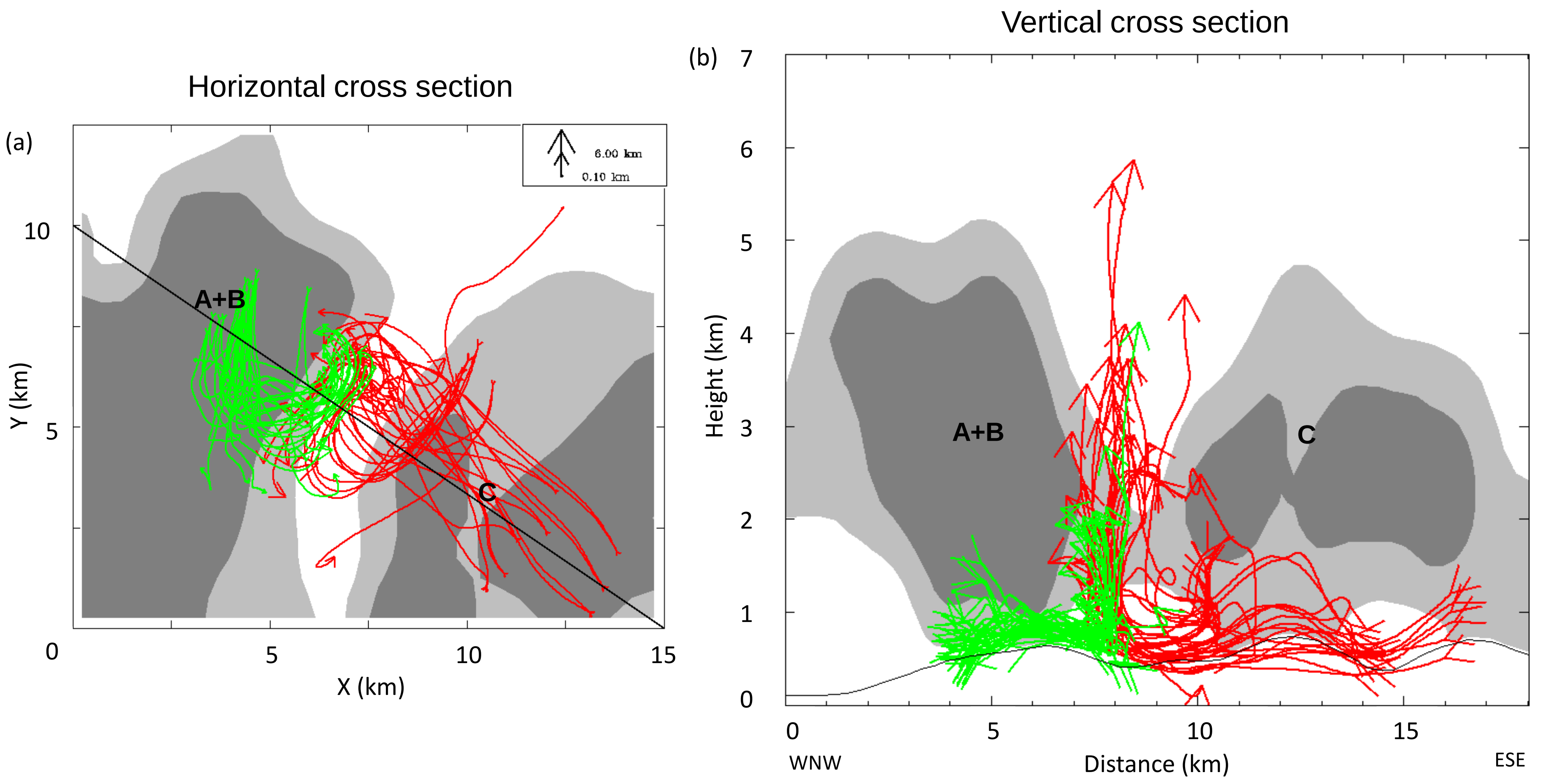


Color: buoyancy Contour: vertical velocity (solid for updraft; dashed for downdraft)



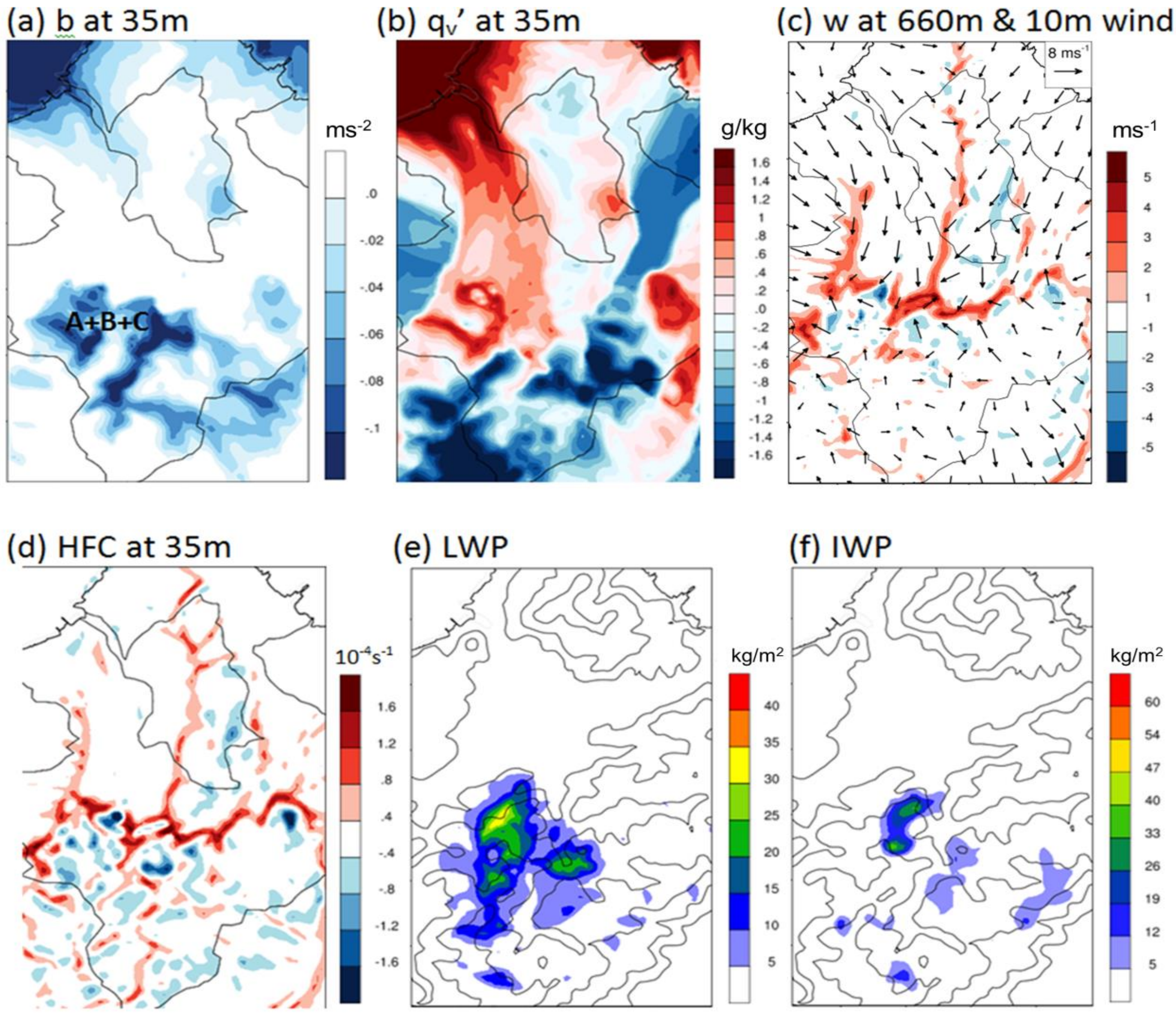
=> Cold pool head is elevated after cell merger between Cell A+B and Cell C

36-min forward trajectory analysis for 62 air parcels near Cell A+B & Cell C

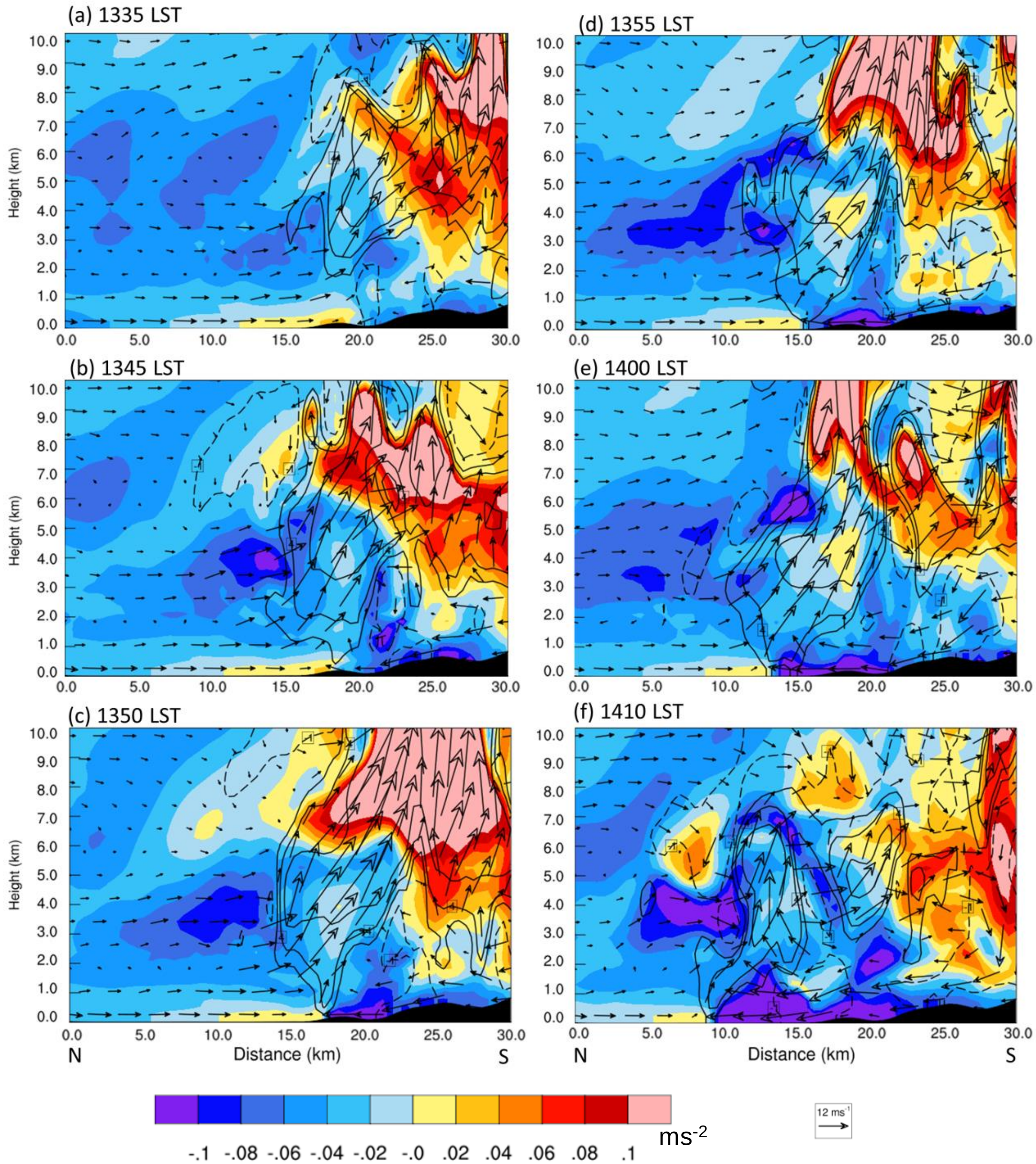


⇒ Head-on collision due to opposite directions of cold pool propagation Between Cell A+B and Cell C

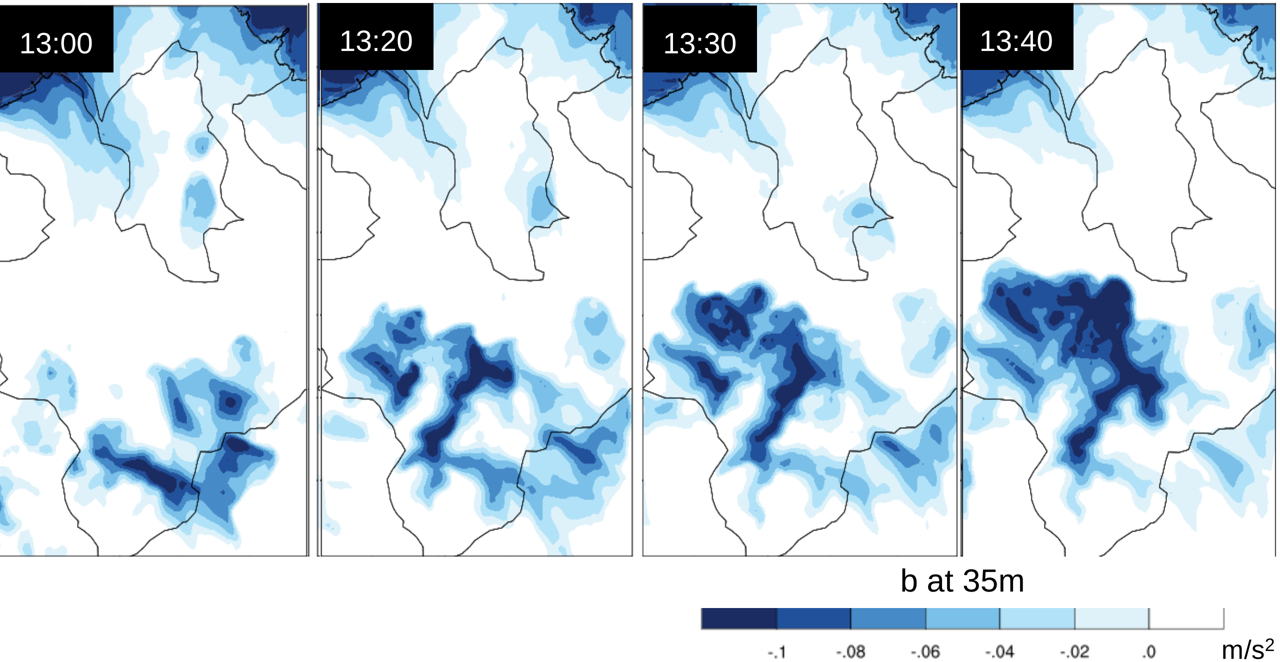
Low-level thunderstorm features after the merger of Cell A+B and Cell C



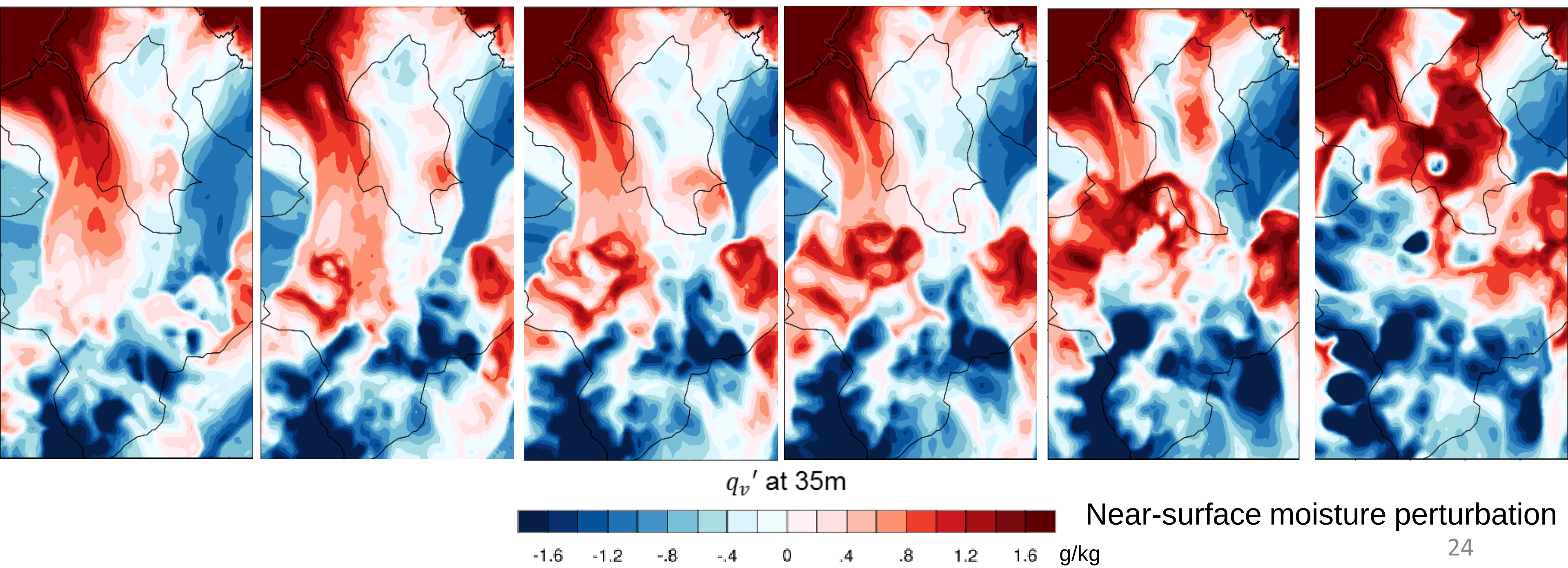
Convergence between sea breeze and thunderstorm coldair ourflow



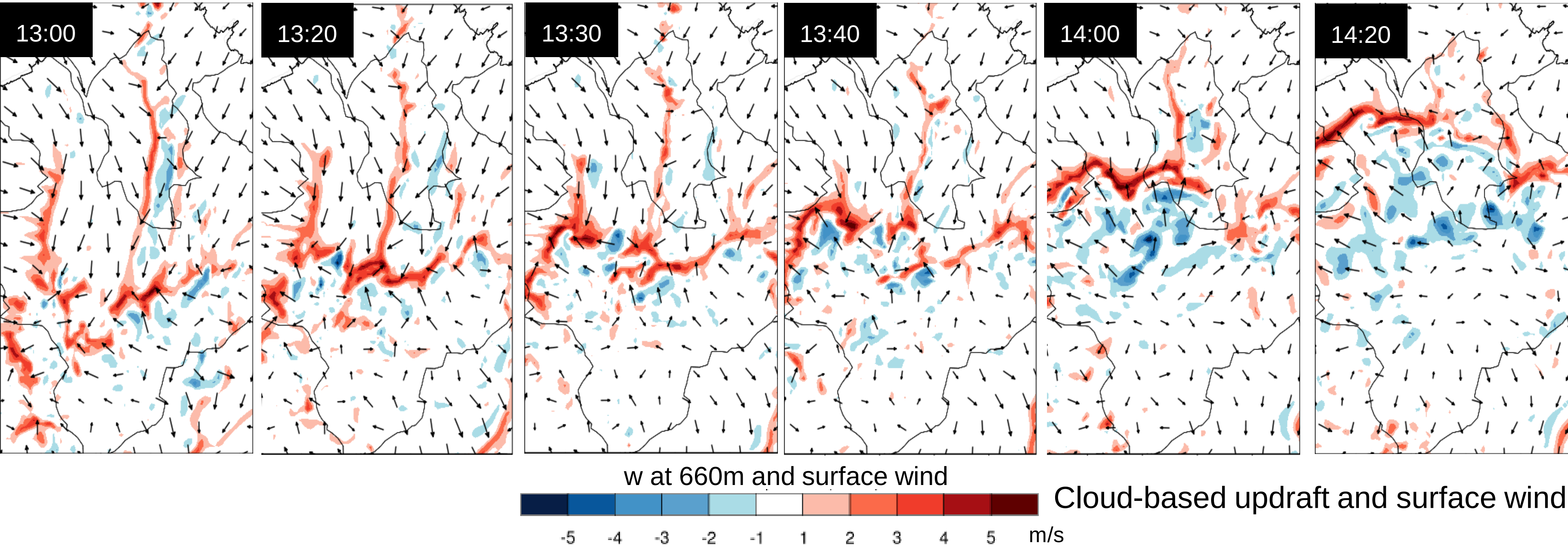
Color: buoyancy , Contour: vertical velocity { -1,2,4,8 } ms^{-1}



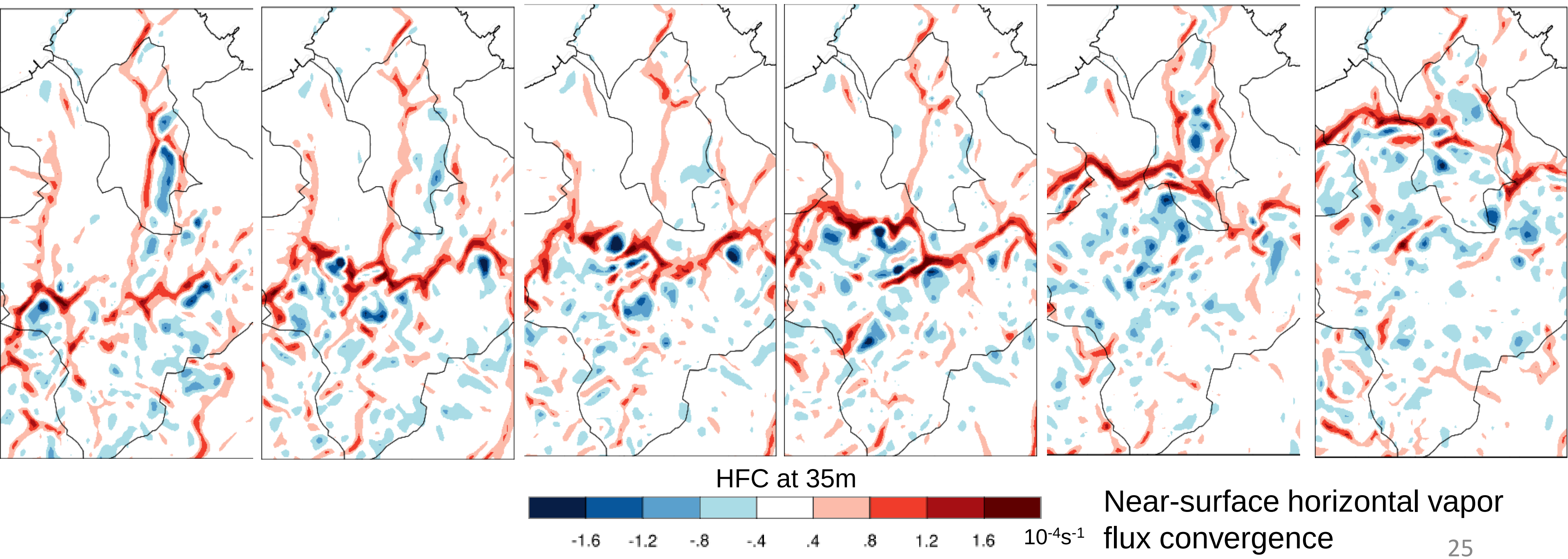
Near-surface buoyancy



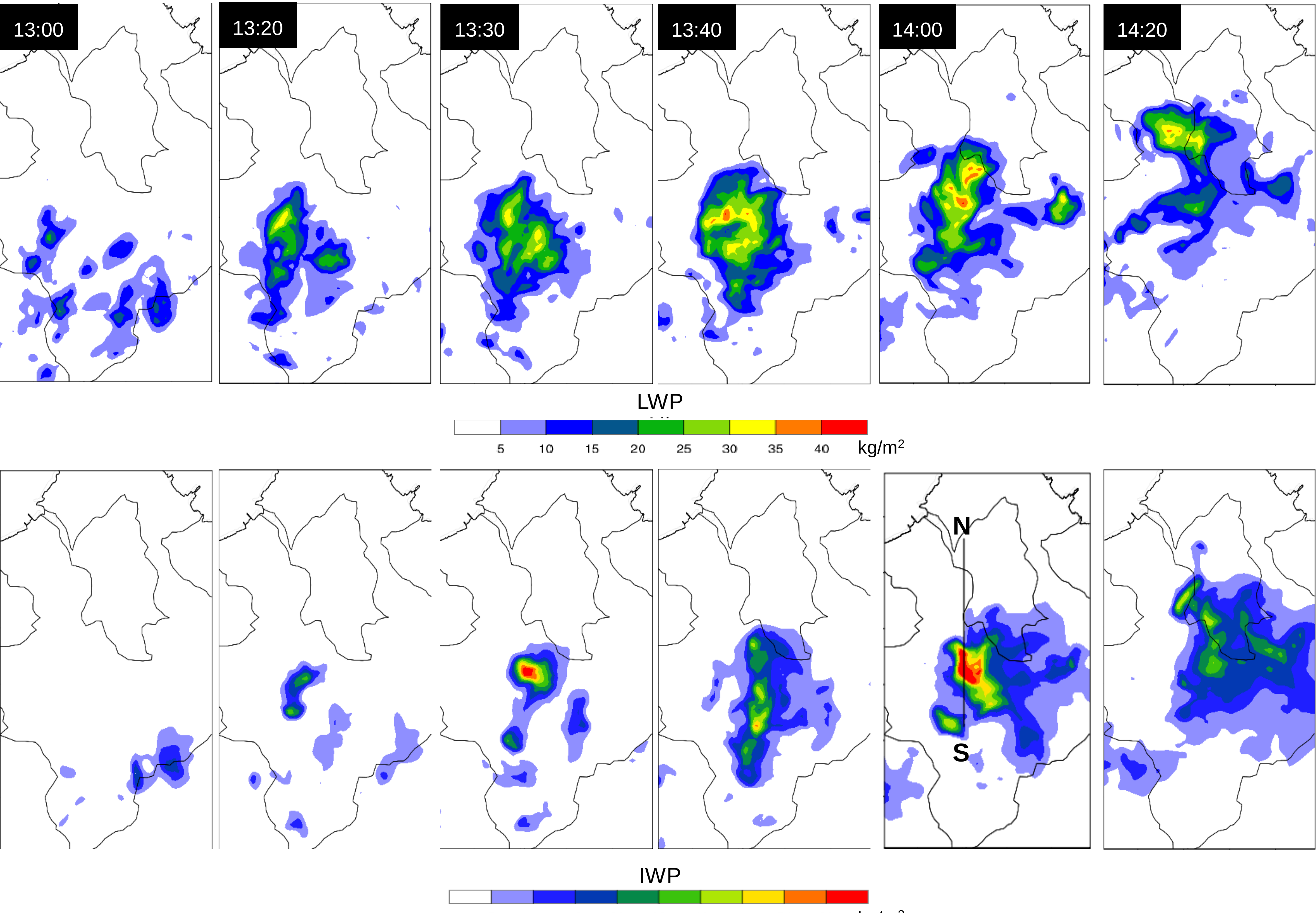
Near-surface moisture perturbation



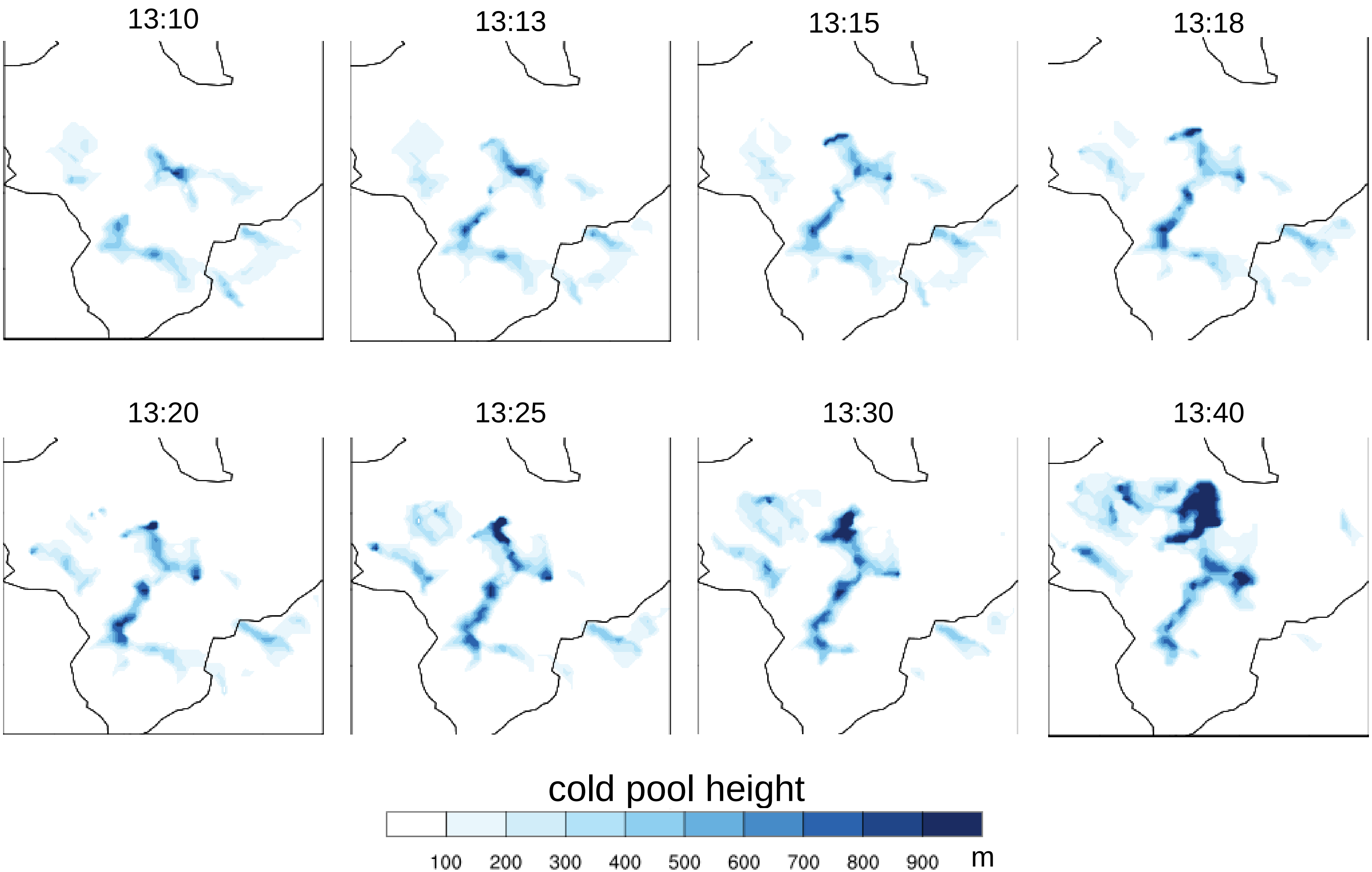
Cloud-based updraft and surface wind



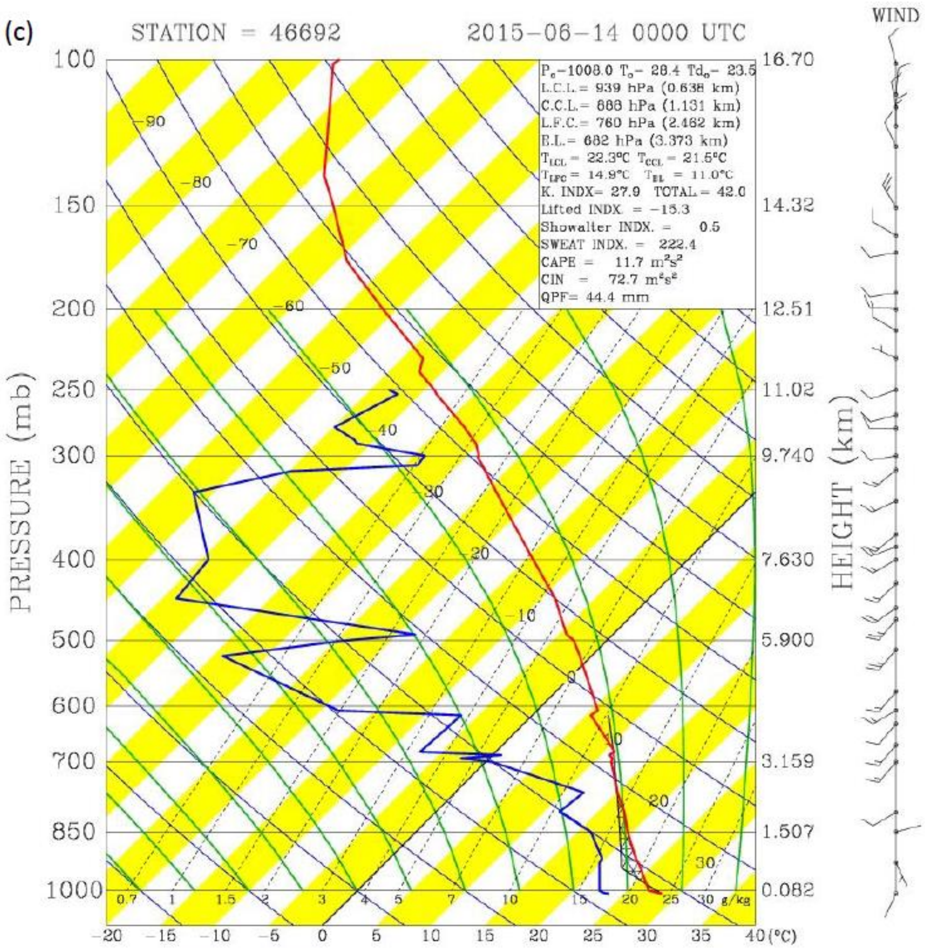
Near-surface horizontal vapor flux convergence



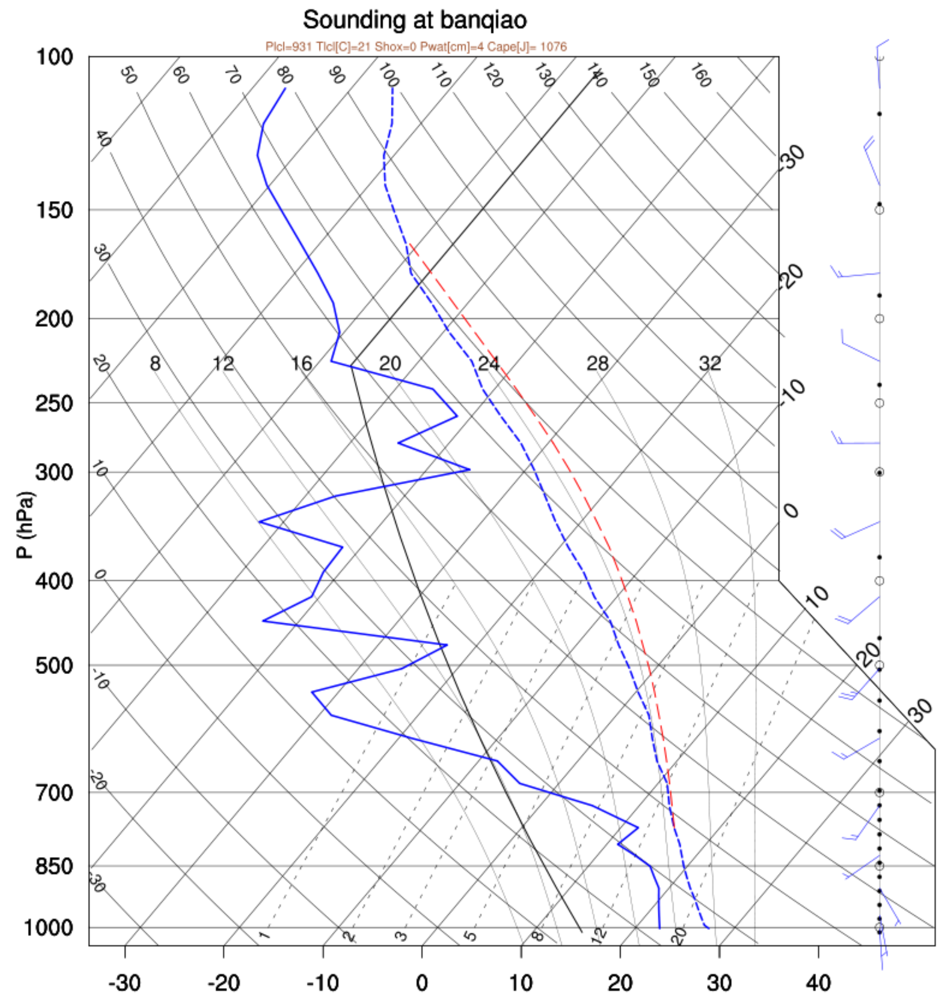
IWP significantly increased after cell merger!



Coldpool height elevated at intersecting cold pool boundaries!

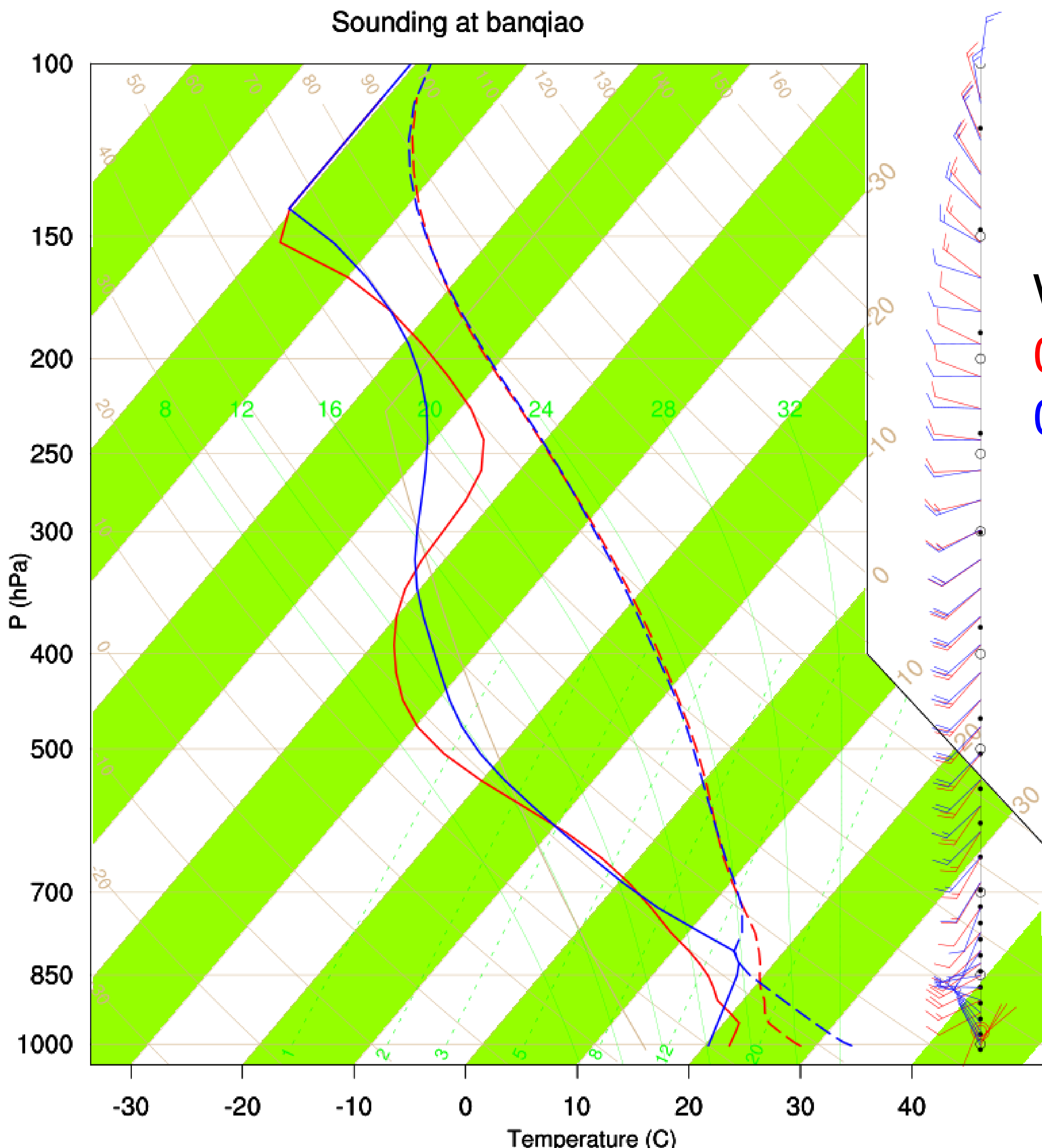


OBS Sounding: CAPE = 11 J/kg



Simulated Sounding: CAPE = 1076 J/kg

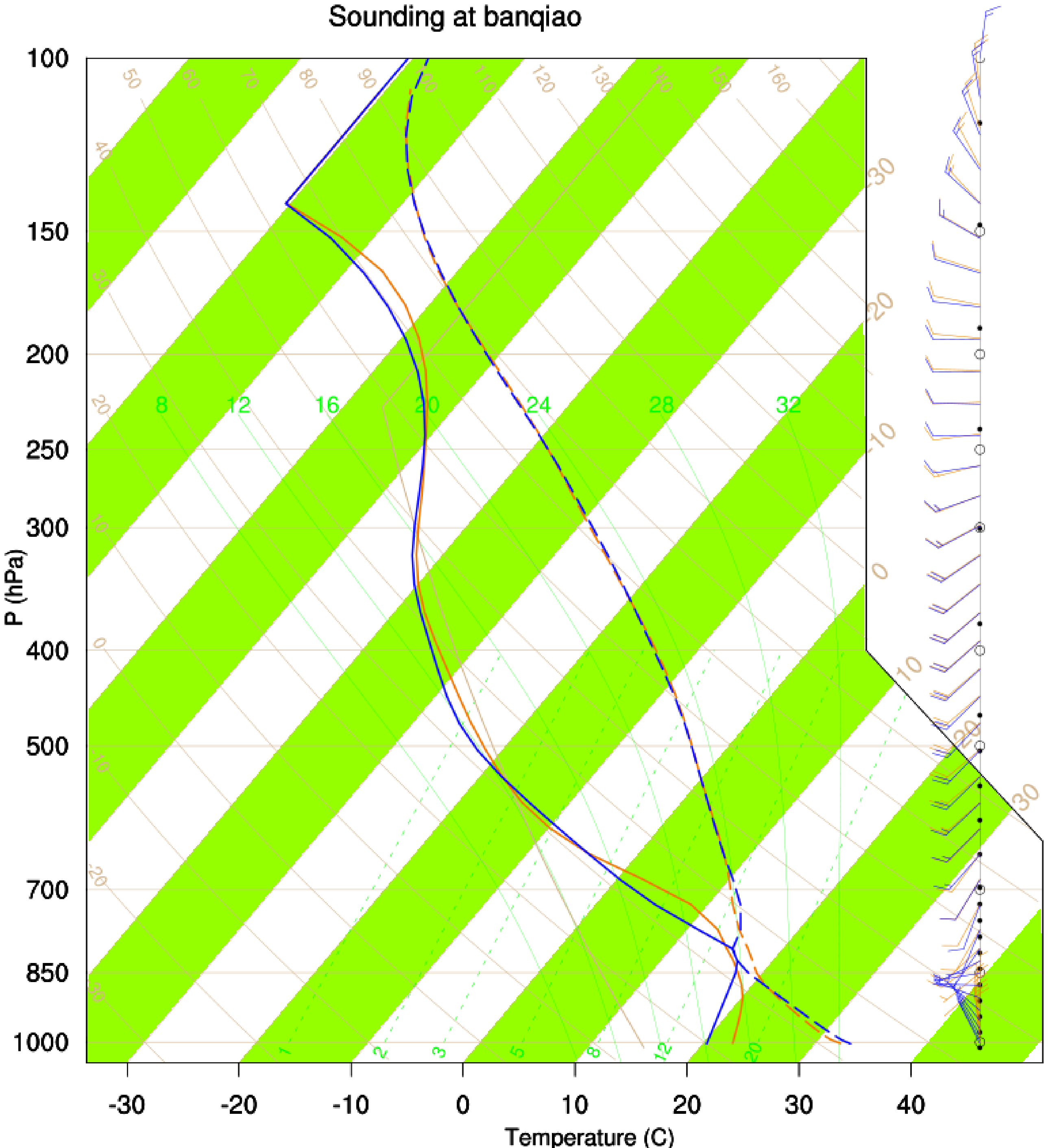
=> The inversion near 700hPa stops the CAPE calculation!



WRF板橋CAPE

00Z: 907 J/kg

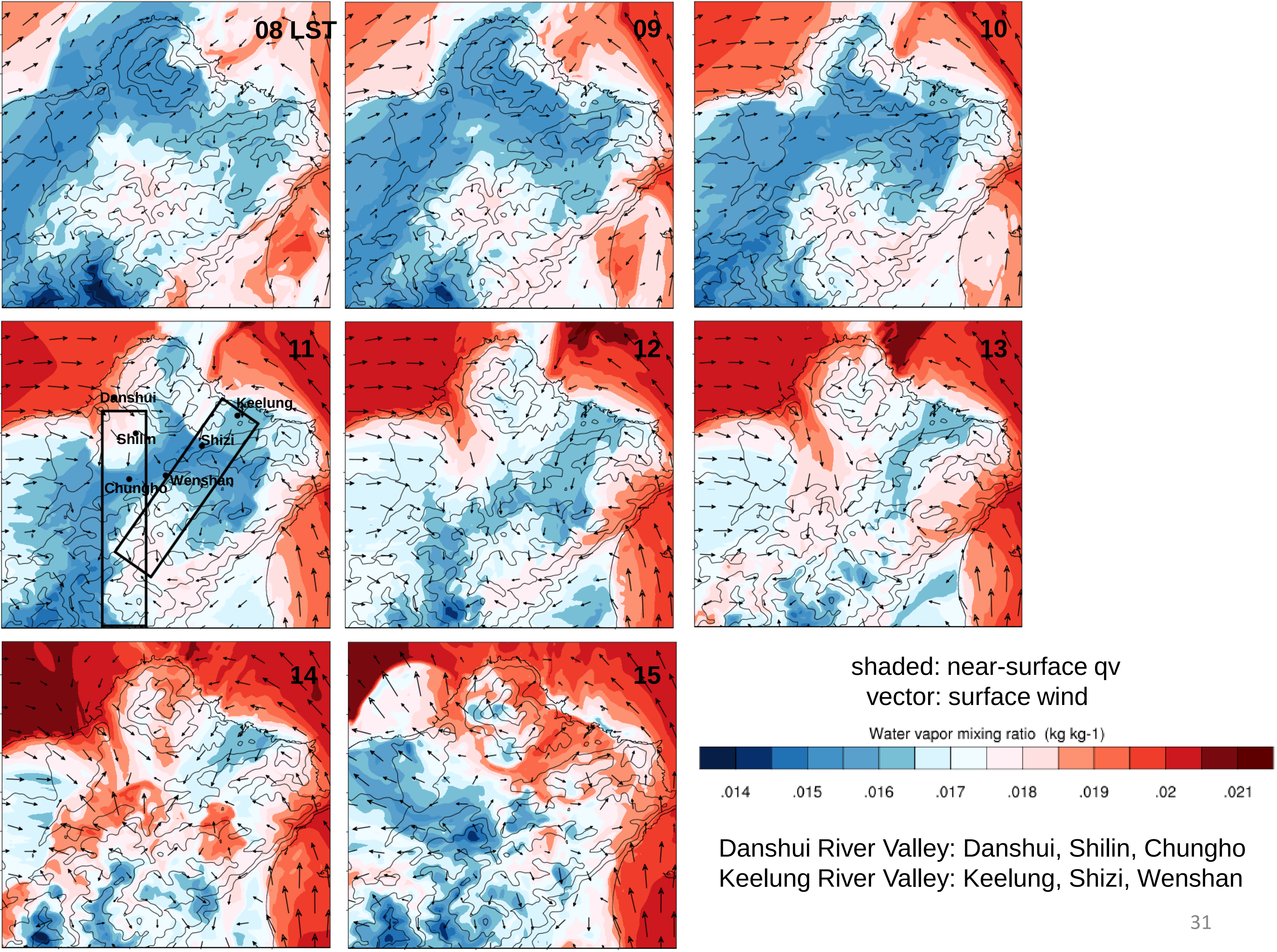
03Z: 1115 J/kg



WRF板橋CAPE

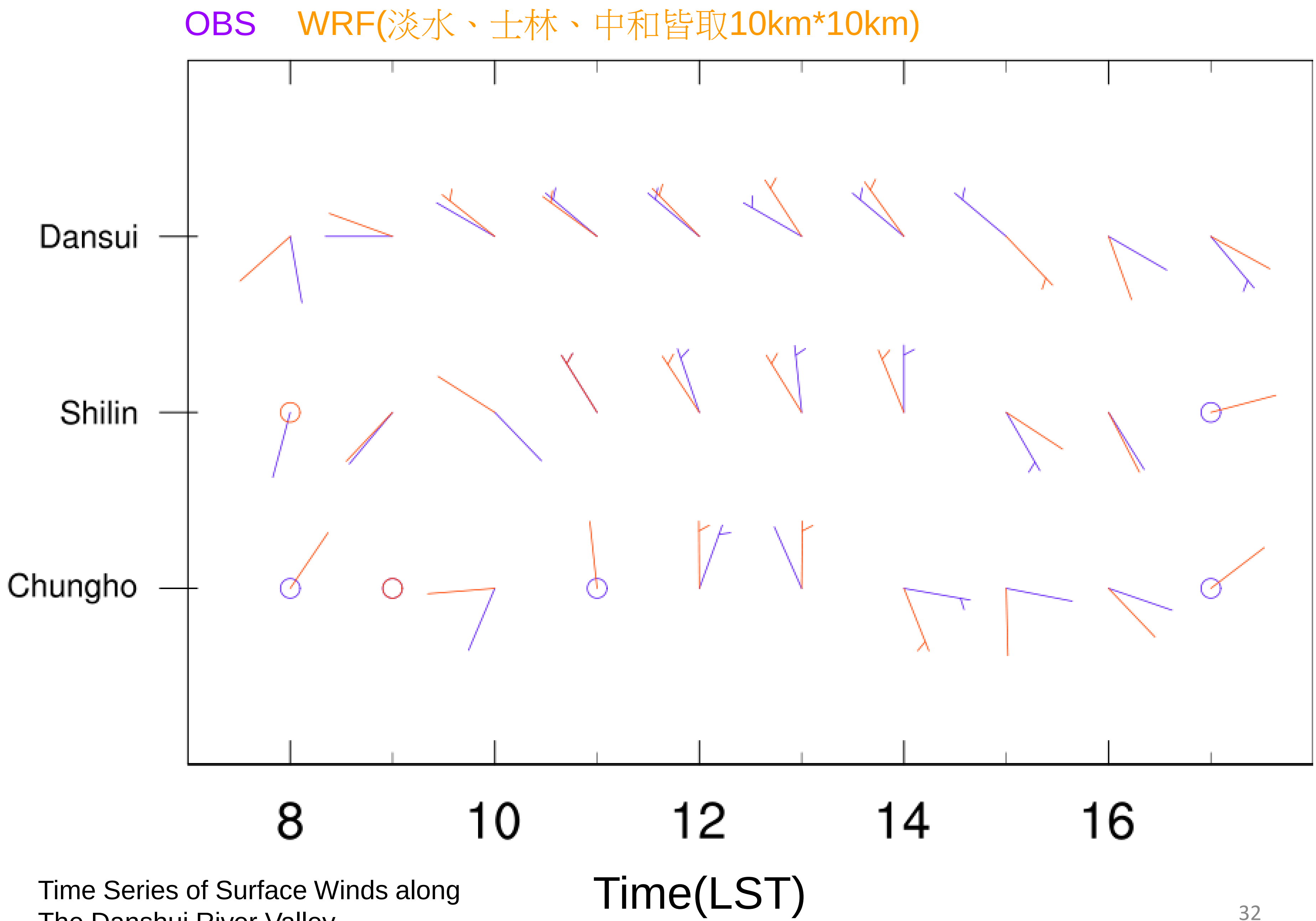
03Z: 1115 J/kg

04Z: 3339 J/kg

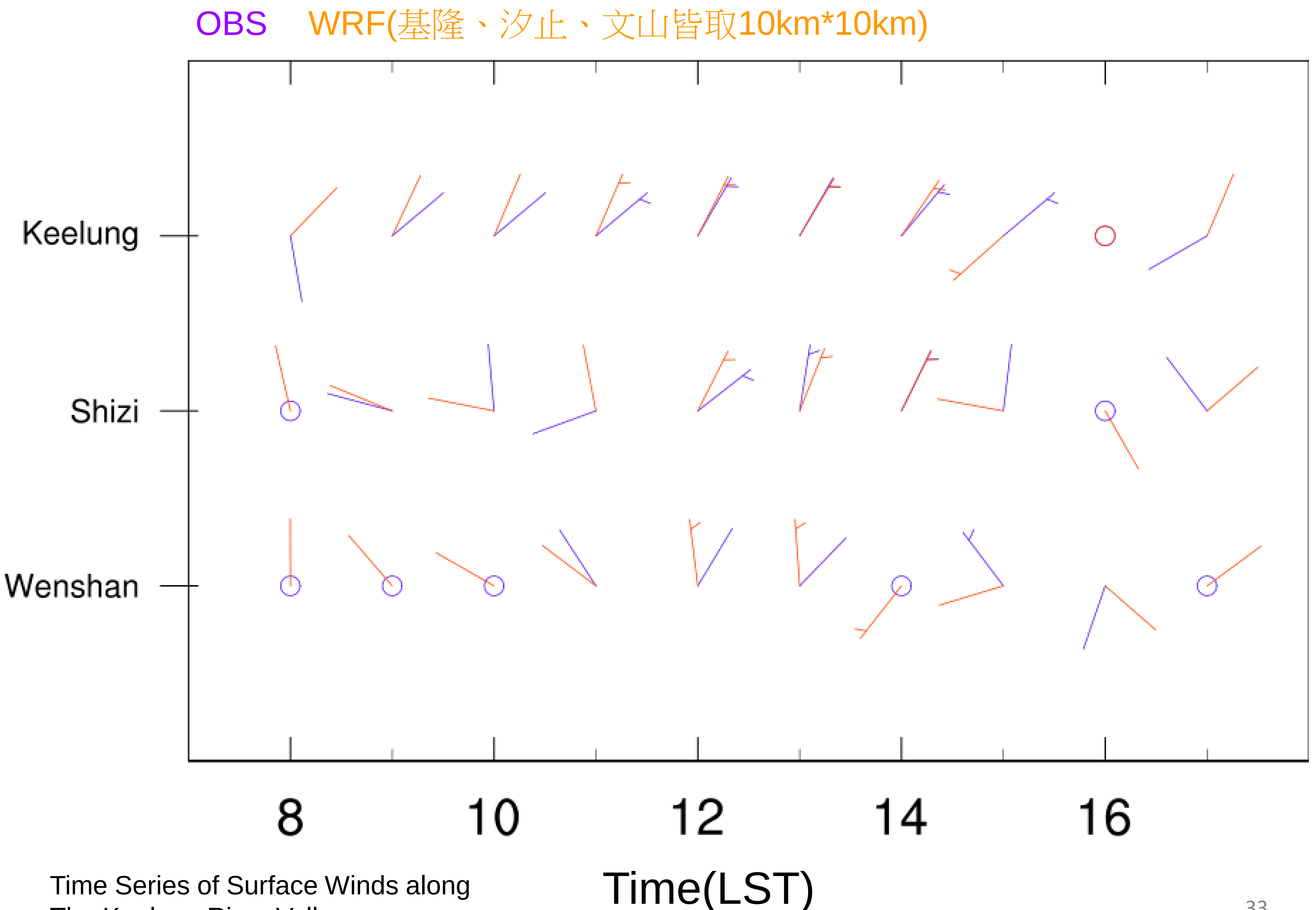


shaded: near-surface qv
vector: surface wind

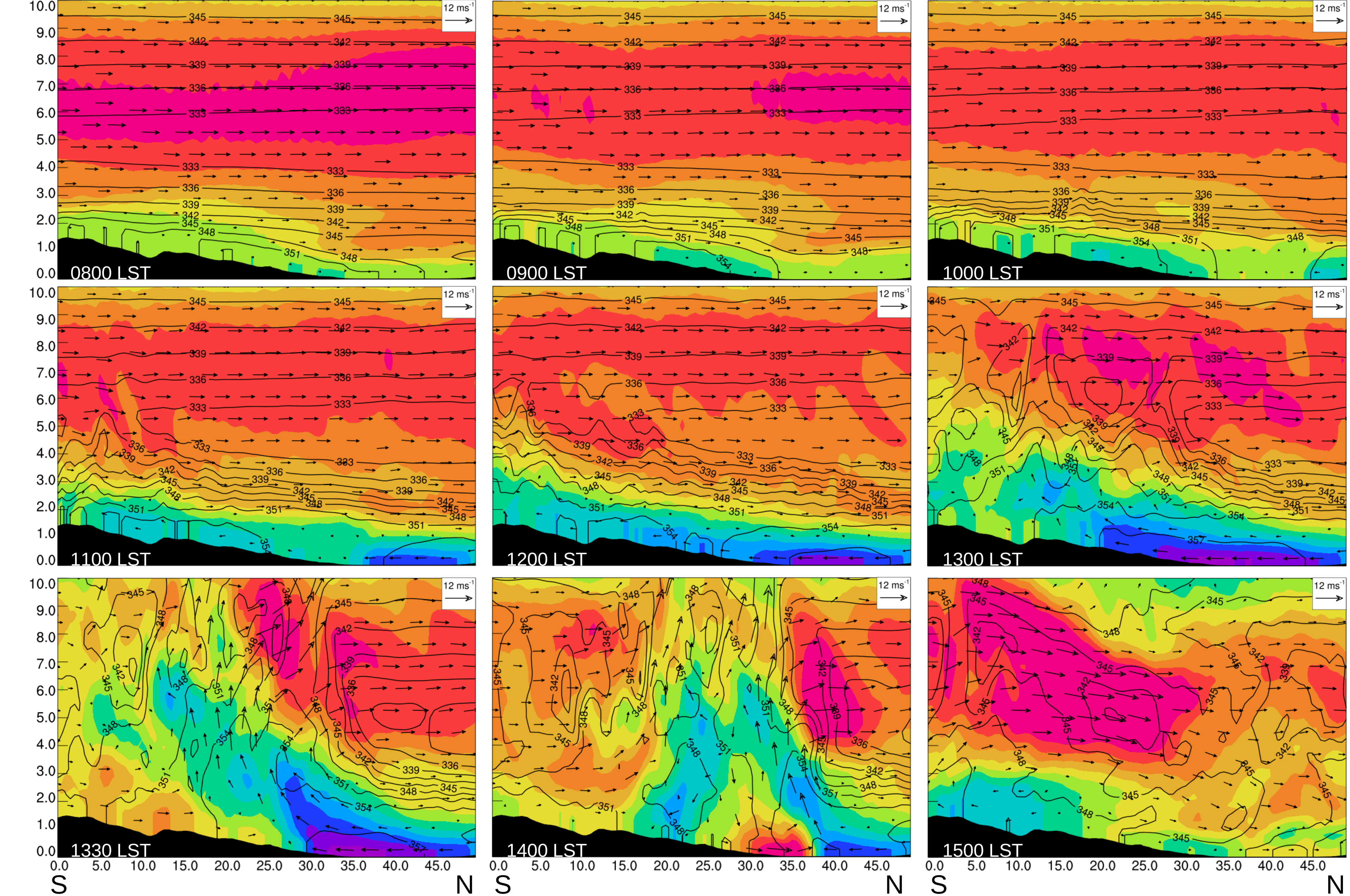
Danshui River Valley: Danshui, Shilin, Chungho
Keelung River Valley: Keelung, Shizi, Wenshan



Time Series of Surface Winds along
The Danshui River Valley



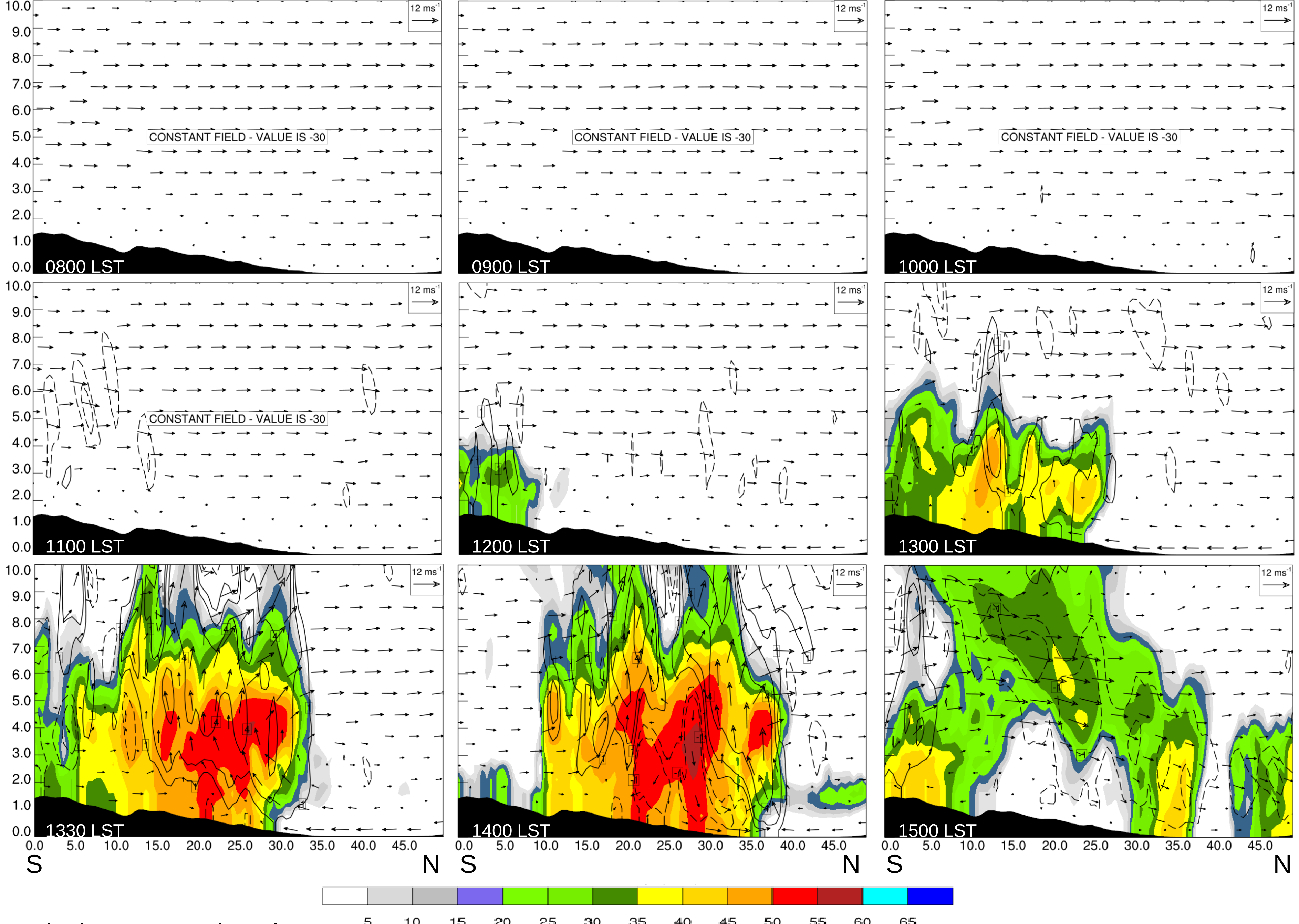
Time Series of Surface Winds along
The Keelung River Valley



Vertical Cross Section along the Danshui River Valley

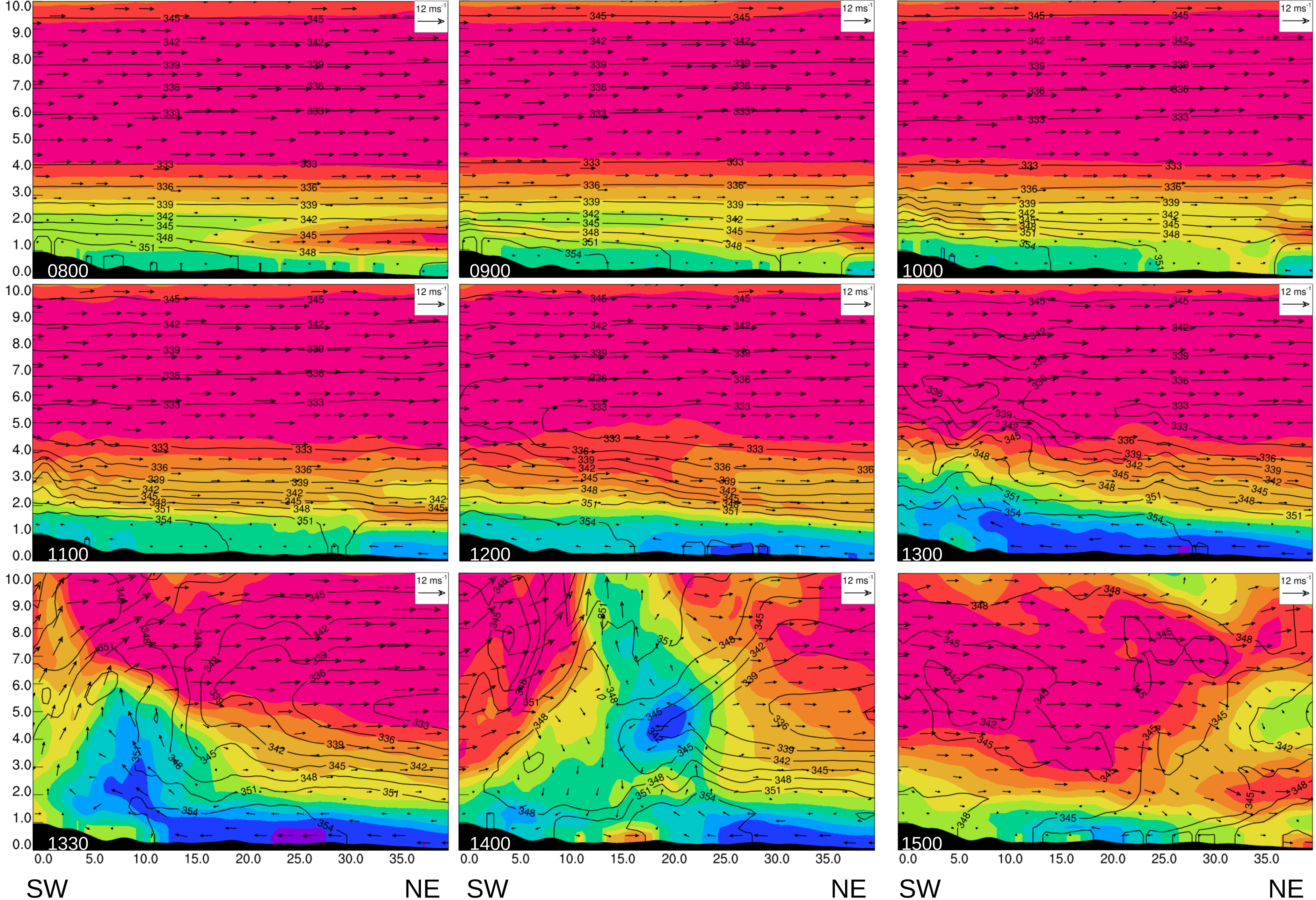
北風 -7.5 -6 -4.5 -3 -1.5 0 1.5 3 4.5 6 7.5 南風

shaded: v(南北風)
contour: 相當位溫(每3K)



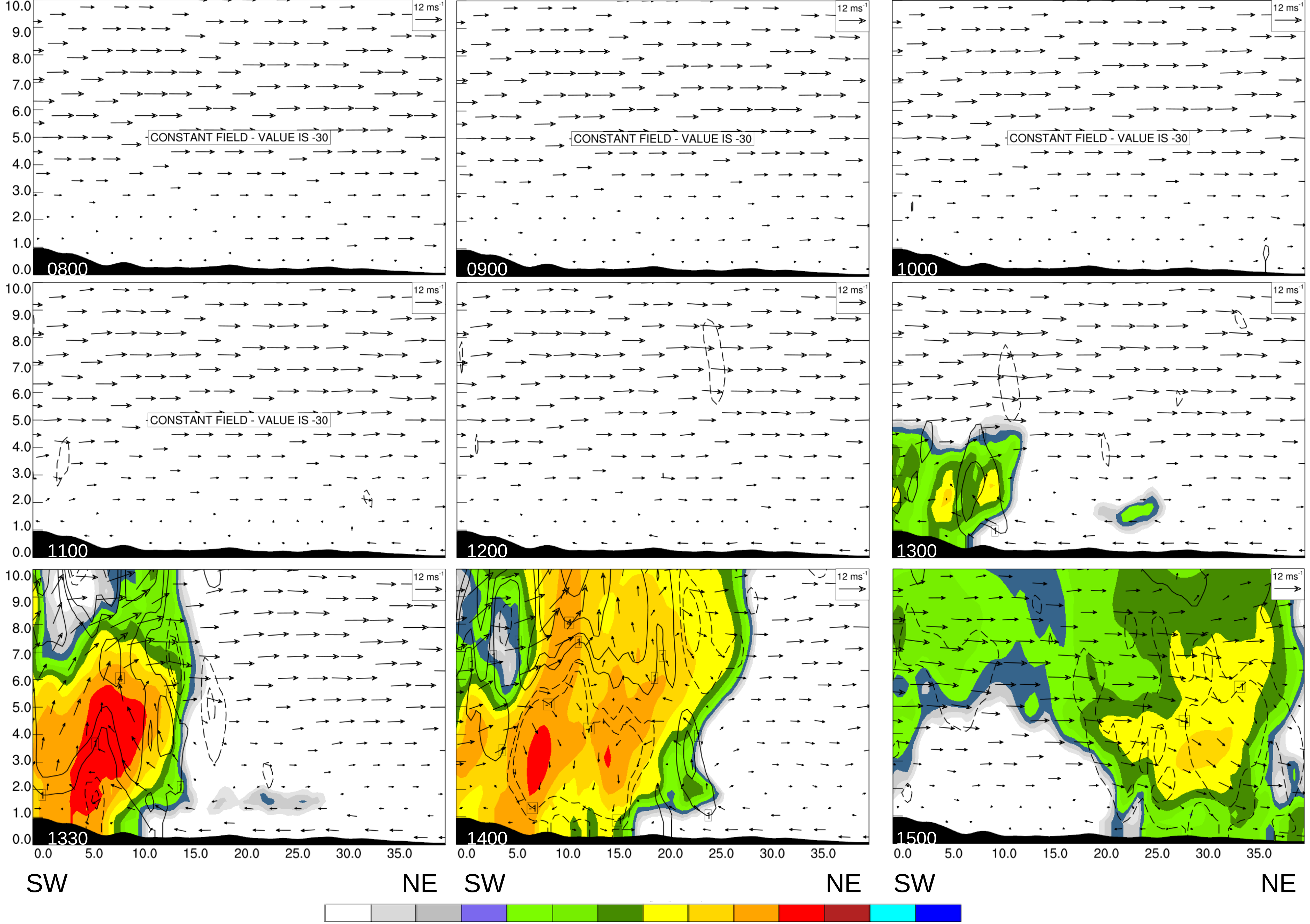
Vertical Cross Section along the Danshui River Valley

w contours: { -1,2,4,8 } m/s, shading: reflectivity



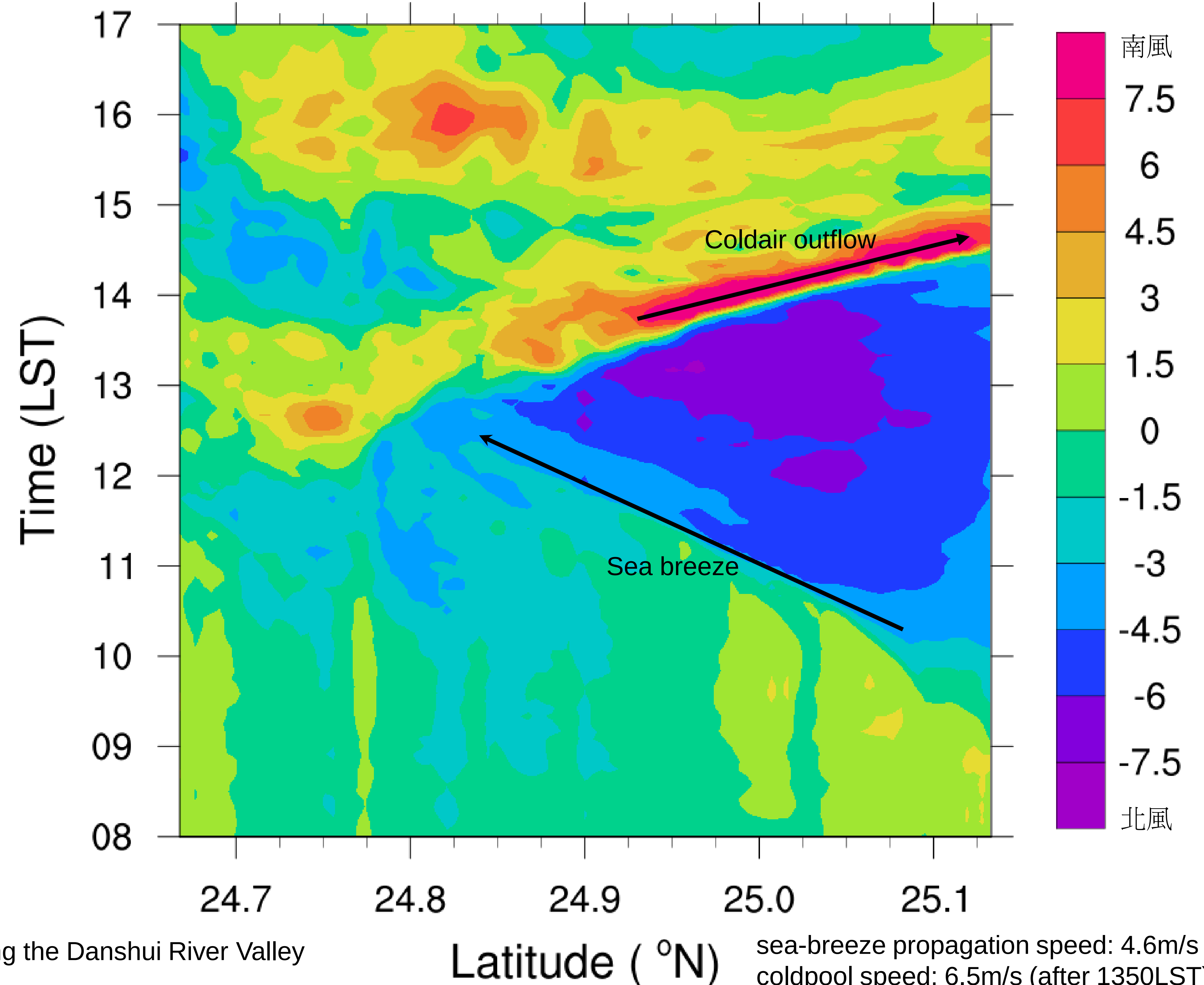
shaded: 東北-西南風
contour: 相當位溫(每3K)

Vertical Cross Section along the Keelung River Valley



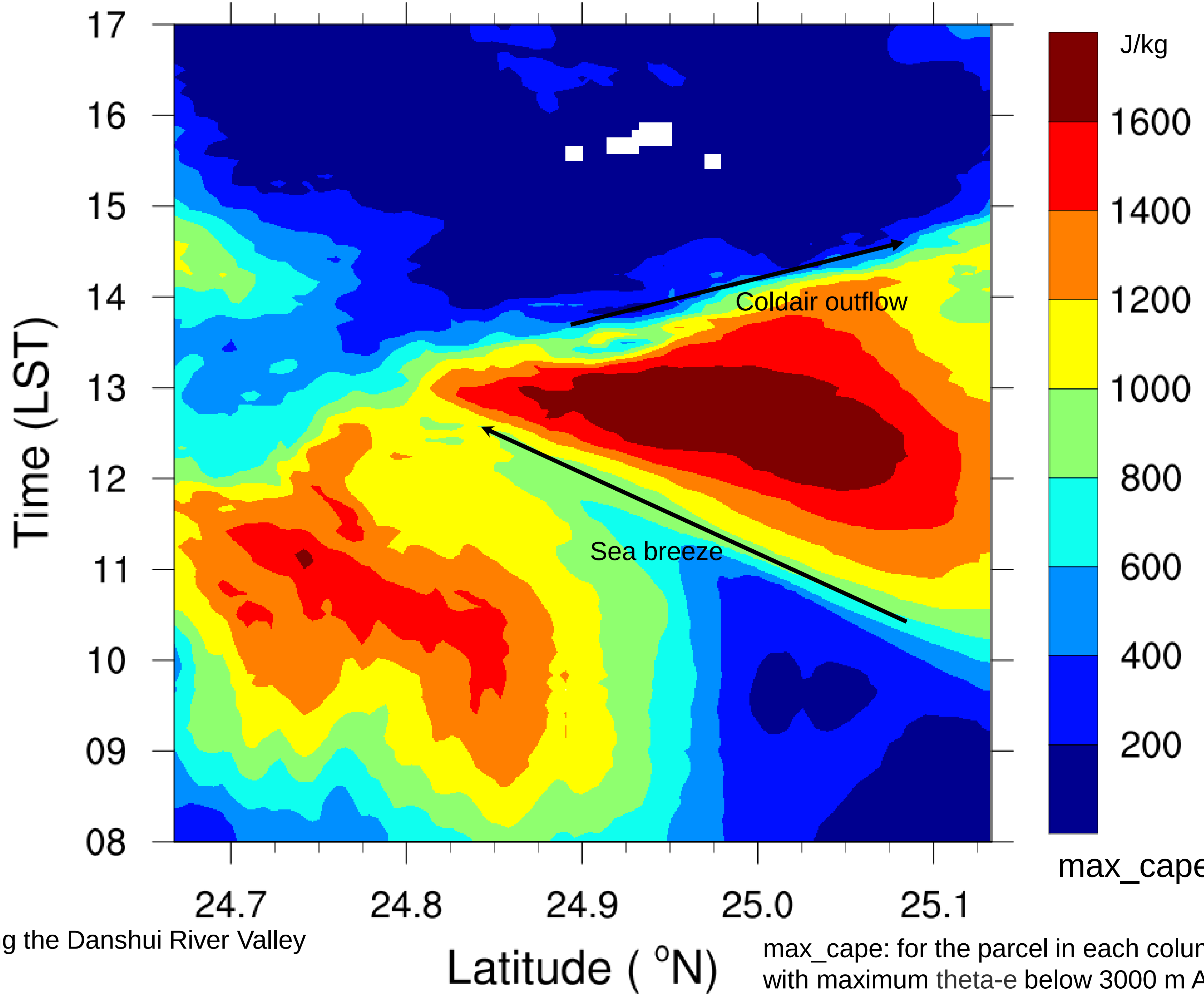
Vertical Cross Section along the Danshui River Valley

w contours: { -1,2,4,8 } m/s, shading: reflectivity



Along the Danshui River Valley

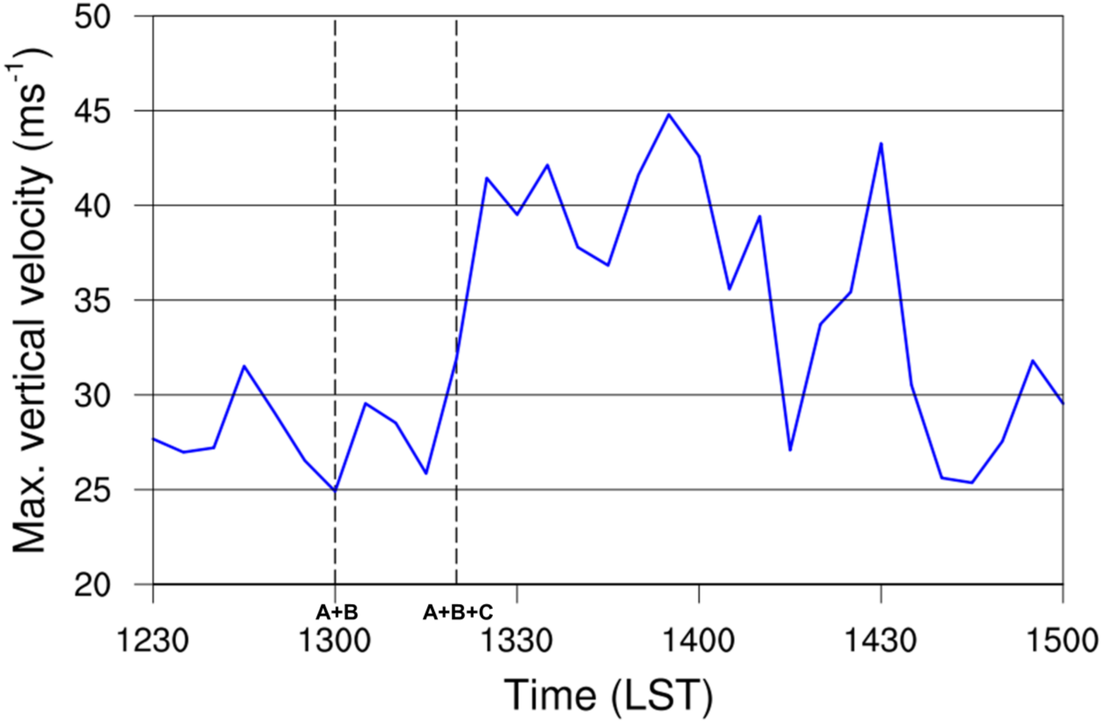
sea-breeze propagation speed: 4.6m/s
coldpool speed: 6.5m/s (after 1350LST)

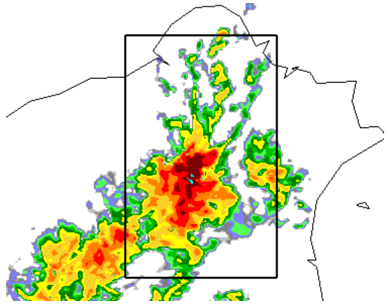


Along the Danshui River Valley

max_cape: for the parcel in each column with maximum theta-e below 3000 m AGL

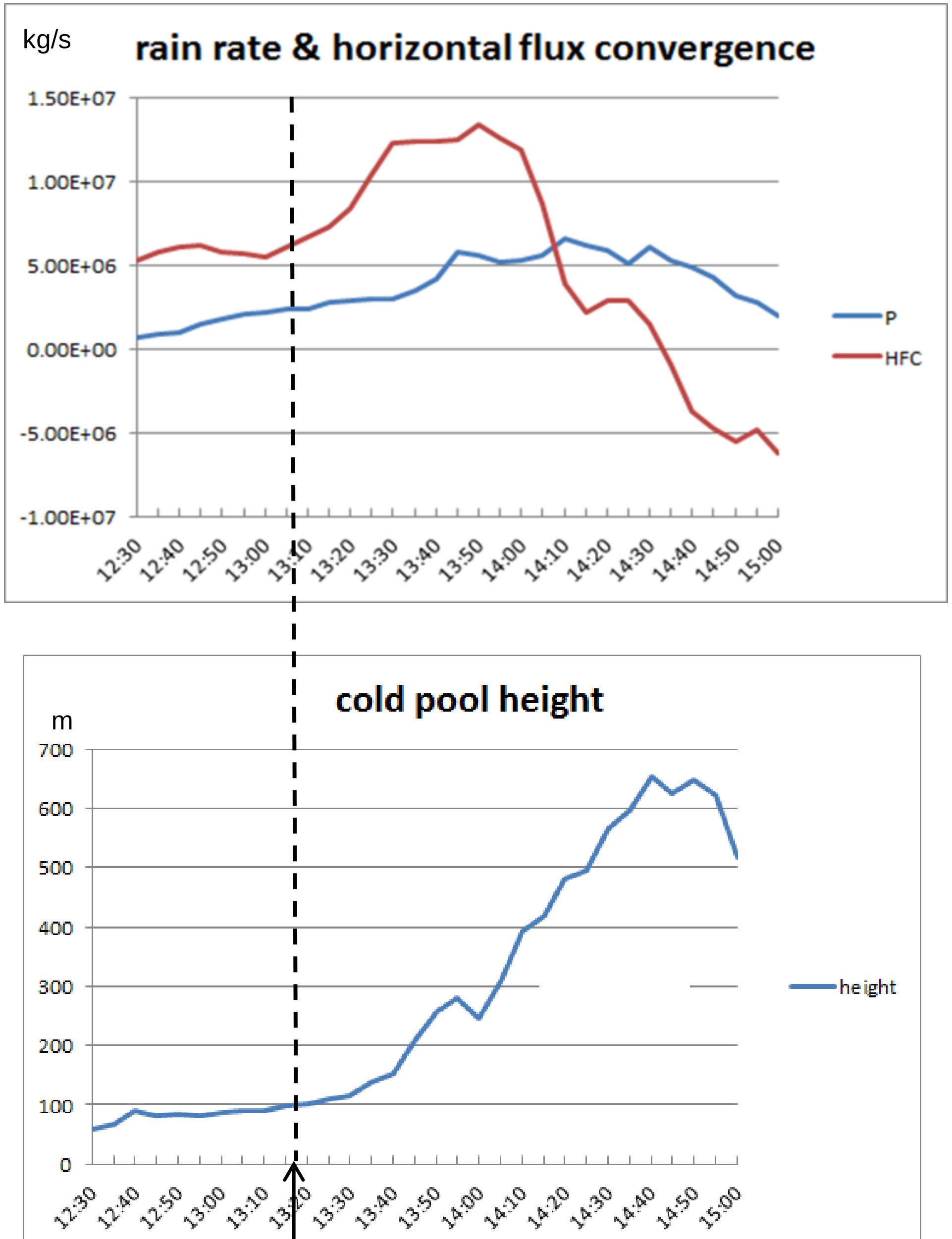
Time series of maximum vertical velocity within the Taipei Basin



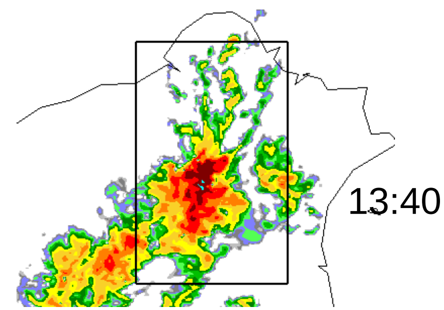


=> Maximum updraft reaches 45 m/s, almost supercell intensity!

Basin-mean Time Series

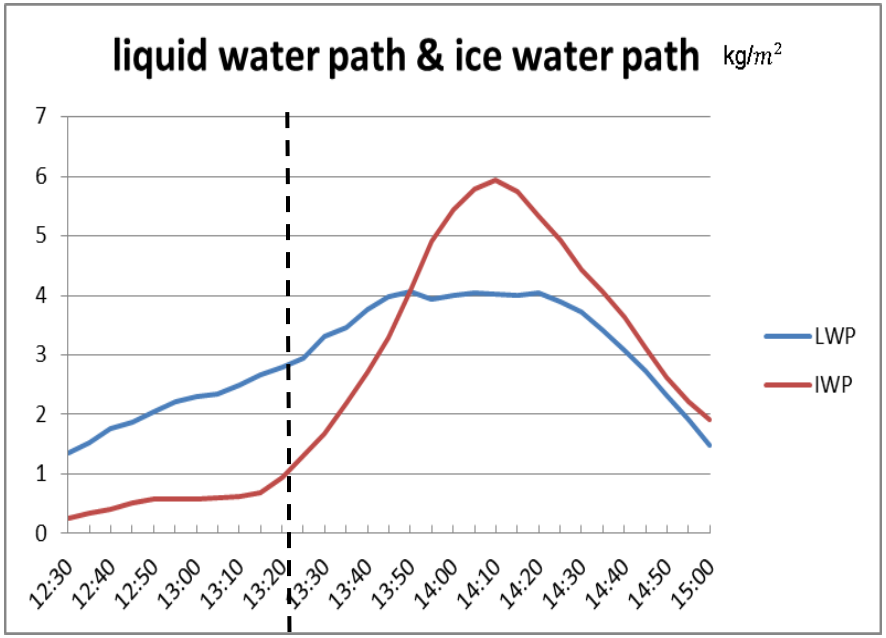


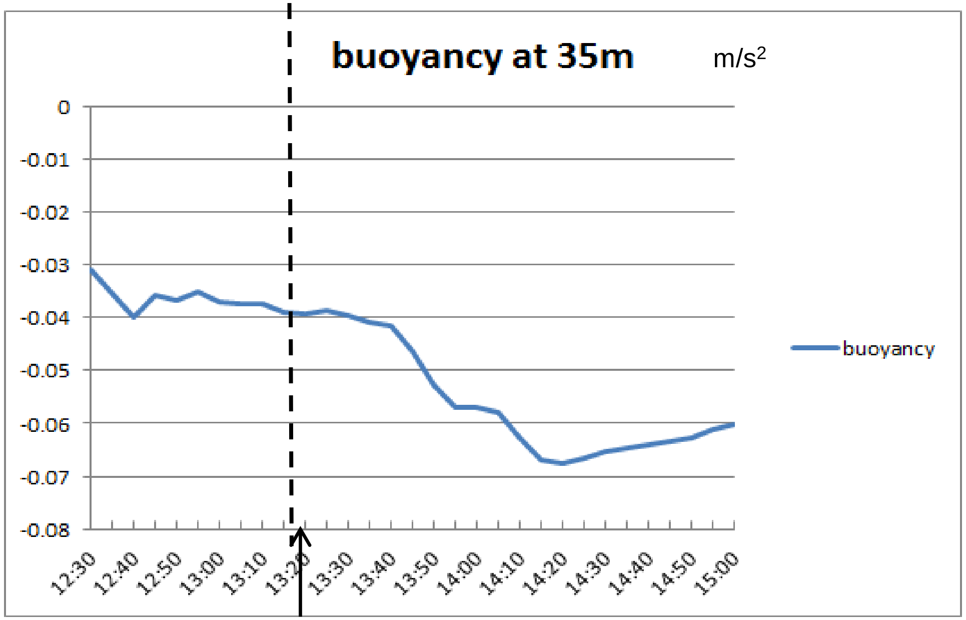
Cell merger



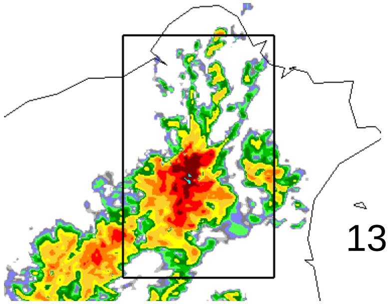
Area:37.5km x 60km

Basin-mean Time Series





Cell merger

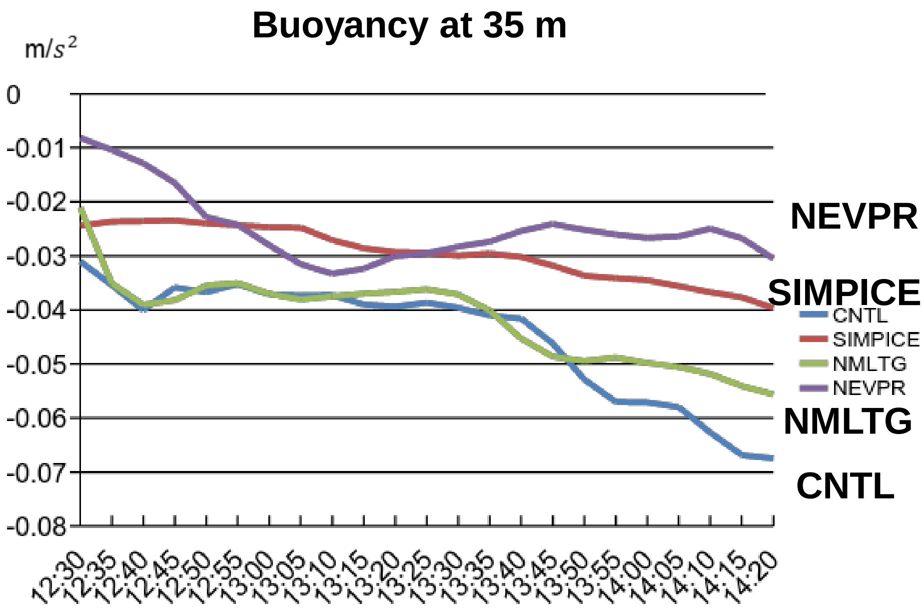


Area:37.5km x 60km

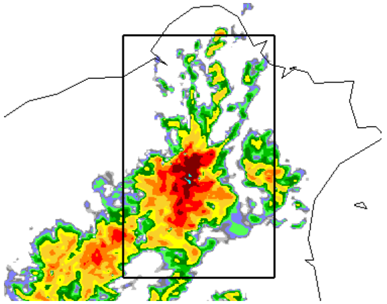
Numerical Experiments

Experiment	Comments
CNTL	full physics
NEVPR	no evaporation cooling of rainwater
NMLTG	no melting cooling of graupel
SIMPICE	simple ice (no mixed phase, no graupel)

Coldpool Characteristics by the Basin-mean Time Series

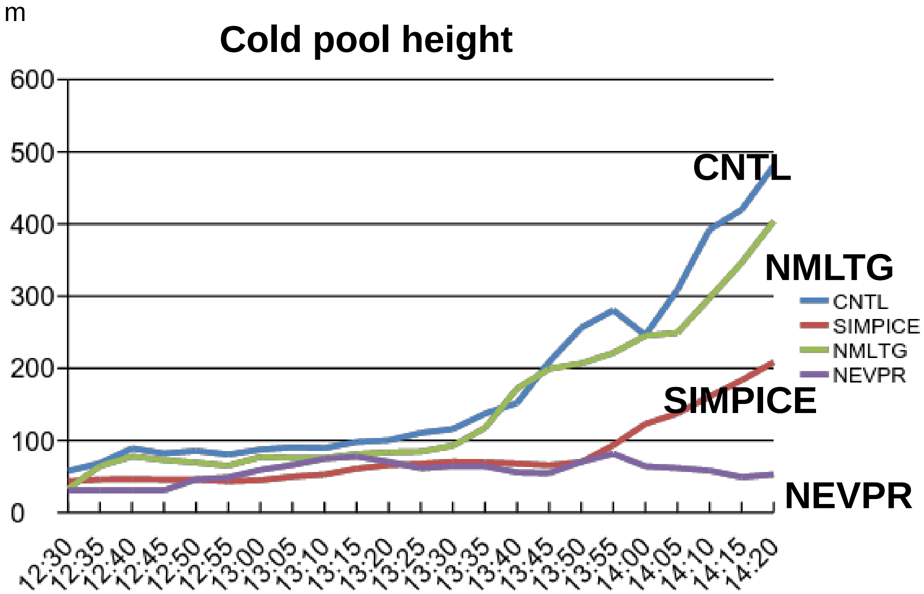


CNTL: full physics
SIMPICE: simple ice
NMLTG: no melting cooling of graupel
NEVPR: no evaporation cooling of rainwater

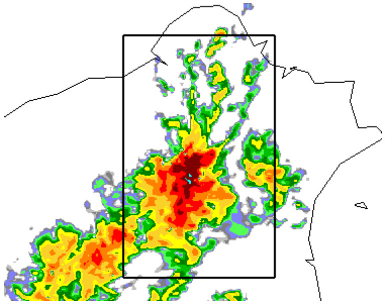


Area:37.5km x 60km

Coldpool Characteristics by the Basin-mean Time Series

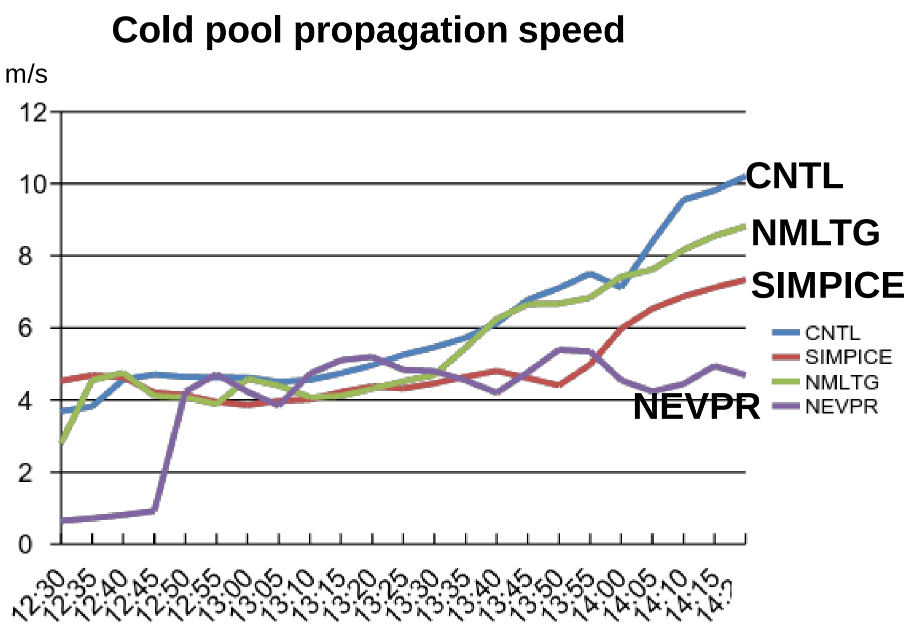


CNTL: full physics
SIMPICE: simple ice
NMLTG: no melting cooling of graupel
NEVPR: no evaporation cooling of rainwater

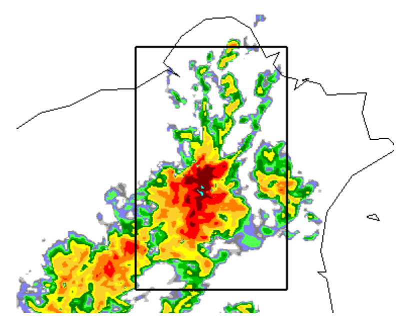


Area:37.5km x 60km

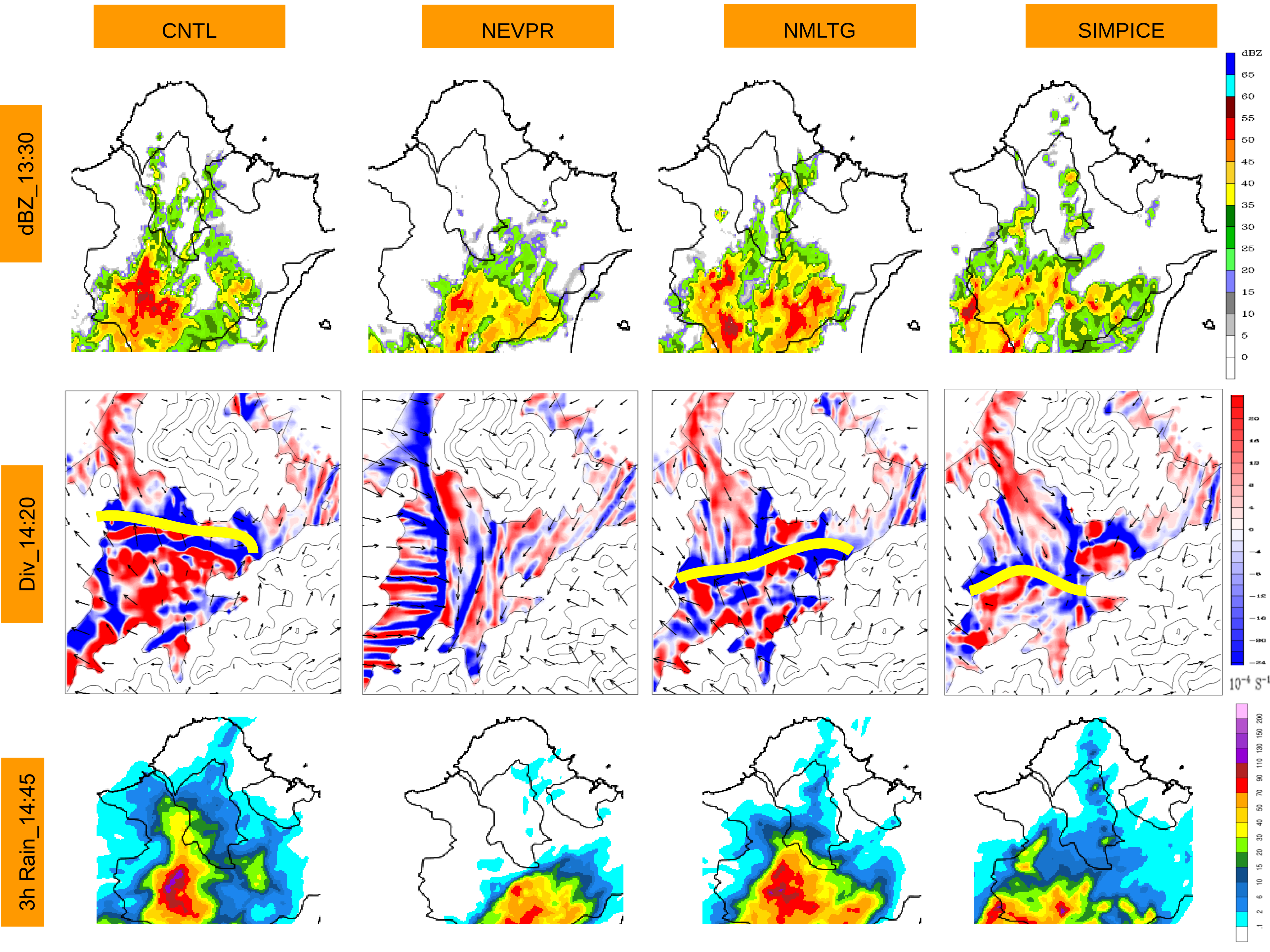
Coldpool Characteristics by the Basin-mean Time Series



CNTL: full physics
SIMPICE: simple ice
NMLTG: no melting cooling of graupe
NEVPR: no evaporation cooling of rainwater



Area:37.5km x 60km



CNTL
NEVPR
NMLTG
SIMPICE
dBZ_13:30
Div_14:20
3h Rain_14:45
dBZ
65
60
55
50
45
40
35
30
25
20
15
10
5
0
20
16
12
8
4
0
-4
-8
-12
-16
-20
-24
10^{-4} s^{-1}
200
150
130
110
90
70
50
40
30
20
15
10
6
2
.1

Conclusions

- Enhanced low-level convergence produced by sea breeze with abundant moisture triggered the development of this afternoon thunderstorm event.

- Water vapor horizontal flux convergence peak occurred earlier than surface rainrate peak by 20 minutes.

- Graupel amount was increased considerably after cell merger. Cold pool height was elevated significantly at the intersecting cold pool boundaries.

- Evaporation cooling played a major role in the propagation and intensification of cold outflow, while melting cooling played a minor role. However, mixed-phase microphysics was still important.

Thank you for listening