Short-Duration Flash Flood Storms in Taipei – A Challenge to Mega City Disaster Risk Reduction Management

BEN JONG-DAO JOU（周仲島教授）

Department of Atmospheric Science, National Taiwan University

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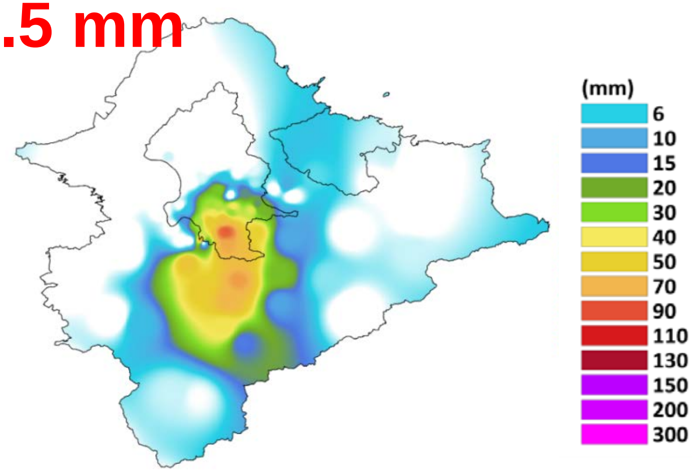
Flash floods/heavy rains and severe convective storms in Taipei

Case studied	Publications	Case description
14 June 2015	Jou et al. (2016), Atmos. Sci., 44, 57-82	193mm/3 hour rain was recorded; Cell merge is identified. Flash flood storm structure and polarimetric signatures are analyzed.
Storm prediction model development	Lin, Chang, Jou (2012a), WAF, 27, 1178-1197. (2012b) Atmos. Sci, 40	Objective prediction of warm season afternoon thunderstorm in Northern Taiwan using a fuzzy logic approach.
Climatology study	Lin et al. (2011) WAF, 26, 44-60	Warm Season Afternoon Thunderstorm Characteristics under Weak Synoptic-Scale Forcing over Taiwan Island. **Reflectivity climatological study.**
29 August 1999/Hail	Lin, Jou and Yu (2003), Atmos. Sci., 31, 122-142	Storm with heavy rain and hail (dual-Doppler wind synthesized). Enhanced convergence induced by sea breeze and the outflows from the pre-existing convection were identified.
21 June 1991	Jou (1994), TAO, 5, 169-197	Flash flood over SE and central districts of Taipei, 140mm/3 hour rain was recorded. The role of sea breeze on storm development was recognized by using single Doppler wind analysis.

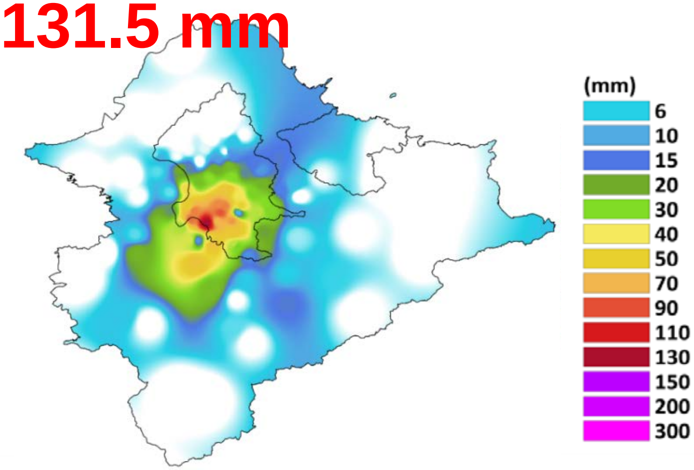
Taipei basin viewed from south and hot spots for severe rain storms

Cases of extreme heavy rain over Taipei in 2015

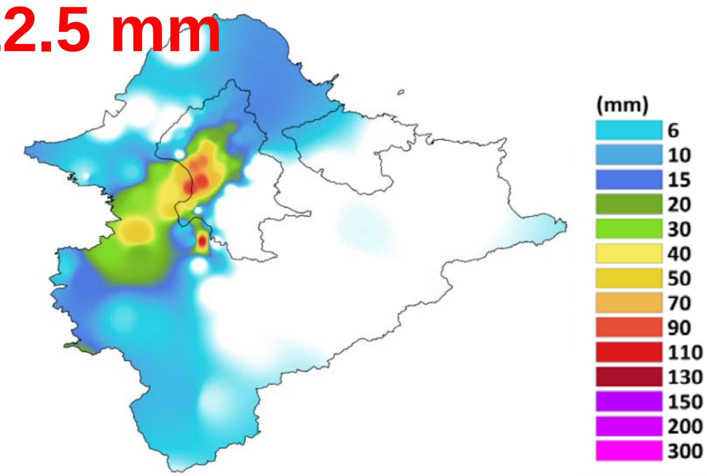
0607 14:50-15:50
89.5 mm



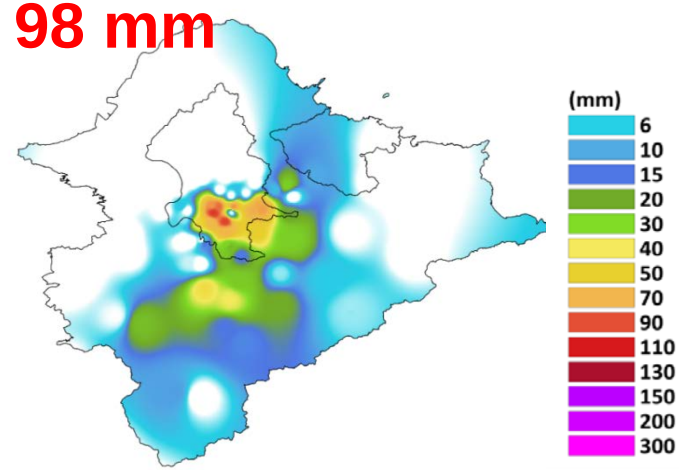
0614 14:30-15:30
131.5 mm



0723 12:50-13:50
112.5 mm



0818 14:50-15:50
98 mm



Taken from
Kuo HC

Rank	Date (May-Sep, 1992-2013)	3-h rainfall in mm (Taipei)	Weather systems
1	2004/9/11	275.5	TD/Monsoon trough
2	2001/9/17	236.0	TC (Nari)
3	2004/8/24	233.5	TC
4	2001/9/5	227.5	TD/monsoon trough
5	1999/6/19	198.0	Meiyu front/MCS
6	2000/11/1	175.5	TC
7	1998/10/15	166.0	TC
8	1997/8/18	163.0	TC
9	2007/10/6	162.0	TC
10	2012/8/2	160.5	TC
11	2009/9/28	157.5	TC/NE monsoon
12	2006/6/10	157.0	Meiyu front/MCS
13	2008/9/13	155.5	TC
14	2004/5/31	153.5	Meiyu front/MCS
15	2012/6/16	152.0	Meiyu front/MCS

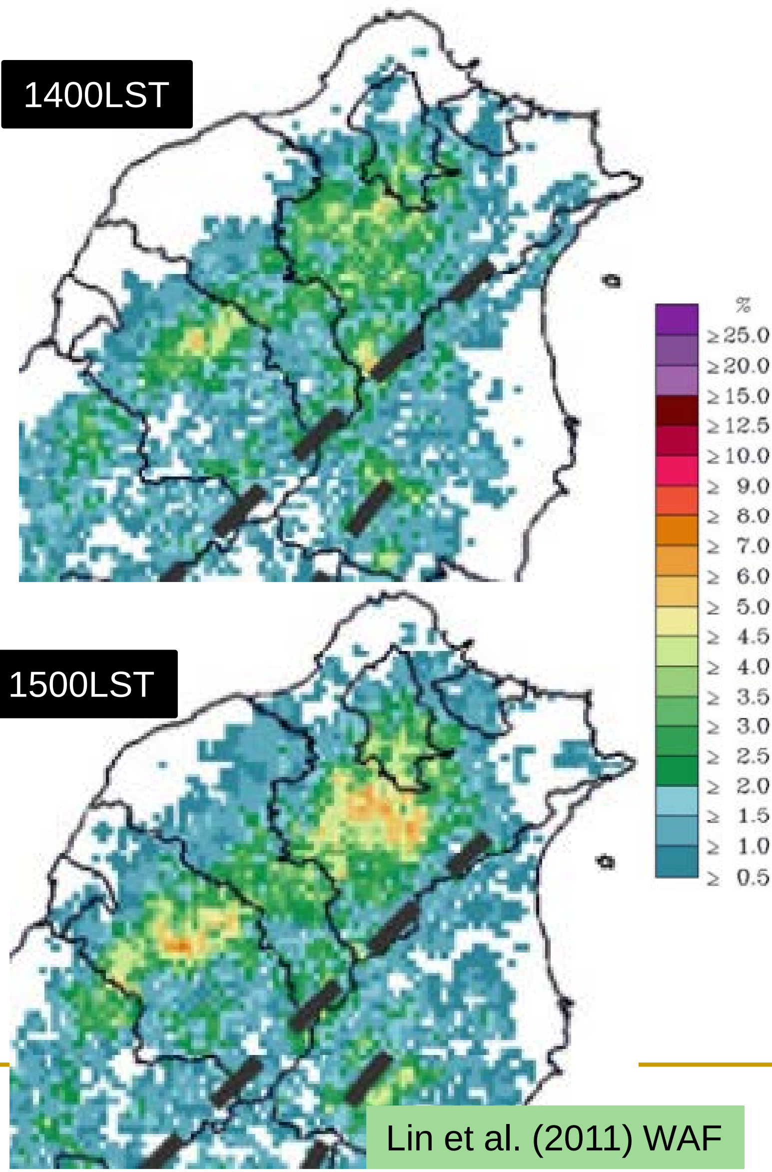
2015/6/14
193mm/3 hour
Afternoon thunderstorm complex

Table from NCDR

Introduction

- In recent years, **flash floods over mega cities** are becoming common, especially in the monsoon region. These urban flash floods sometimes cause un-expected disasters due to lack of in-time warning and poor emergency response.
- The urban flash floods are sometimes associated with complex feature of convective storm development. Merging several individual convective cells into one gigantic complex storm entity is frequently observed.
- The newly upgraded WSR-88D polarimetric radar system combining with dense mesoscale network can provide important information for the **formation and development** of the storm complexes.
- In this presentation, a case occurred in Taipei city (14 June 2015) is examined using polarimetric radar and mesoscale surface network. The formation mechanisms and **polarimetric signatures** from the flash flood storm are particularly emphasized.

Occurrence frequency (in percentage) of reflectivity larger than 40 dBZ in the summer season (May-September, 2001-2006)



Lin et al. (2011) WAF

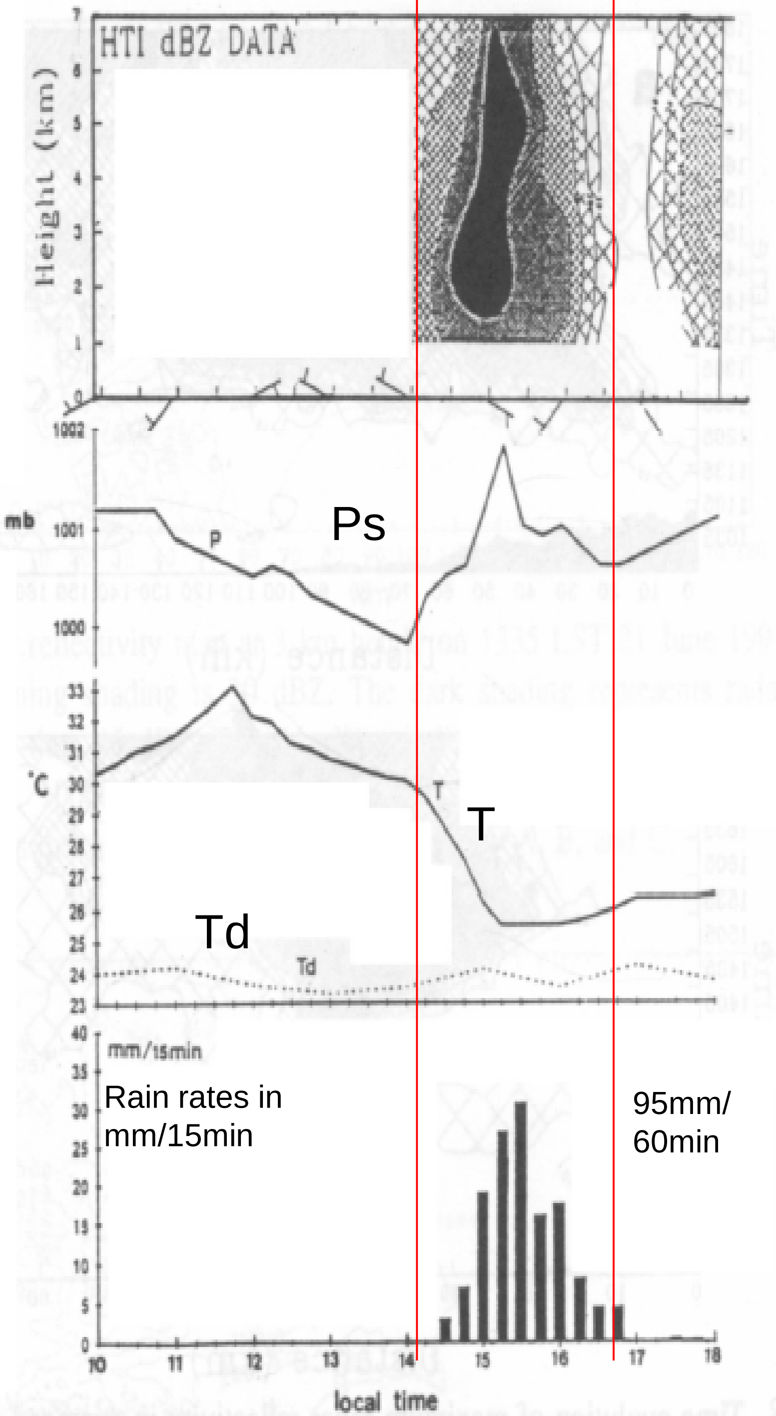
STATION	Hour	8	9	10	11	12	13
淡水 (46990)	VPRE(hpa)	29	30.5	31	31.5	31	31
		V	FALSE	FALSE	FALSE	FALSE	V
	HUMD(%)	74	70.5	69	67.5	67	67.5
		V	FALSE	FALSE	FALSE	FALSE	V
	WDIR(degree)	160	250	240	270	280	280
		190	310	310	310	320	320
		V	V	V	FALSE	V	V
	WDSD(m/s)	1.5	2	2	3.5	4.5	4.5
		V	V	FALSE	V	V	V
基隆 (46694)	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

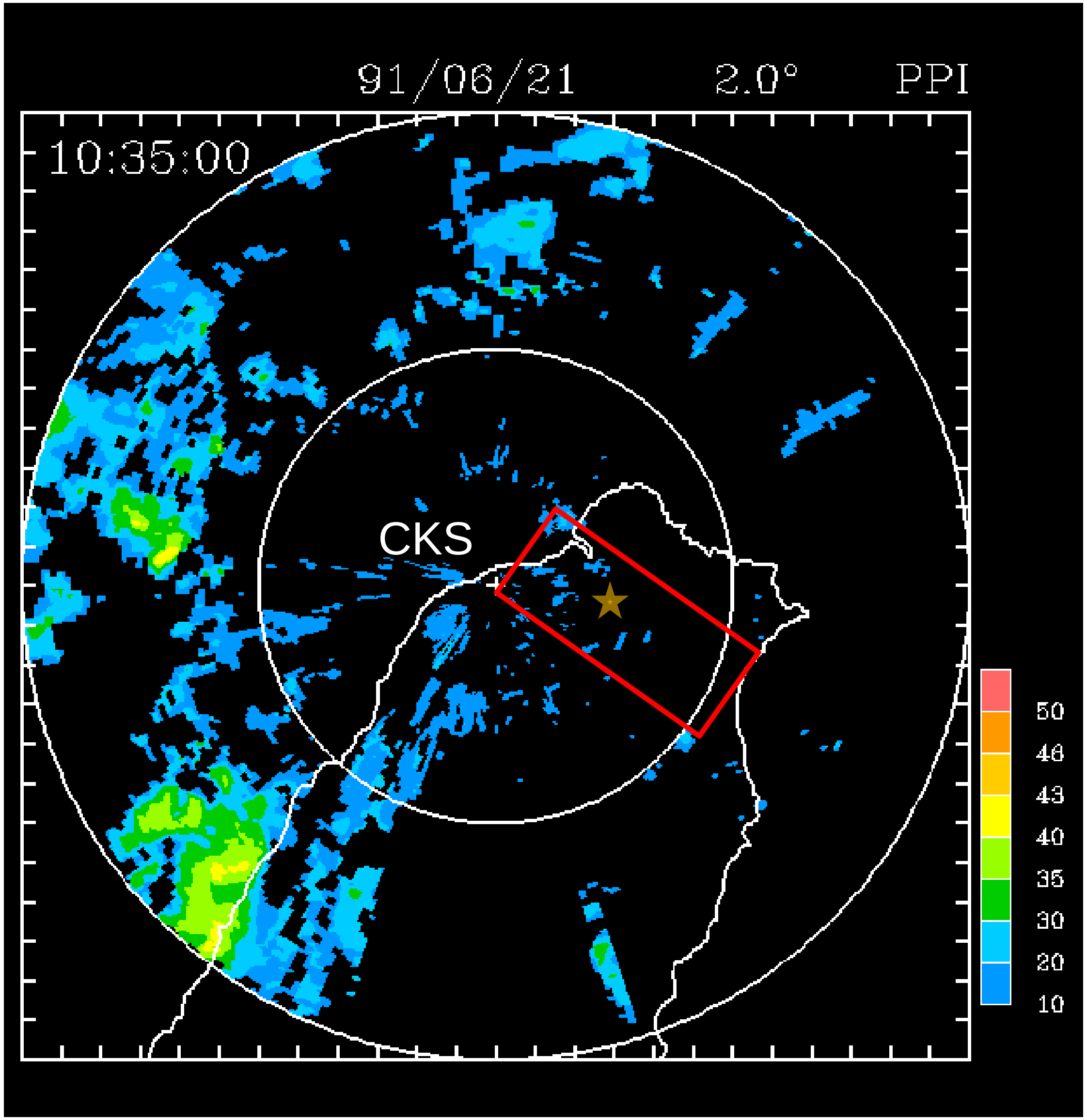
08LST	hpa	1000	925	850	700	500
板橋探空	CAPE	>500				
		X				
	T-Td	<4	<4	<6	<9.5	<11
		X	X	V	X	X
	WDIR	210	230-280	220-280	200-270	200-250
		V	X	X	V	V
	WDSD	<1.5	<4	<4.5	<6.5	<6.5
		V	V	V	V	X
		2	1	2	2	1

20150614

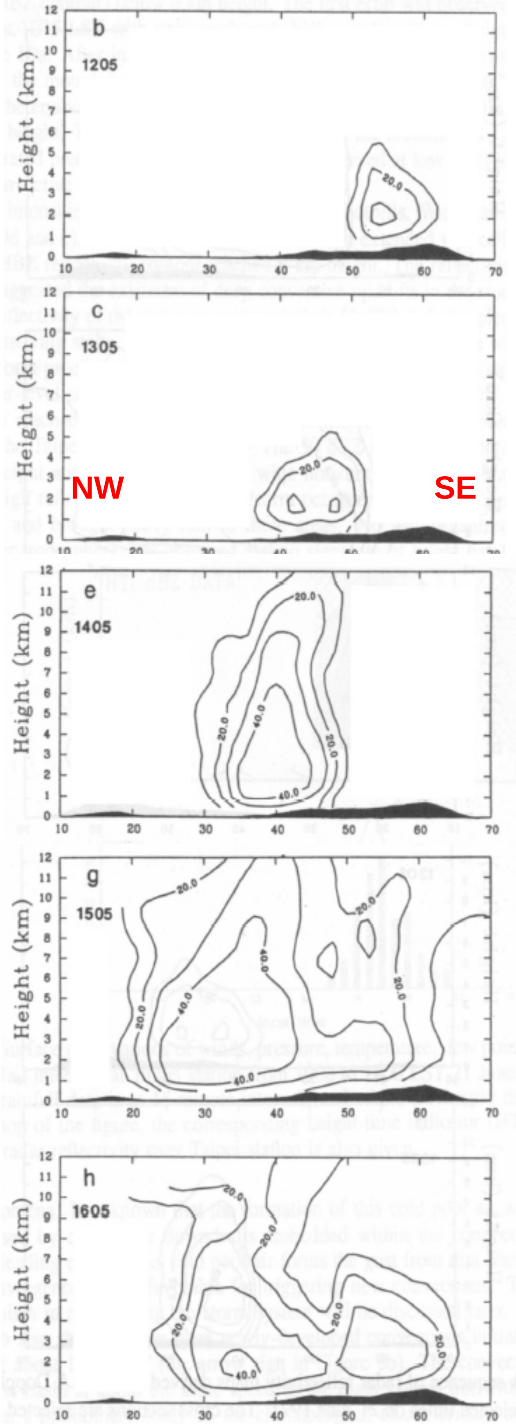
Lin et al. (2012) WAF

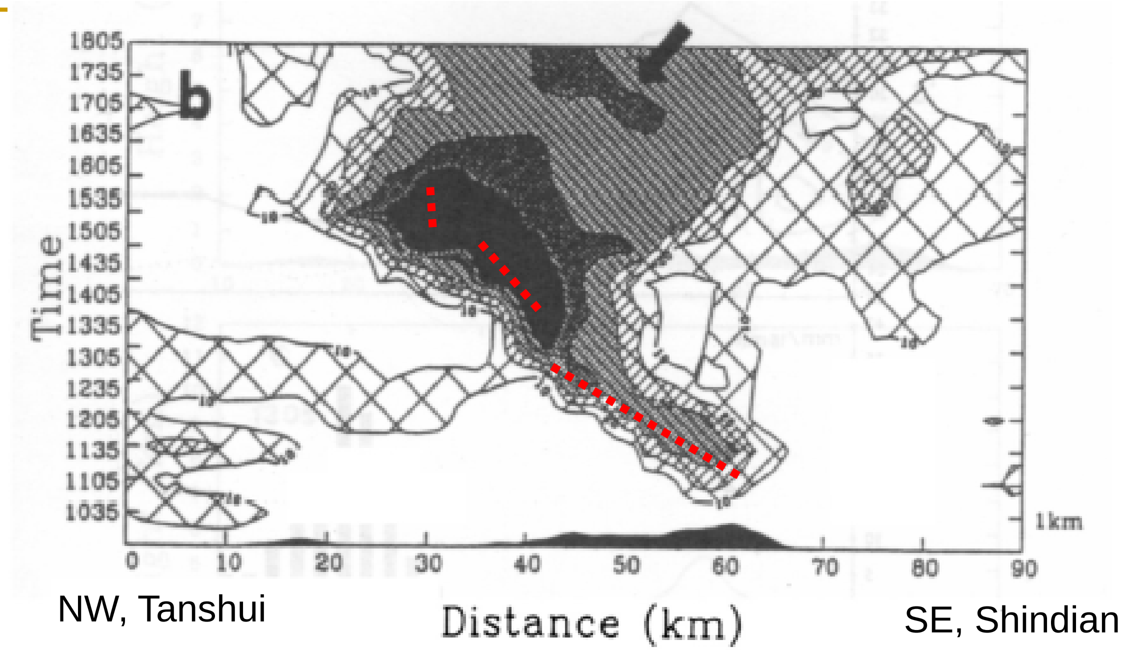
Late afternoon organized convection and flash flood in Taipei (1991/6/21) (Jou 1994)

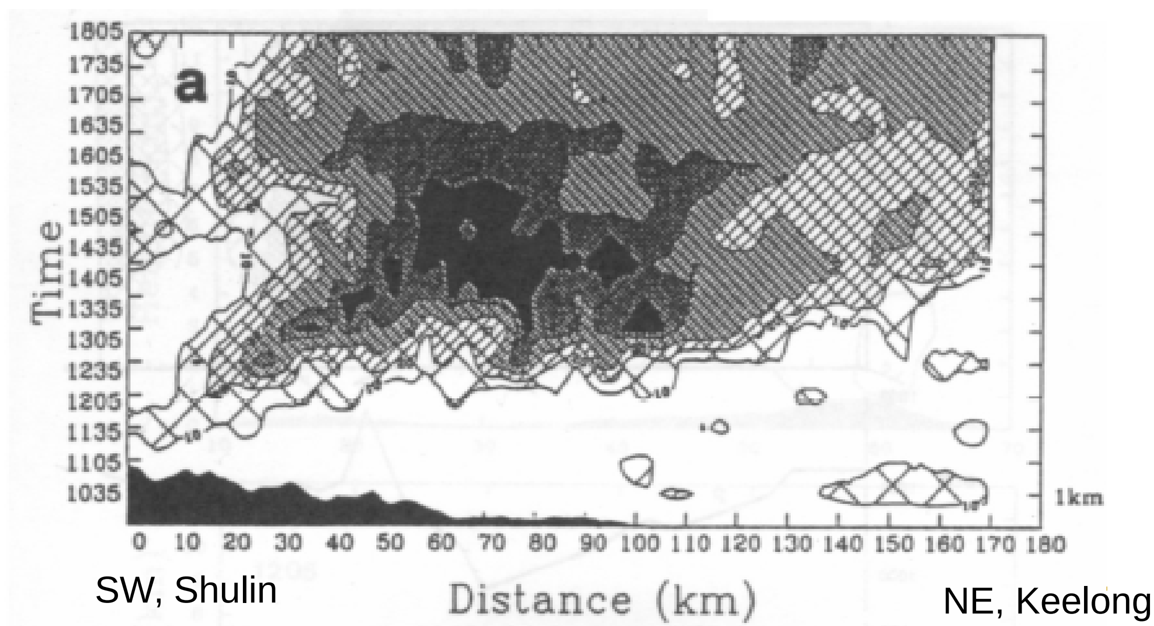




Keelung/135mm, Taipei/140mm, within 3 hours.

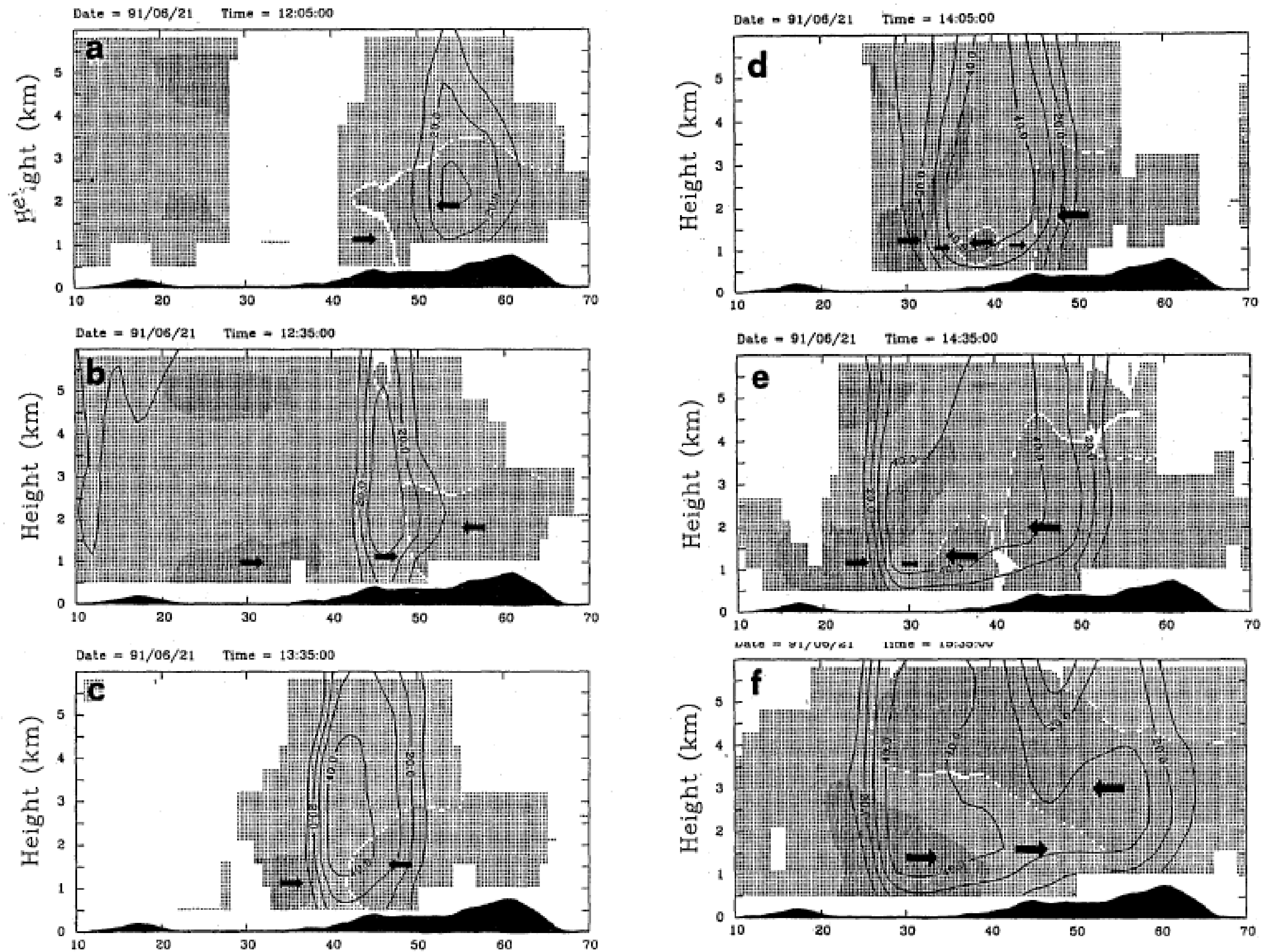

b
1205
c
1305
NW
SE
e
1405
g
1505
h
1605
Height (km)


b
Time
Distance (km)
1km
NW, Tanshui
SE, Shindian

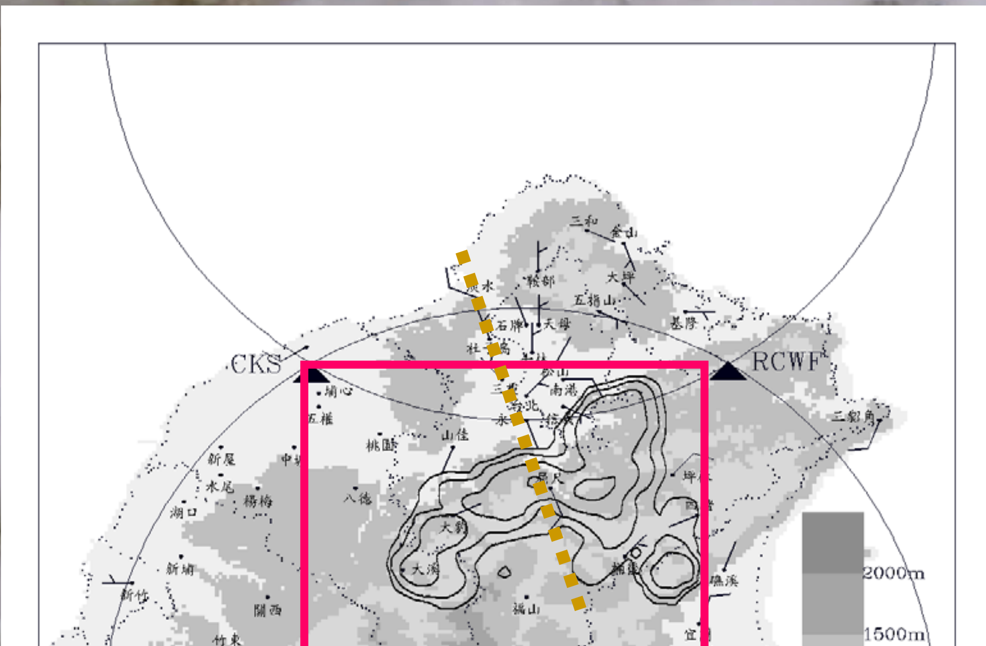

a
Time
Distance (km)
1km
SW, Shulin
NE, Keelong

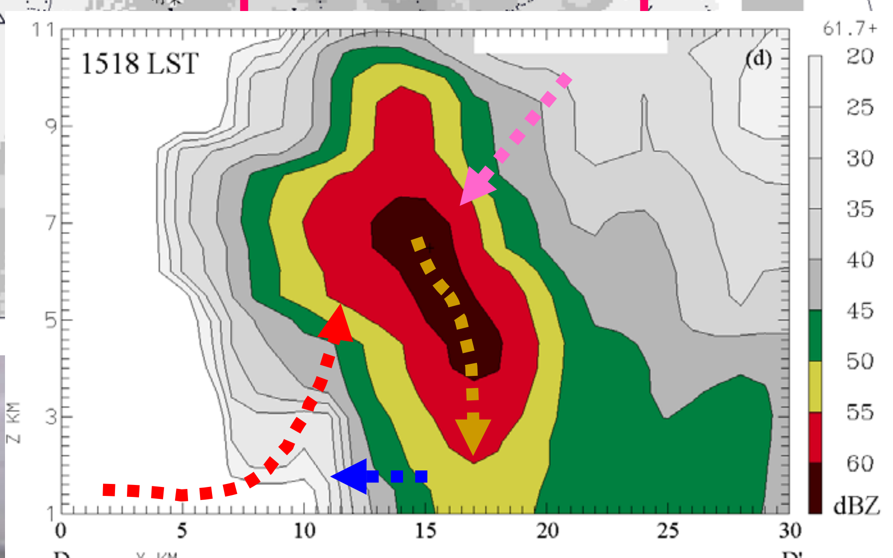
Jou (1994) TAO

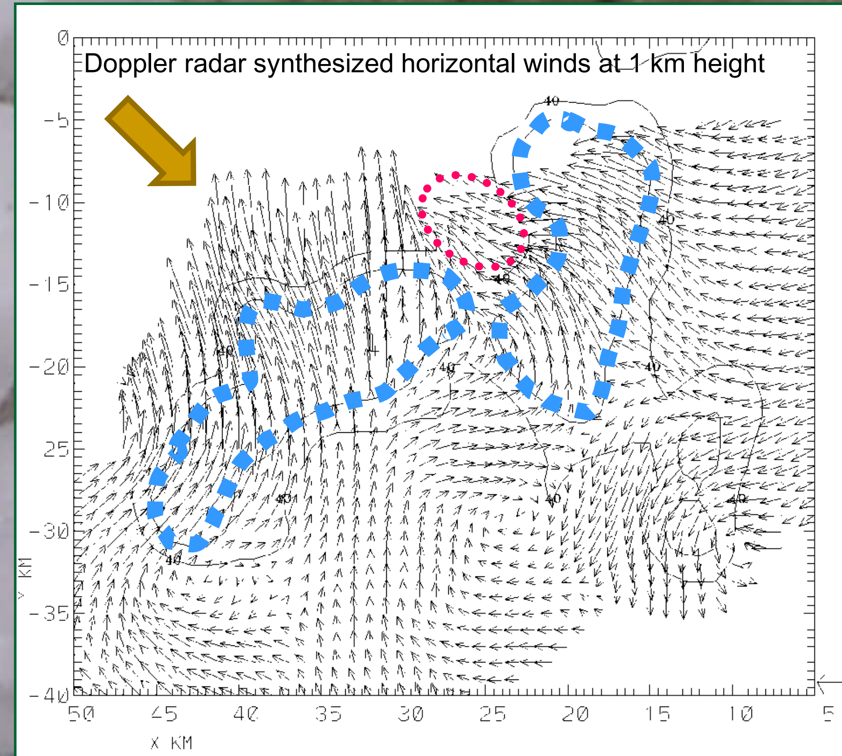
Signature of sea breeze and storm cold pool from single Doppler velocity (Jou 1994)

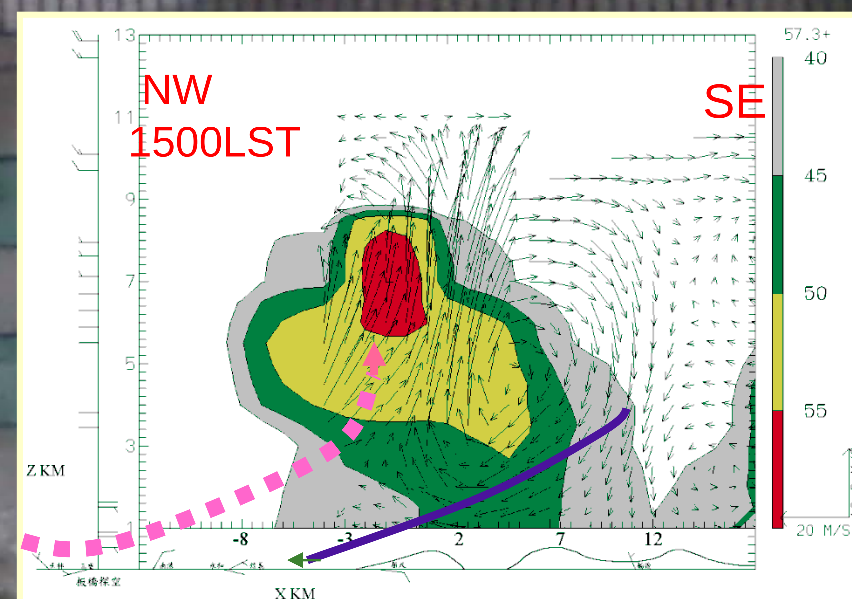


Dual-Doppler analysis of a hailstorm in the Taipei basin (1999/8/29) (Lin et al. 2003)



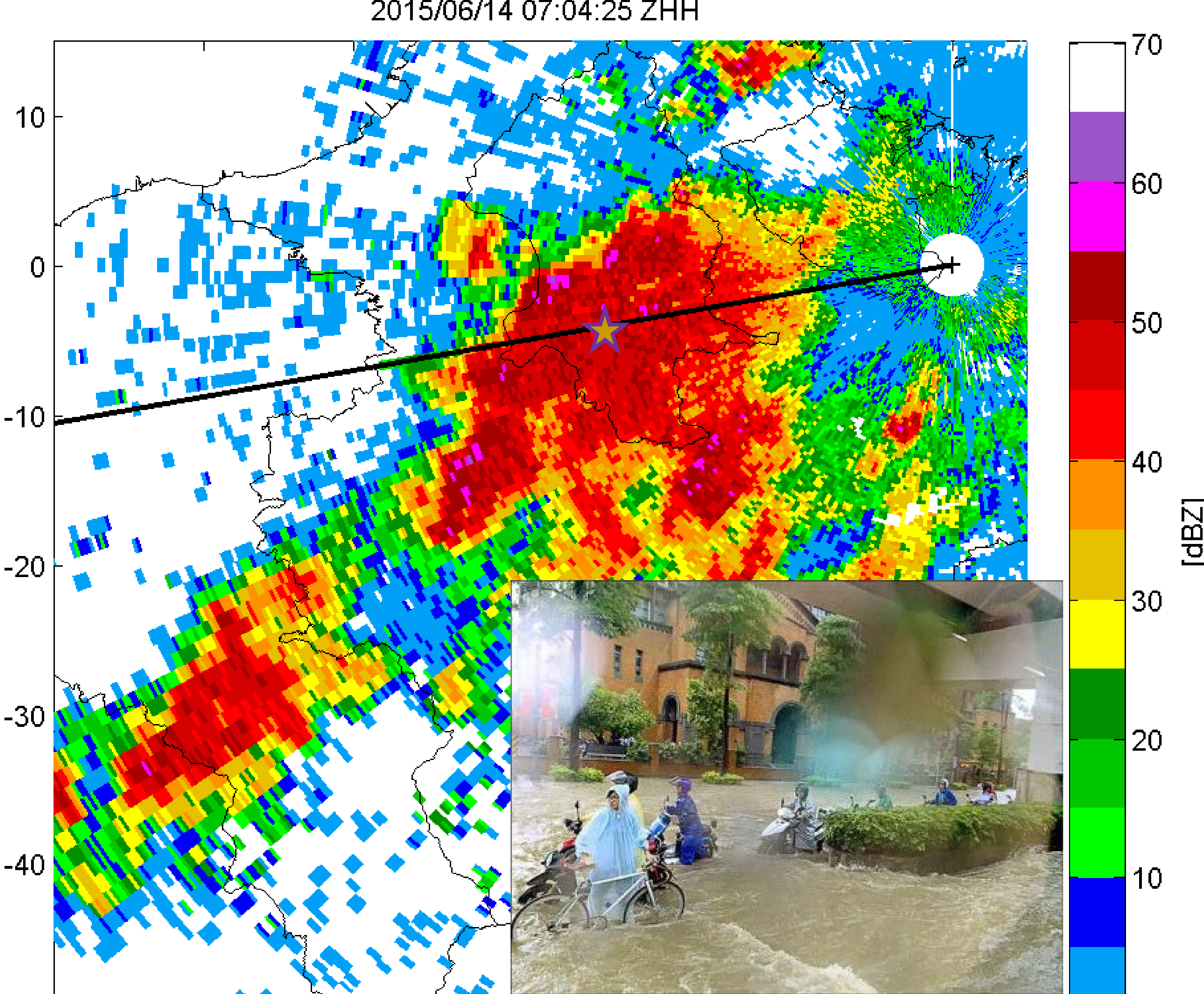




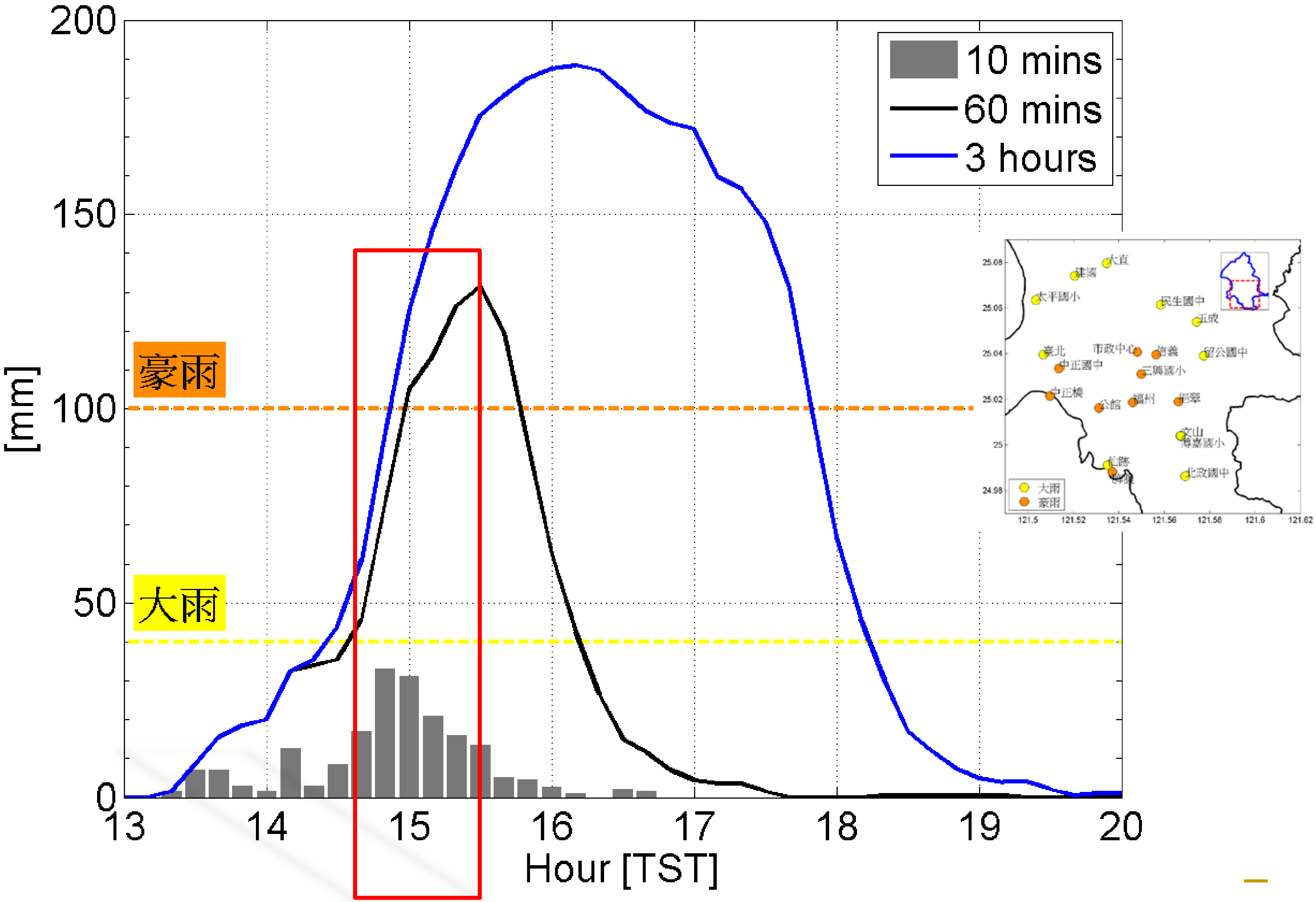


Outline

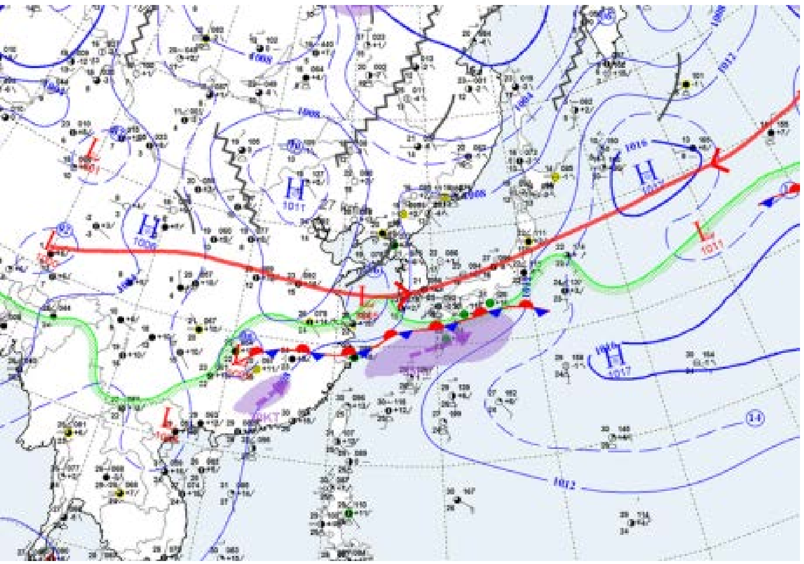
- The CWB newly upgraded WSR-88D polarimetric radar system combining with Taipei City's dense mesoscale weather station network provide important information for the formation and development of these thunderstorm complex systems.
- In this presentation, a flash flood case occurred in Taipei city **(June 14, 2015**) is introduced. The dual-Doppler synthesized winds and polarimateric signatures related to the flash flood event caused by the afternoon thunderstorms with complex features is investigated.

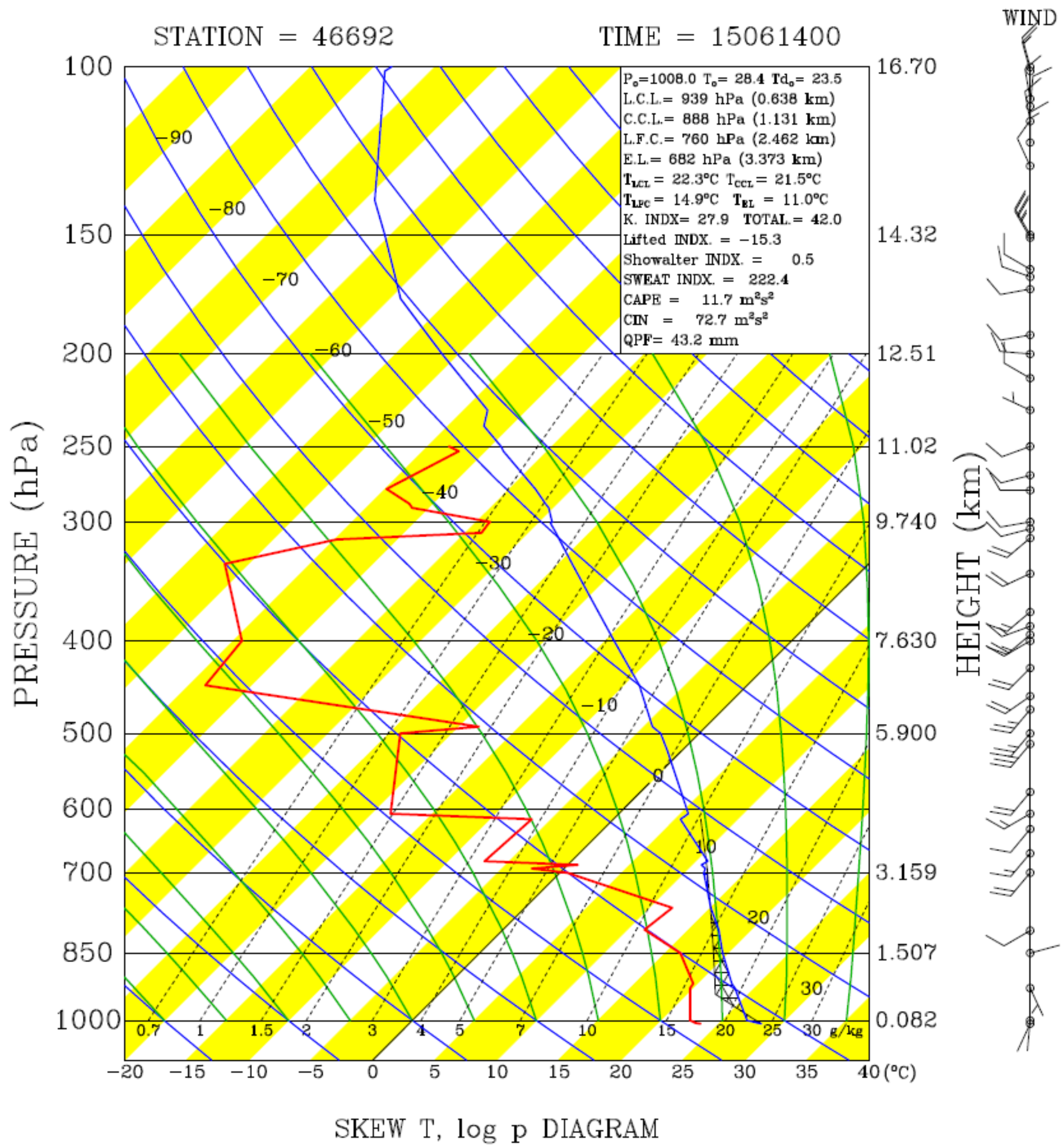

2015/06/14 07:04:25 ZHH
10
0
-10
-20
-30
-40
70
60
50
40
30
20
10
[dBZ]

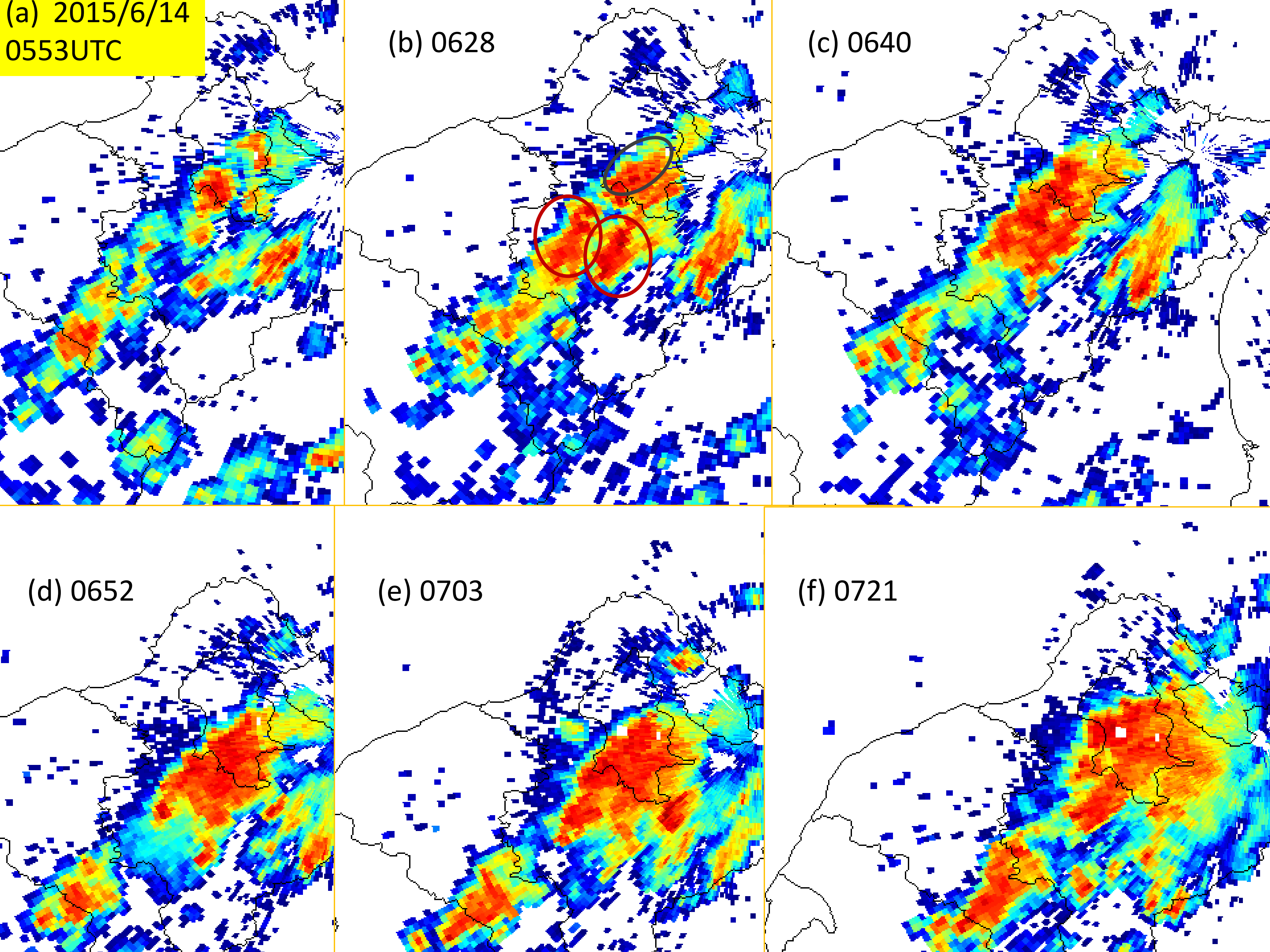
C1A730 公館



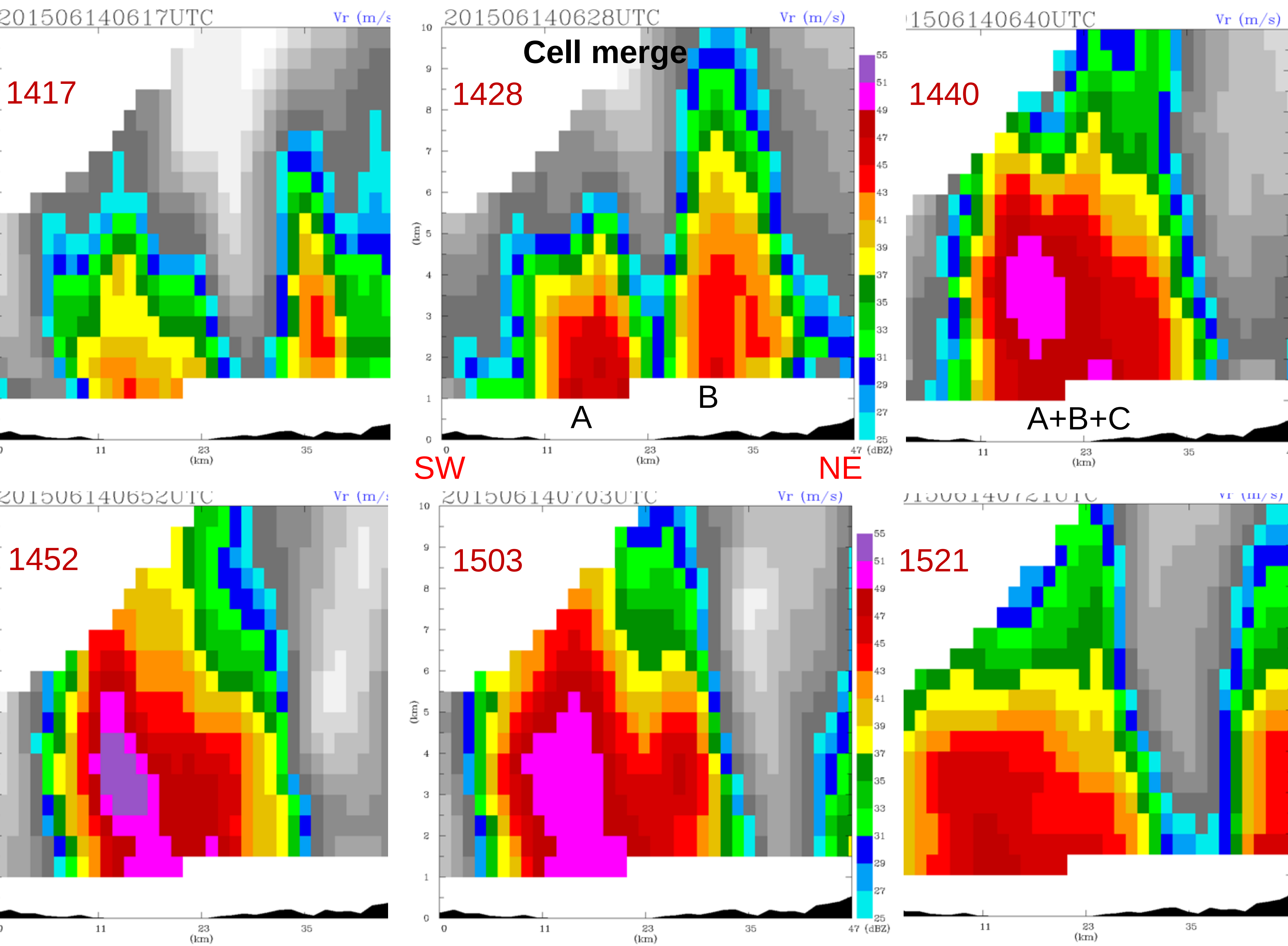
200
150
100
50
0
[mm]
豪雨
大雨
10 mins
60 mins
3 hours
13
14
15
16
17
18
19
20
Hour [TST]
25.08
25.06
25.04
25.02
25
24.98
121.5
121.52
121.54
121.56
121.58
121.6
121.62
大直
建國
太平國小
民生國中
玉成
臺北
市政中心
信義
留公國中
中正國中
三興國小
中正橋
公館
福州
文山
博嘉國小
仙跡
北政國中
大雨
豪雨




STATION = 46692
TIME = 15061400
WIND
P_o=1008.0 T_o= 28.4 Td_o= 23.5
L.C.L.= 939 hPa (0.638 km)
C.C.L.= 888 hPa (1.131 km)
L.F.C.= 760 hPa (2.462 km)
E.L.= 682 hPa (3.373 km)
T_{LCL} = 22.3°C T_{CCL} = 21.5°C
T_{LFC} = 14.9°C T_{EL} = 11.0°C
K. INDX= 27.9 TOTAL.= 42.0
Lifted INDX. = −15.3
Showalter INDX. = 0.5
SWEAT INDX. = 222.4
CAPE = 11.7 m^2s^2
CIN = 72.7 m^2s^2
QPF= 43.2 mm
PRESSURE (hPa)
HEIGHT (km)
SKEW T, log p DIAGRAM

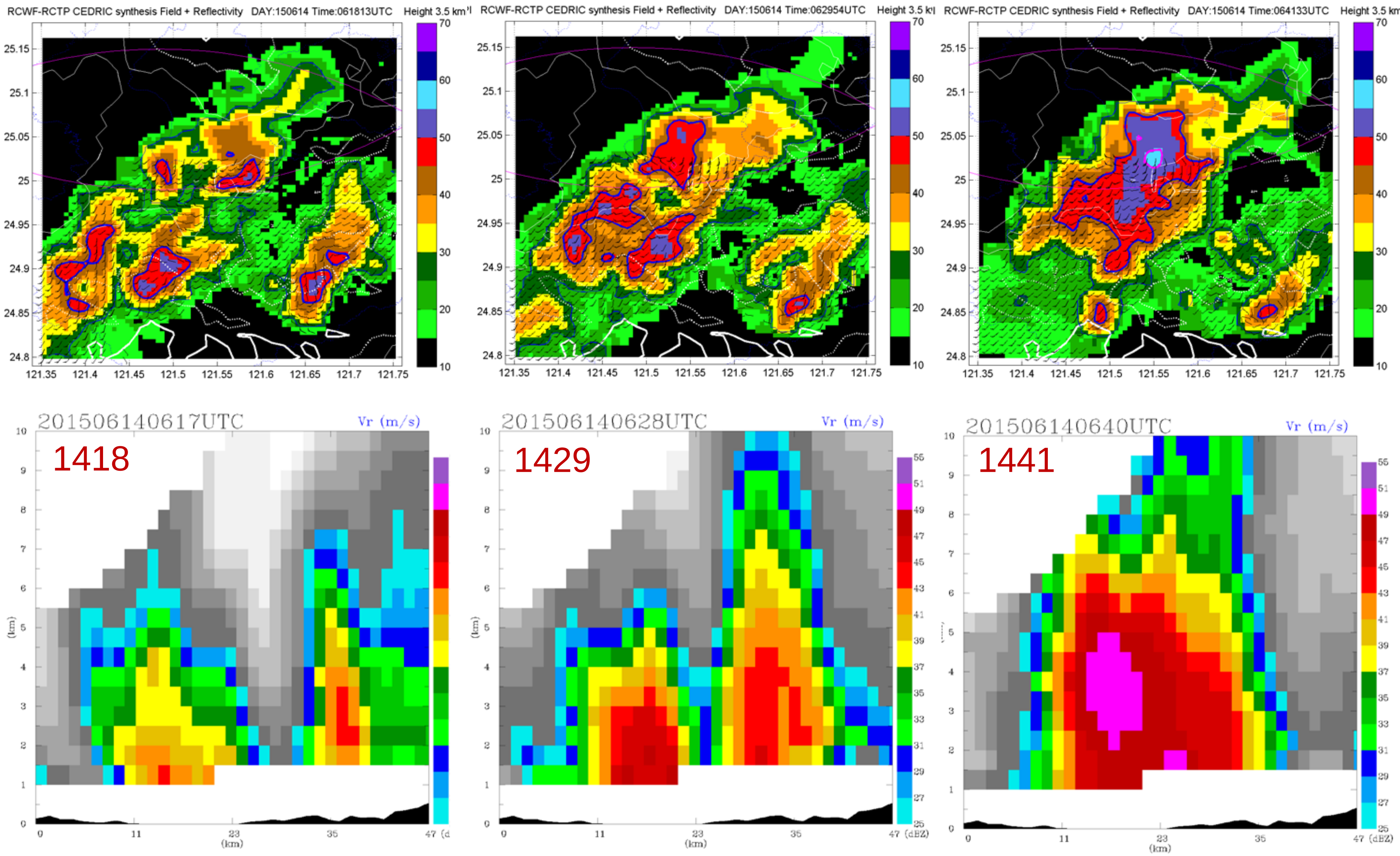


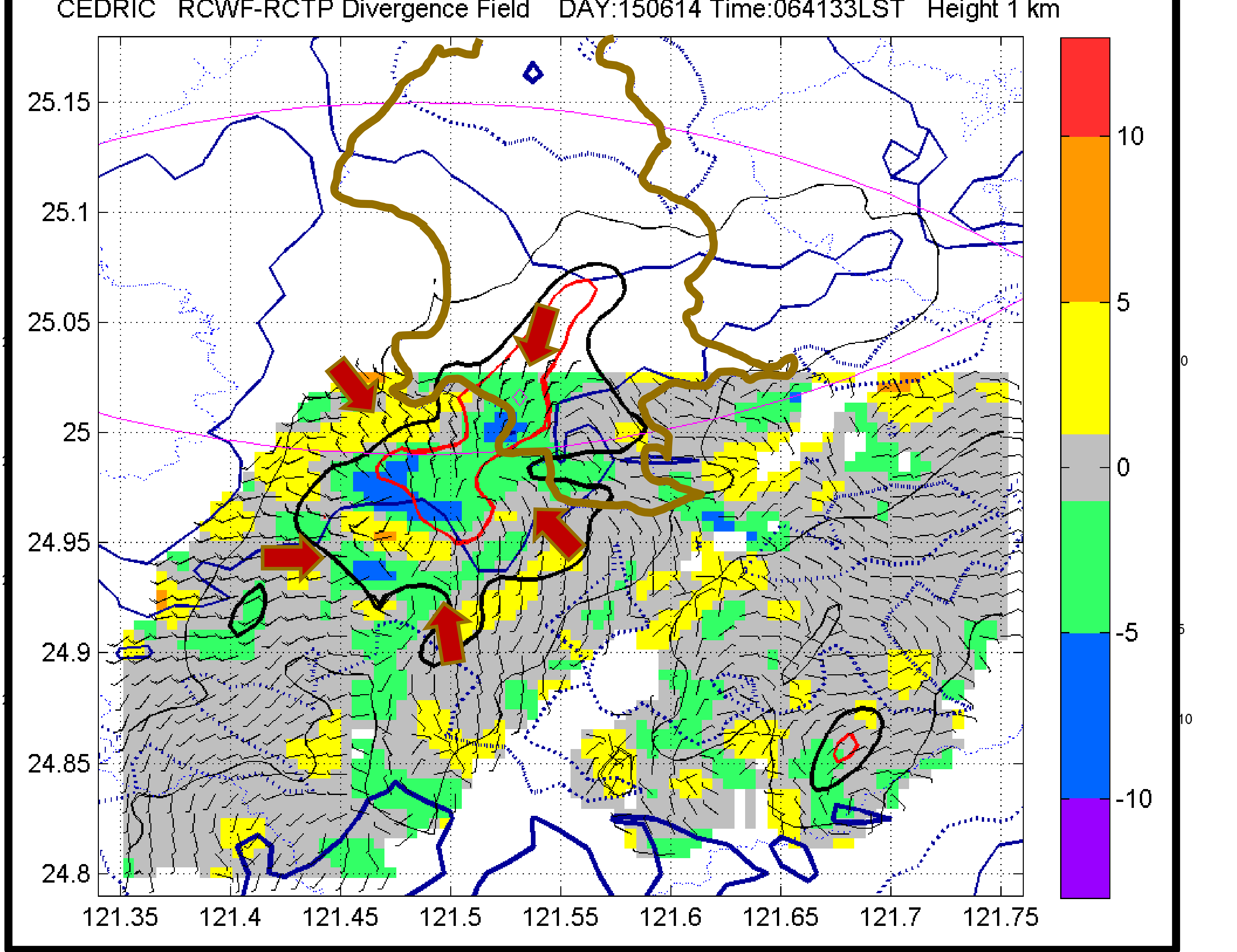
(a) 2015/6/14
0553UTC
(b) 0628
(c) 0640
(d) 0652
(e) 0703
(f) 0721



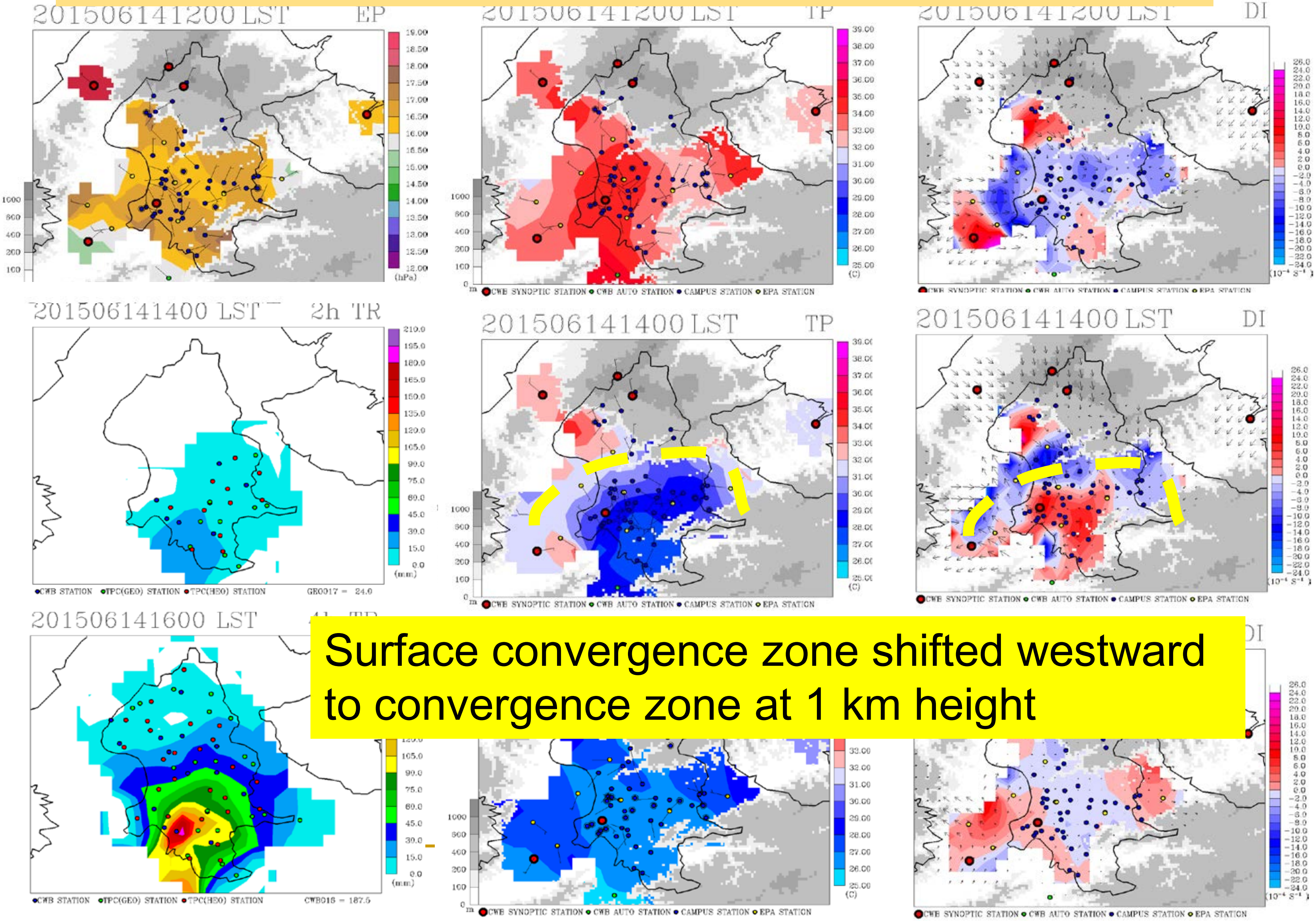
201506140617UTC
1417
201506140628UTC
Vr (m/s)
Cell merge
1428
A
B
1506140640UTC
Vr (m/s)
1440
A+B+C
SW
NE
1452
1503
1521
(km)
(dBZ)

Signature of cell merge: Zhh at 3.5km on 1418, 1429, and 1441 LST, 14 June 2015, reflectivity factor larger than 45 dBZ is enhanced with deep blue contour and vertical cross sections passing through the leading edge

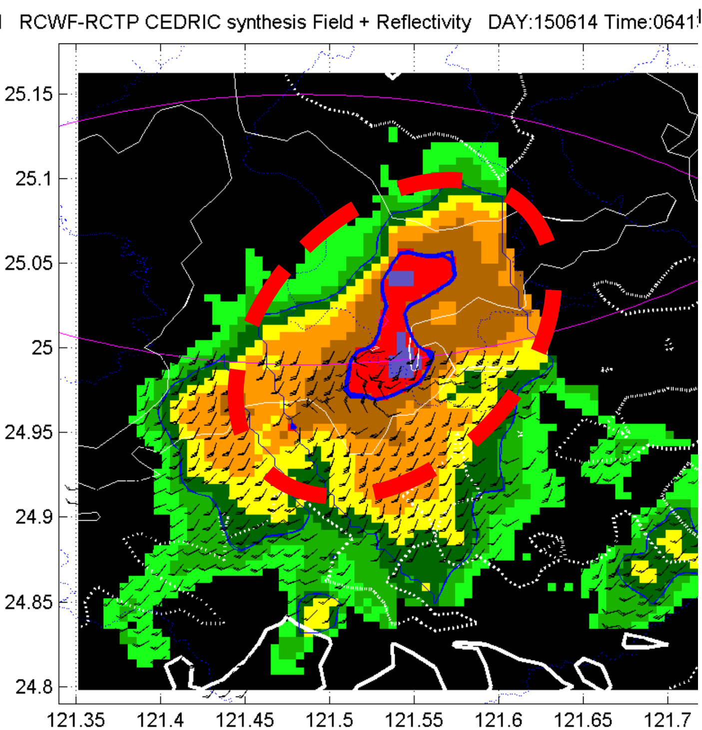


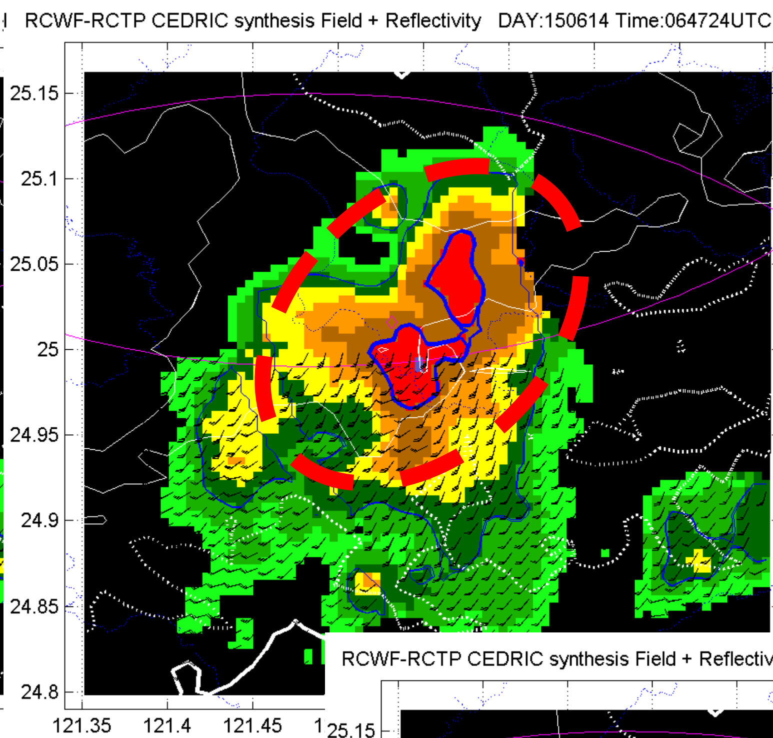

CEDRIC RCWF-RCTP Divergence Field DAY:150614 Time:064133LST Height 1 km
25.15
25.1
25.05
25
24.95
24.9
24.85
24.8
121.35
121.4
121.45
121.5
121.55
121.6
121.65
121.7
121.75
10
5
0
-5
-10

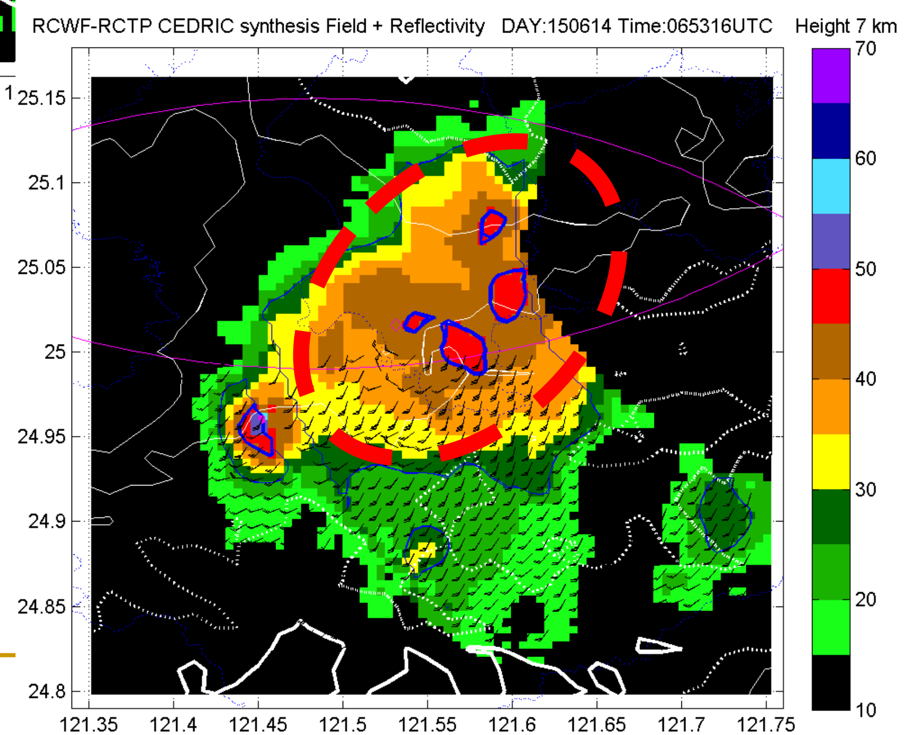
Enhanced low-level convergence with earlier precipitation



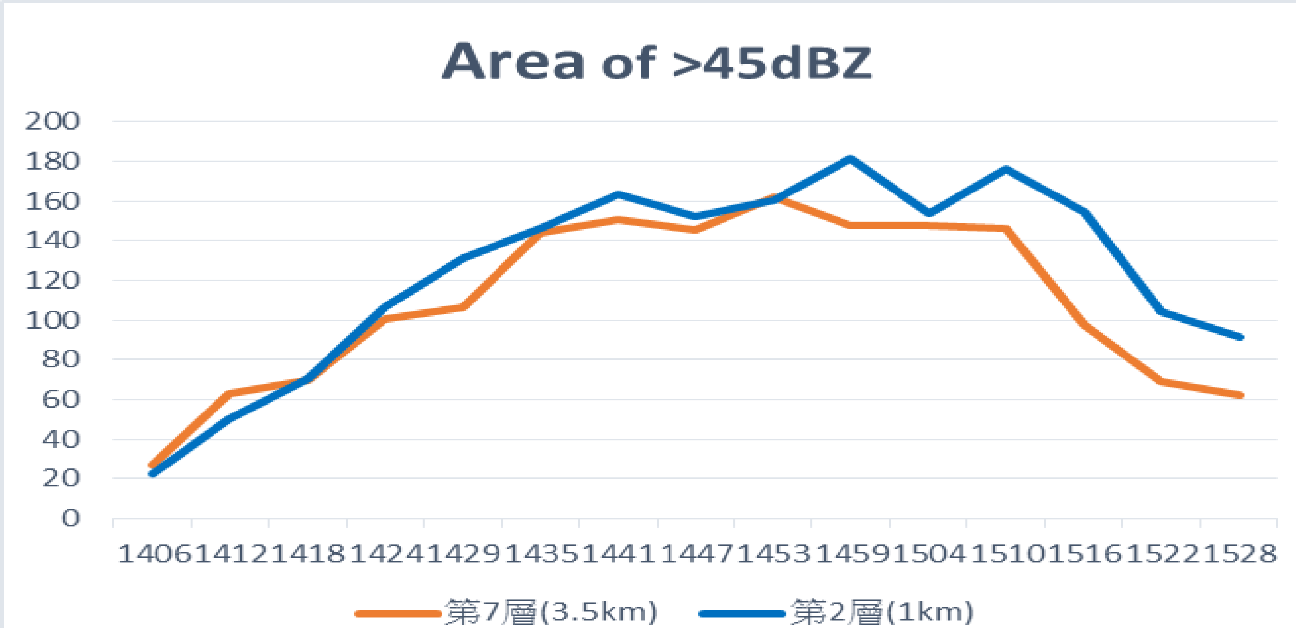
Surface convergence zone shifted westward to convergence zone at 1 km height



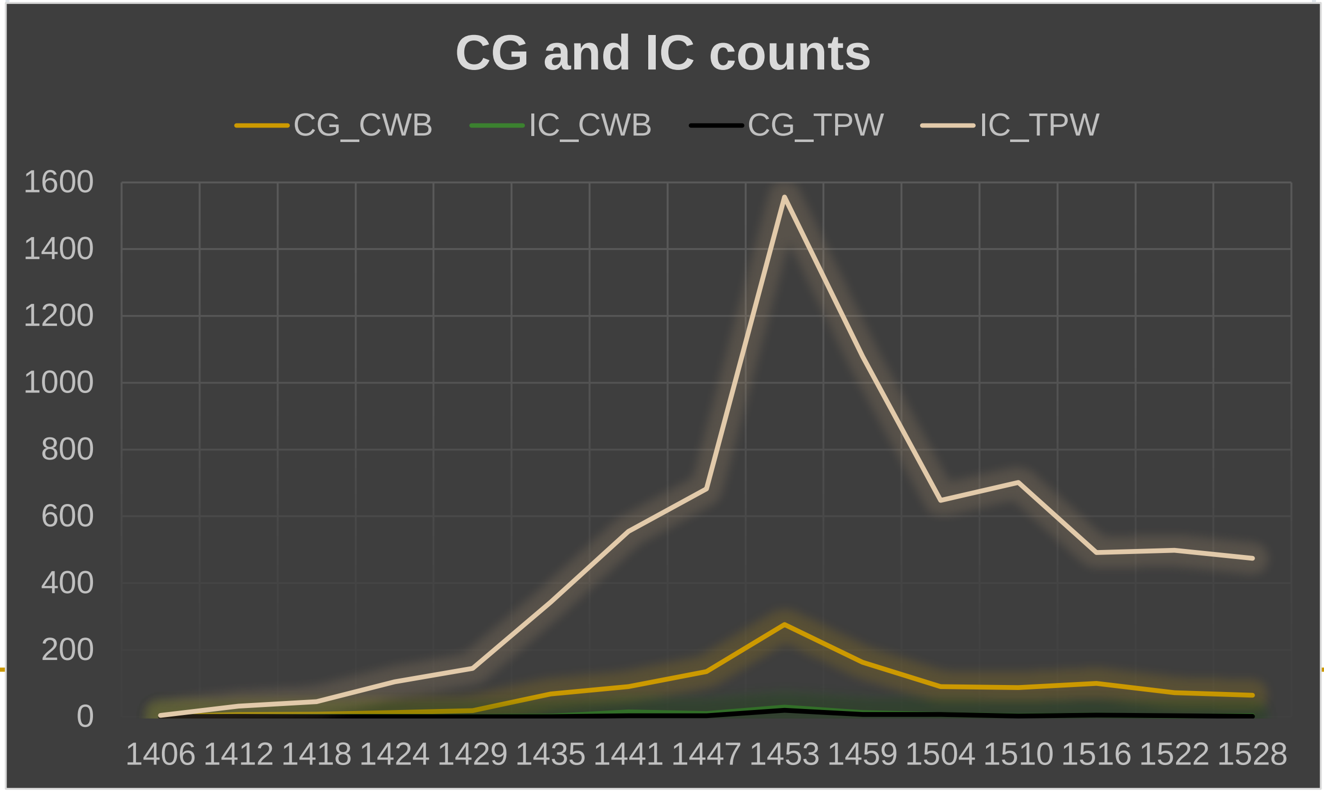




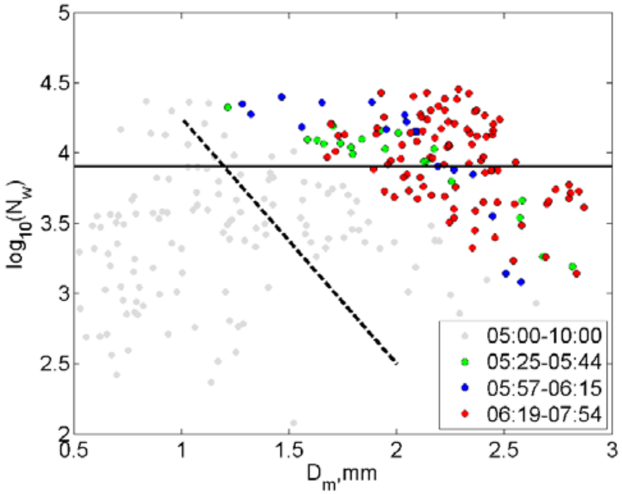
Signature of quasi-steady storm: Zhh at 7 km on 1441-1447-1453 LST 14 June 2015. Large reflectivity area of the storm reached a quasi-steady state after moved into Taipei basin.



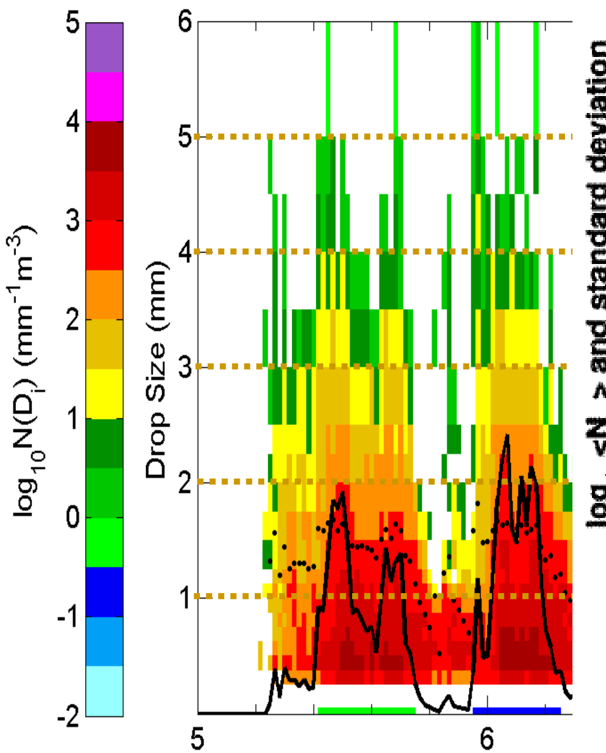
Area with reflectivity larger than 45 dBZ (in km**2)

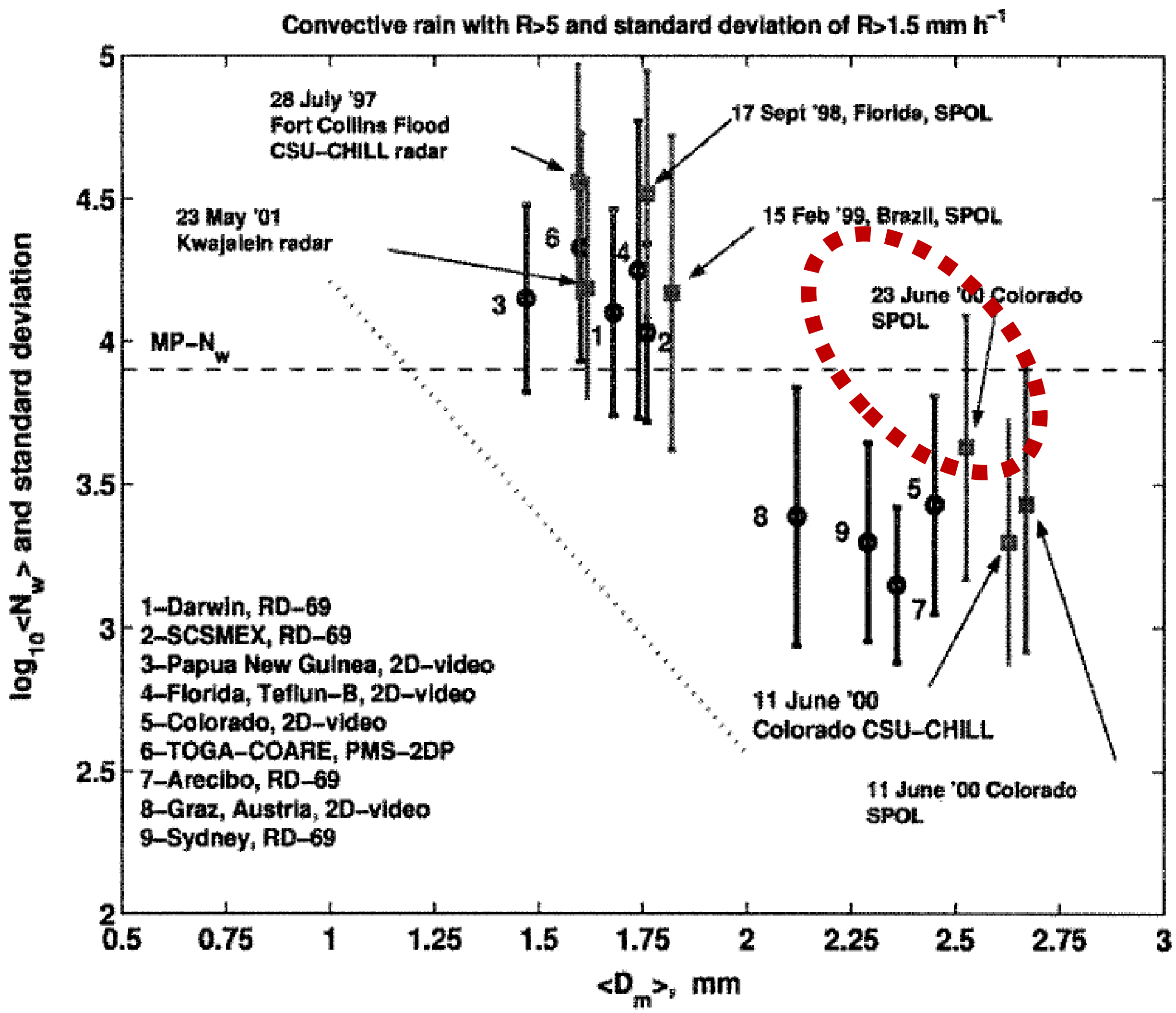


Lightning counts per every 6 minutes in the area of (121.35-121.76E, 24.80-25.17N)

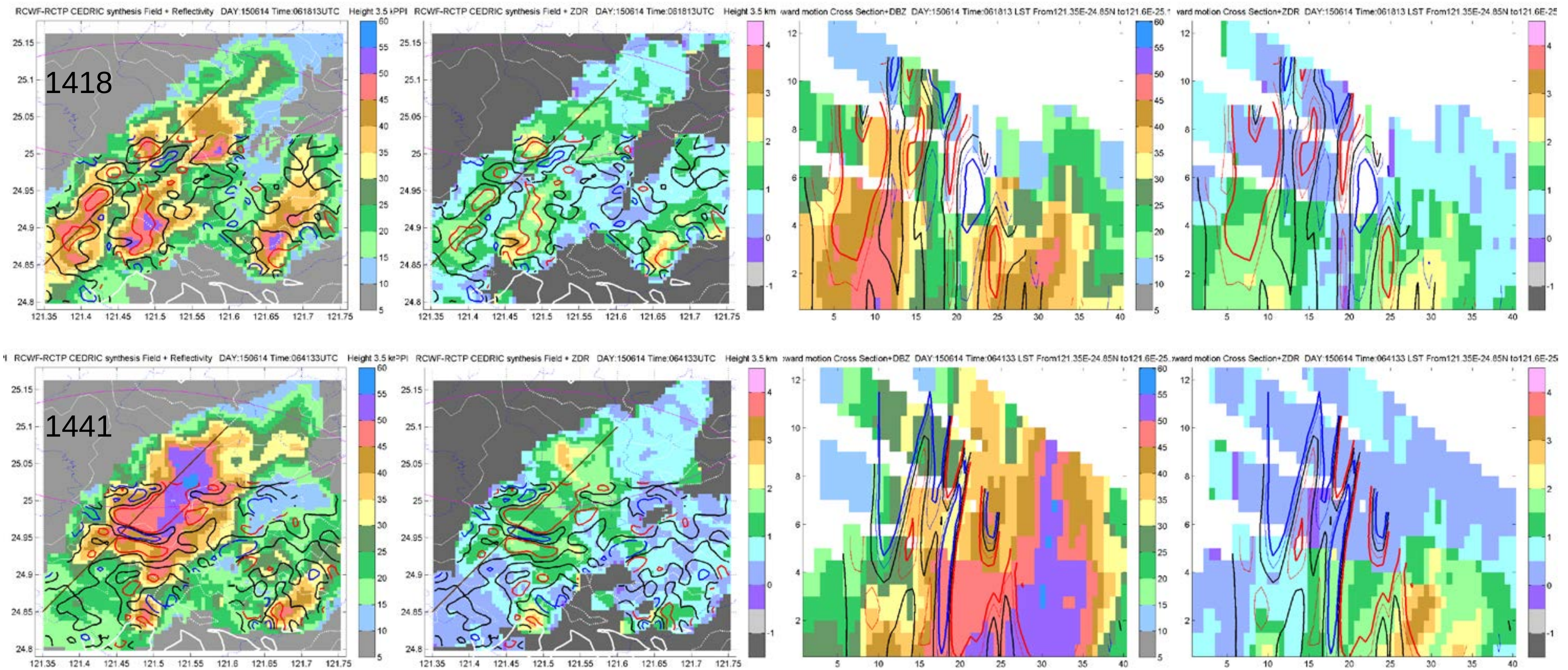


Raindrops observed at Taida: drop numbers are increased at all sizes, and much more increase on smaller drops during the quasi-steady period (1440-1515 LST)





Horizontal reflectivity factor (ZHH) and differential reflectivity (ZDR) at 3.5 km height and vertical cross sections along the leading edge of the storm (parallel to the vertical wind shear) on 1418 (upper) and 1441 (lower) LST 14 June 2015, respectively.

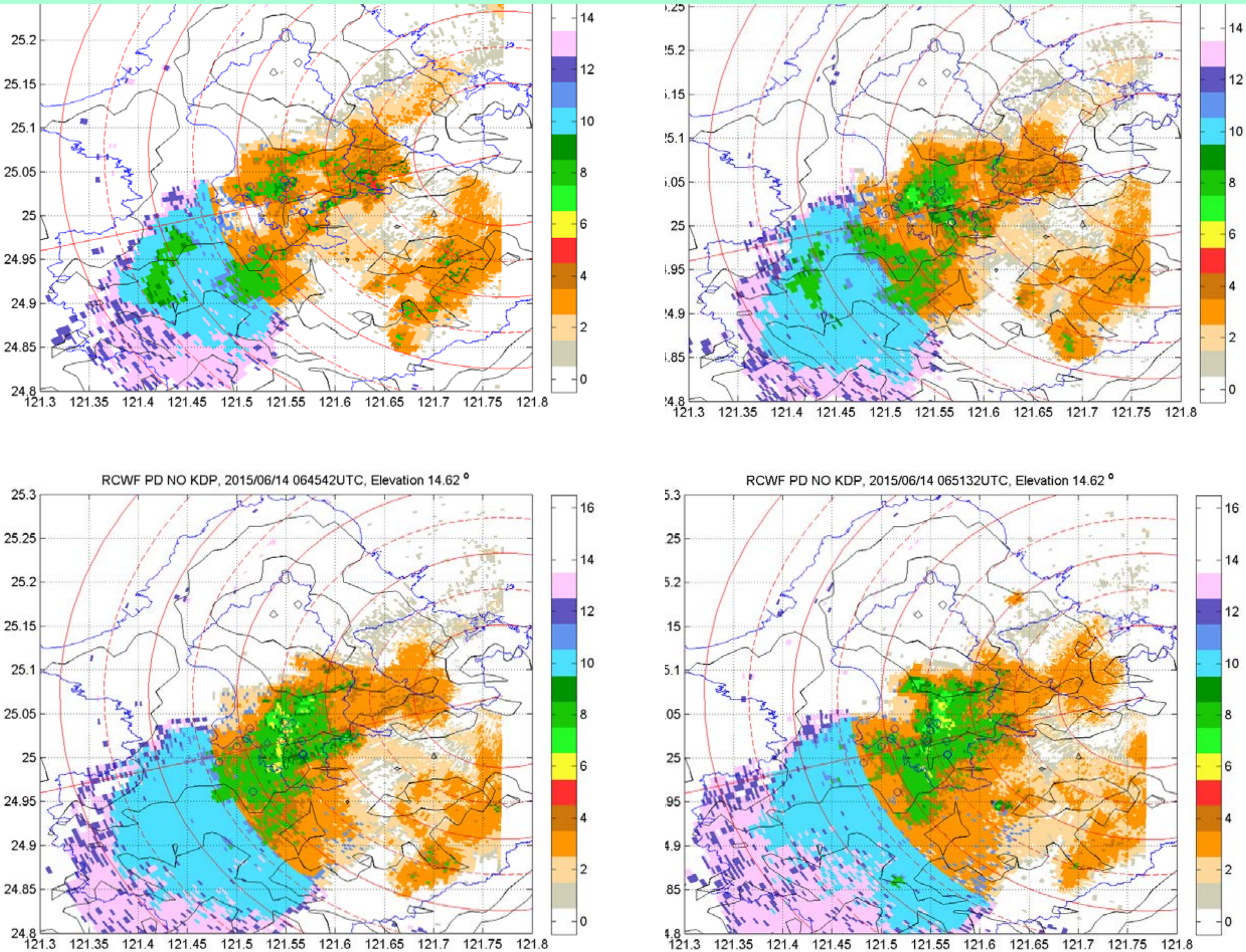


1418 (upper), 40-45 to 45-50 dBZ with ZDR of 2-2.5 dB; higher than 5.5km, ZDR 0.0-0.5 or 0.5-1.0 dB
1441 (lower), 50-55 to 55-60 dBZ with ZDR of 3.0-3.5dB; higher than 5.5 km, ZDR 1.0-1.5dB
The updrafts are small for individual cores associated with each convective cell before merge. After merge, the updraft core has been enlarged into ~10 km in diameter (2-3 times large than earlier) indicating very strong mass and energy transport in the storm.

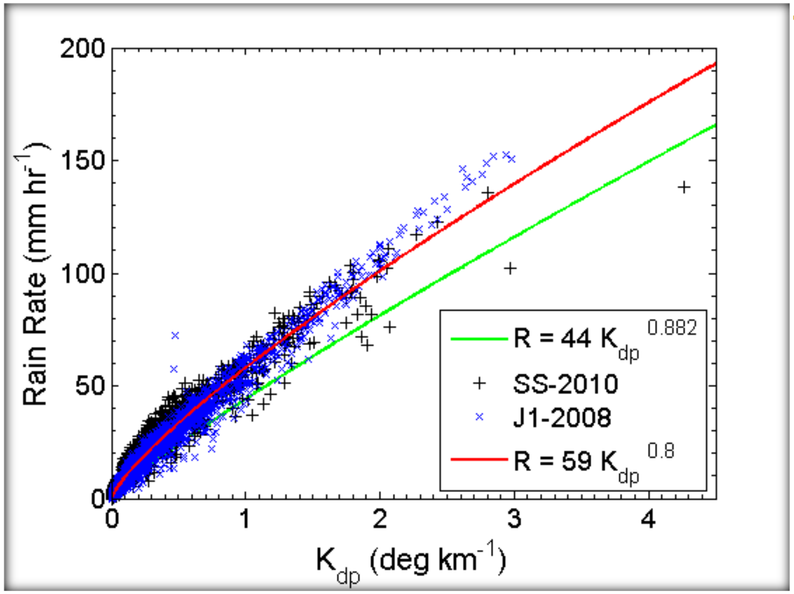
Time sequence of area-averaged horizontal reflectivity (in dBZ), differential reflectivity (in dB), horizontal convergence (10^{-3}/s), and vertical velocity (m/s) at 1.0 and 3.5 km height from 1418-1447 LST 14 June 2015.

H= 3.5 km	(LST) 1418	1424	1429	1435	1441	1447
Horizontal reflectivity ZHH (dBZ)	28.3	31.4	39.4	45.9	48.3	48.0
Differential reflectivity ZDR (dB)	0.8	0.9	1.3	1.4	1.4	1.3
Horizontal convergence (10^{-3} s^{-1})	-1.3	-0.1	**0.8**	0.5	0.1	1.8
Vertical velocity (m/s)	0.5	3.0	7.3	5.0	9.8	4.5
H= 1.0 km	(LST) 1418	1424	1429	1435	1441	1447
Horizontal reflectivity ZHH (dBZ)	35.1	35.4	39.3	46.0	48.5	49.1
Differential reflectivity ZDR (dB)	1.5	1.4	1.6	1.9	1.8	1.6
Horizontal convergence (10^{-3} s^{-1})	**0.6**	**0.9**	**1.8**	**1.7**	**2.8**	0.7
Vertical velocity (m/s)	1.1	1.4	1.9	2.3	3.9	0.1

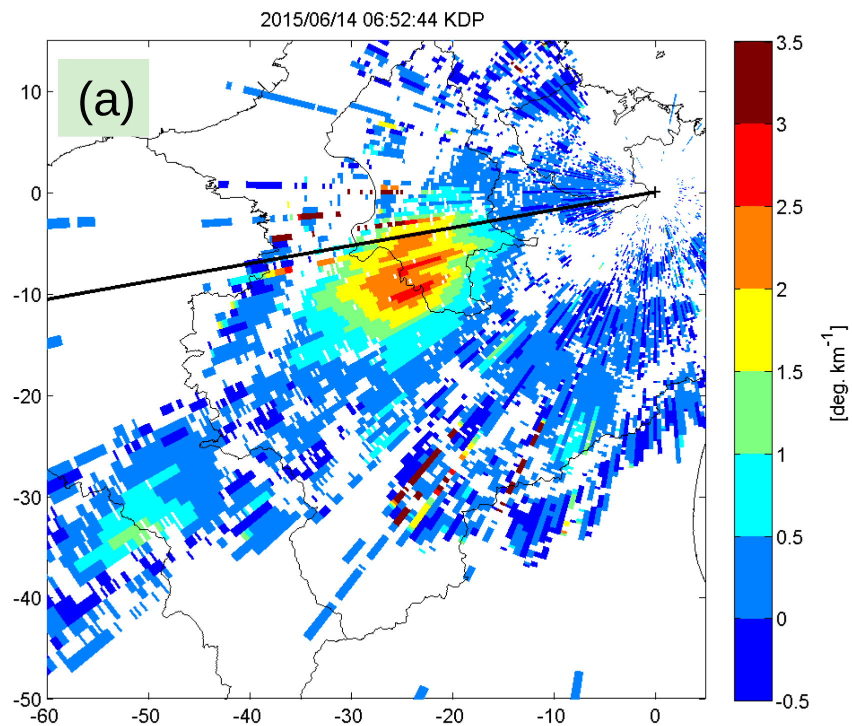
Appearance of mixed-phase hydrometeors is a signature for heavy rainfall. Objective detection algorithm could be developed to serve as an indicator for early warning purpose.

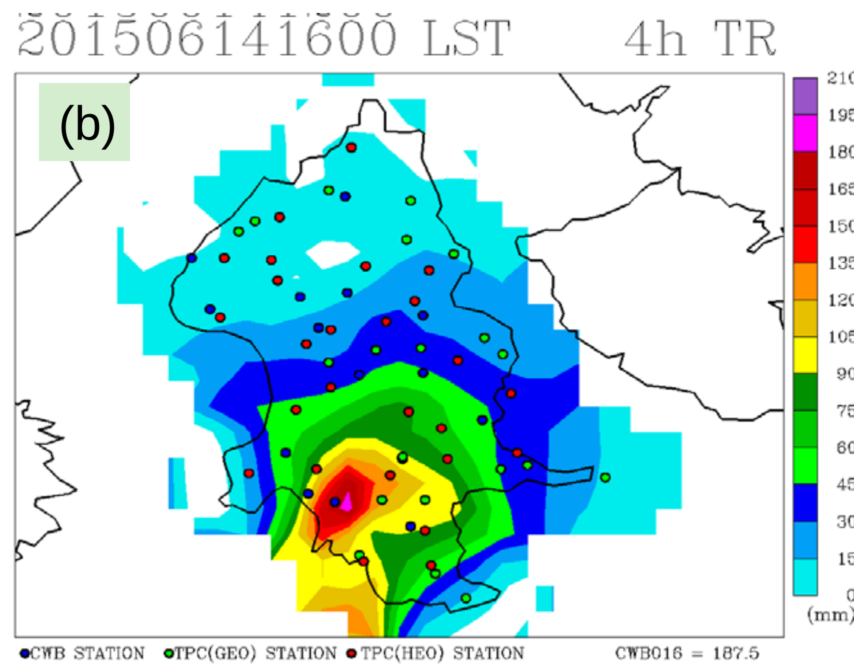


17. Clutter
16. 2nd trip
15. Insects
14. Supercool
13. Irre ice crystal
12. Ice crystal
11. Wet snow
10. Dry snow
9. graupel/ rain
8. Graupel
7. hail/rain
6. Hail
5. Heavy rain
4. Middle rain
3. Small rain
2. drizzle
1. cloud

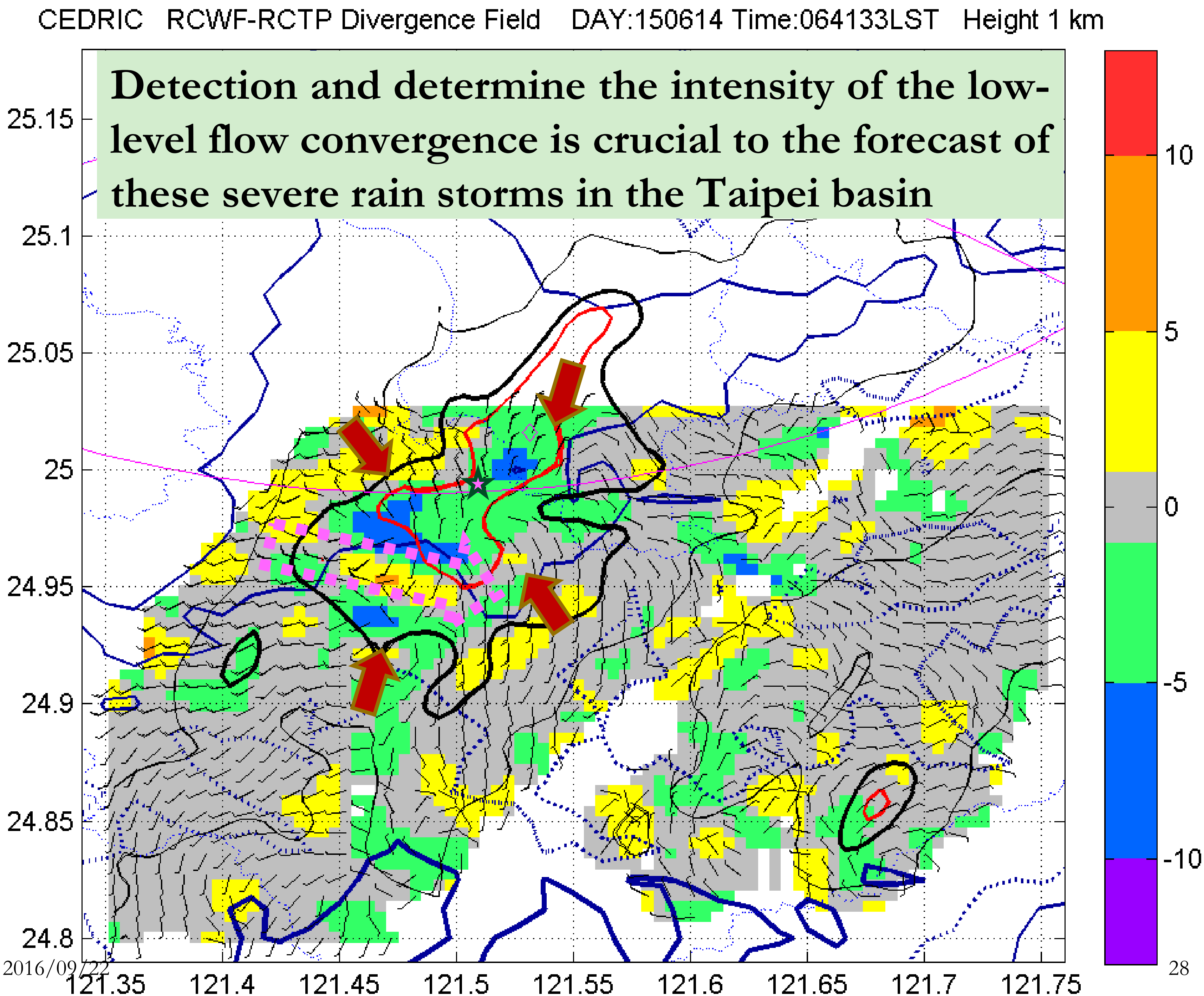


Kdp (a) observed by polarimetric radar (1452 LST 14 June 2015) and rainfall accumulated measured by rain gauges (b)

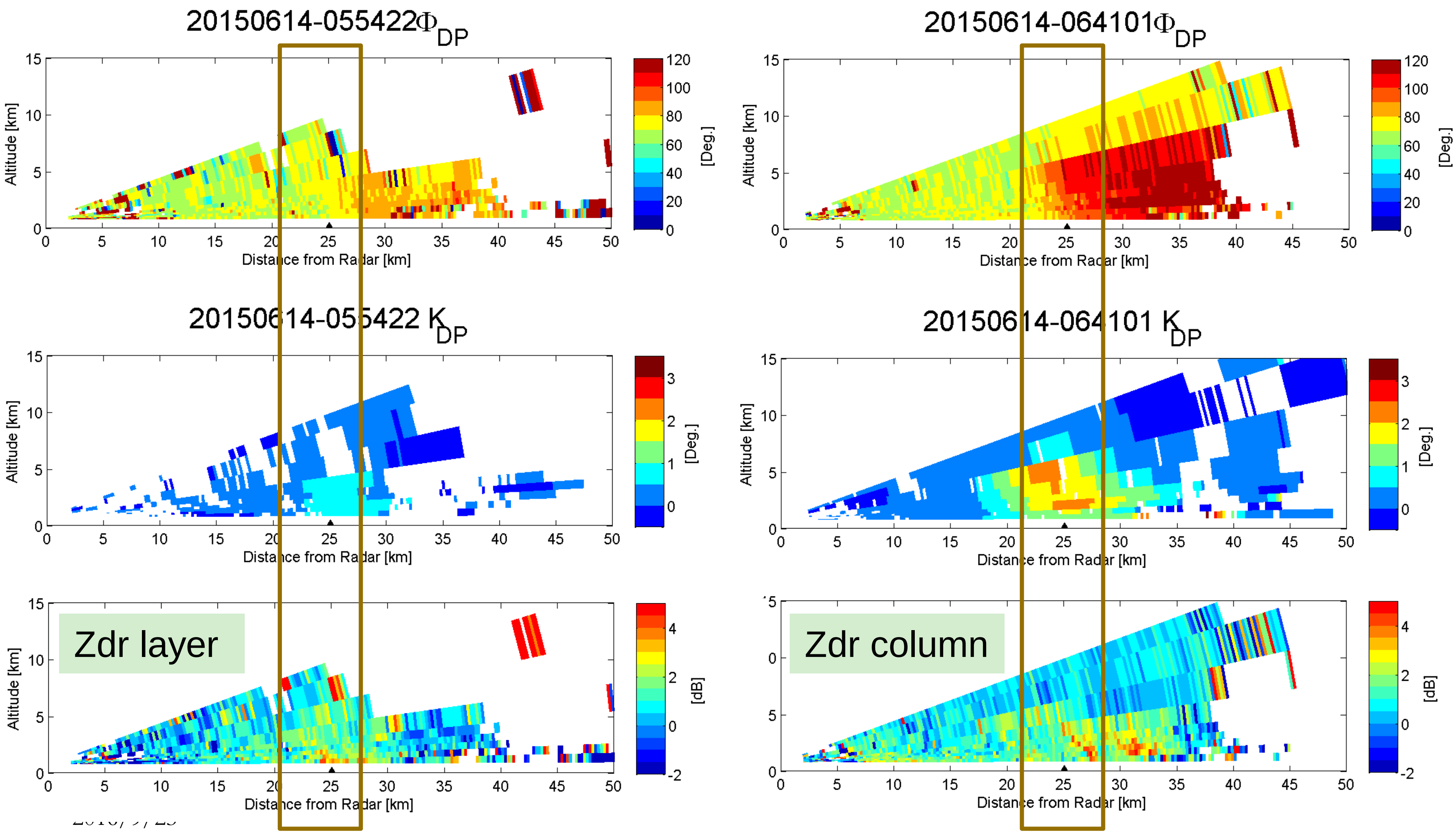




Detection and determine the intensity of the low-level flow convergence is crucial to the forecast of these severe rain storms in the Taipei basin



Identify regions with large change of differential phase (Φ_{DP}) and using specific differential phase (K_{DP}) for rainfall estimation is the possible solution to the early warning of these severe rain storms



Summary

- Forecast of a flash flood storm in the Taipei basin is discussed.
- **Cell merge** caused by the interaction between sea breeze and outflow of pre-existing storm produces gigantic storm complex and enlarges the horizontal extend and enhances the intensity of rainfall.
- Radar signatures of Zdr can be used to infer the state of storm development. **Zdr layer** is a result of size sorting indicating a weaker storm. **Zdr column** is closely related to strong convergence and intense upward vertical velocity intensity (strong enough to hold larger drops in the higher layer) indicating an intensifying state of the storm.
- Rainfall intensity can be inferred by Kdp distribution which is calculated from differential phase (Phi-dp) observed by the polarimetric radar. When estimate rainfall, Kdp (**Kdp-R relation**) is much more accurate than using Zhh (Z-R relation)
- Joint effort between **TCG and NTU task force team** has been working together to reduce the possible losses related to this kind of hazard in Taipei.

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jouben43@gmail.com

THANK YOU!

Straka and Zrnic (1993) HC criteria/NCAR PID

Type	Zhh (dBZ)	Zdr (dB)	Rhv	Kdp (deg/km)
Drizzle	< 25	0	> 0.99	0
Rain	25 to 60	0.5 to 4.0	> 0.97	0 to 10
Dry snow	< 35	0 to 0.5	> 0.99	0 to 0.5
Dense snow (aggregate)	< 25	0 to 5.0	> 0.99	0 to 1
Wet snow	< 45	0 to 3.0	0.8 to 0.95	0 to 2
Dry graupel (LD)	40 to 50	-0.5 to 1.0	> 0.99	-0.5 to 0.5
Wet graupel	40 to 50	-0.5 to 3.0	> 0.99	-0.5 to 2
Wet hail (< 2 cm)	50 to 60	-0.5 to 0.5	> 0.95	-0.5 to 0.5
Wet hail (> 2 cm)	55 to 70	< -0.5	> 0.96	-1 to 1
Rain with hail	50 to 70	-1.0 to 1.0	> 0.90	0 to 10