臺灣區域豪雨觀測與預報觀測實驗(TAHOPE):簡介與初步成果

Taiwan-Area Heavy rain Observation and Prediction Experiment (TAHOPE): Overview and preliminary results

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Pay-Liam Lin 林沛練[3], Po-Hsiung Lin 林博雄[1], Hung-Chi Kuo 郭鴻基[1]

Kuo-Chen Lu 呂國臣[2], Chung-Chieh Wang 王重傑[4], Ching-Hwang Liu 劉清煌[5],

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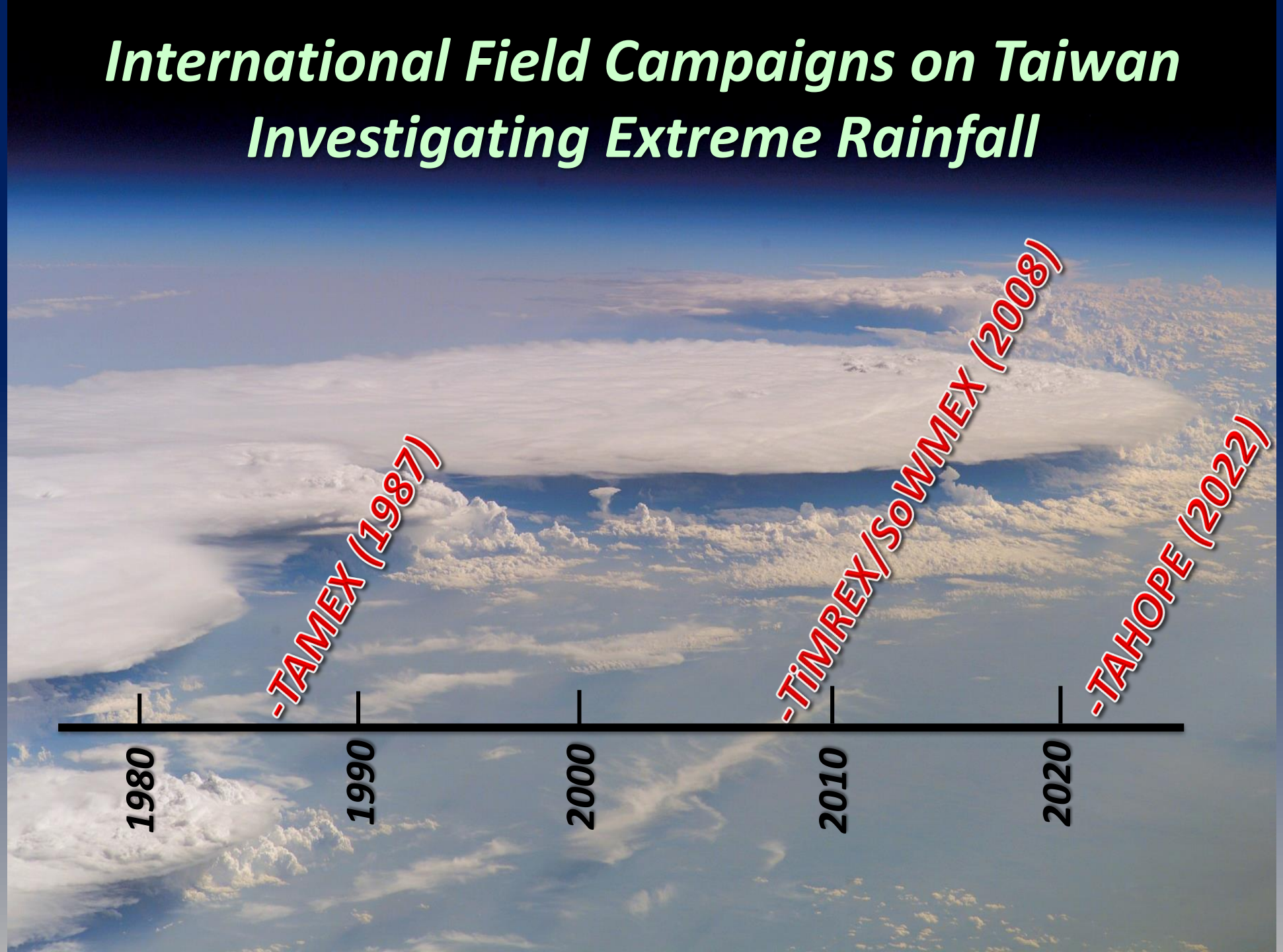
Wei-Yu Chang 張偉裕[3], Shu-Chi Yang 楊舒芝[3], Ching-Yuang Huang 黃清勇[3], Ping-Fang Lin 林品芳[2]

[1]National Taiwan University, [2]Central Weather Bureau, [3]National Central University, [4]National Taiwan Normal University, [5]Chinese Culture University,

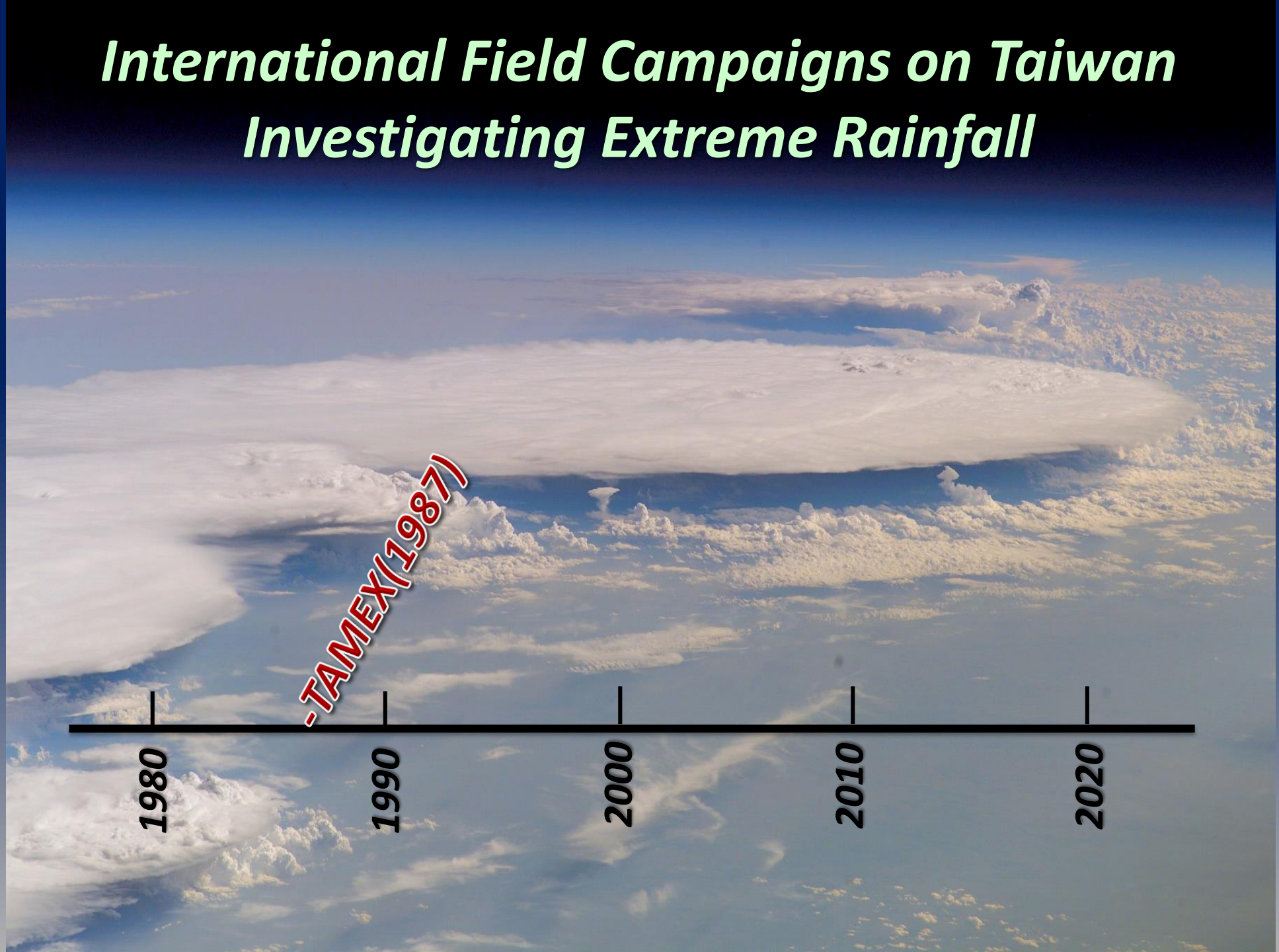
[6]National Defense University

Seminar at NTU/DAS on November 21, 2023

International Field Campaigns on Taiwan Investigating Extreme Rainfall



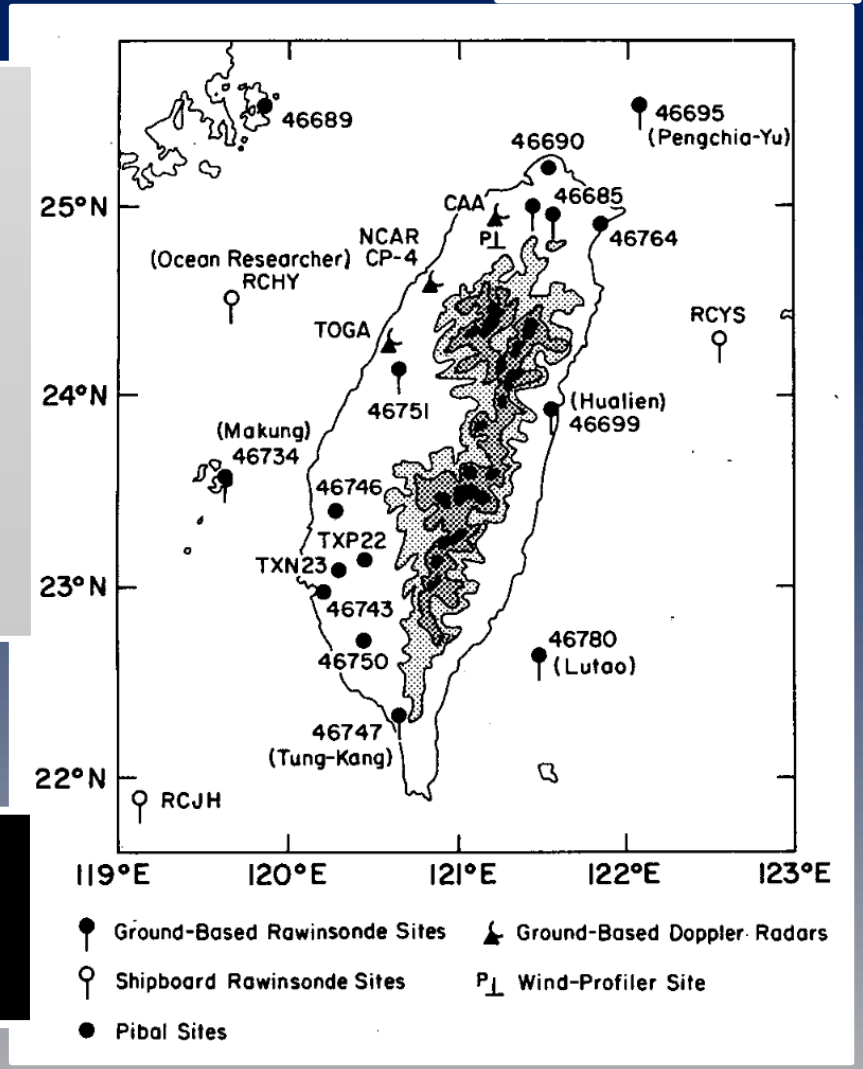
International Field Campaigns on Taiwan Investigating Extreme Rainfall



The Taiwan Area Mesoscale Experiment (TAMEX, May-June 1987)

Taiwan-USA

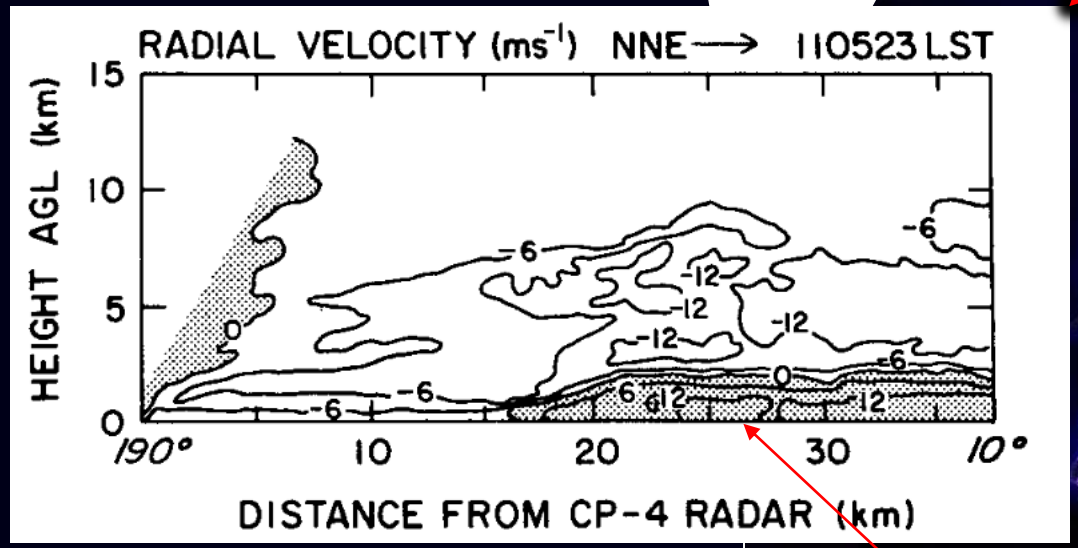
- **Study of heavy rainfall**
  - Meiyu front
  - Mesoscale convective systems
  - Orographic effects
  - Local circulations



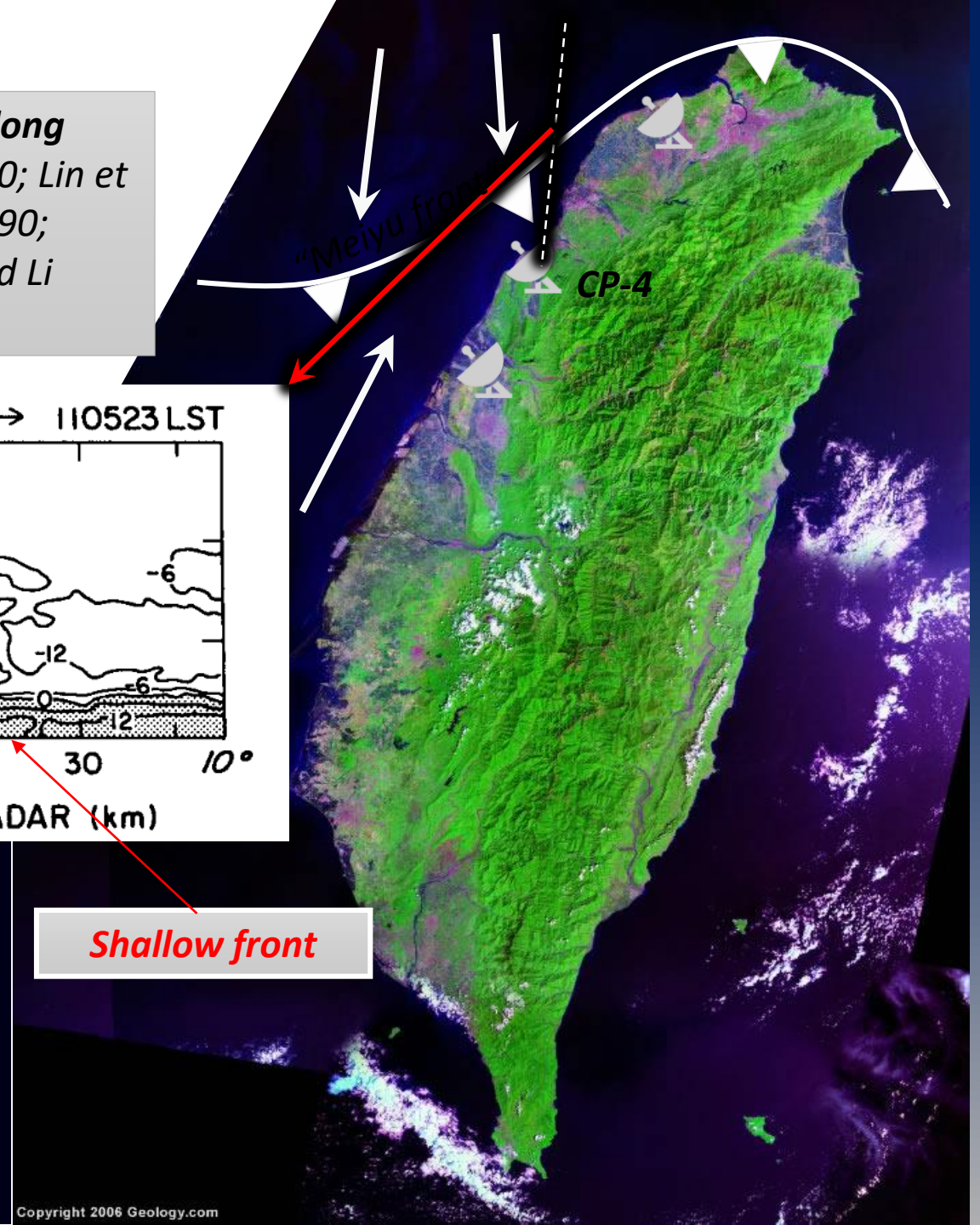
Doppler radars, soundings, surface stations, NOAA P-3 aircraft

Courtesy: Richard Johnson

TAMEX Radar observations along "Meiyu" front *(Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)*

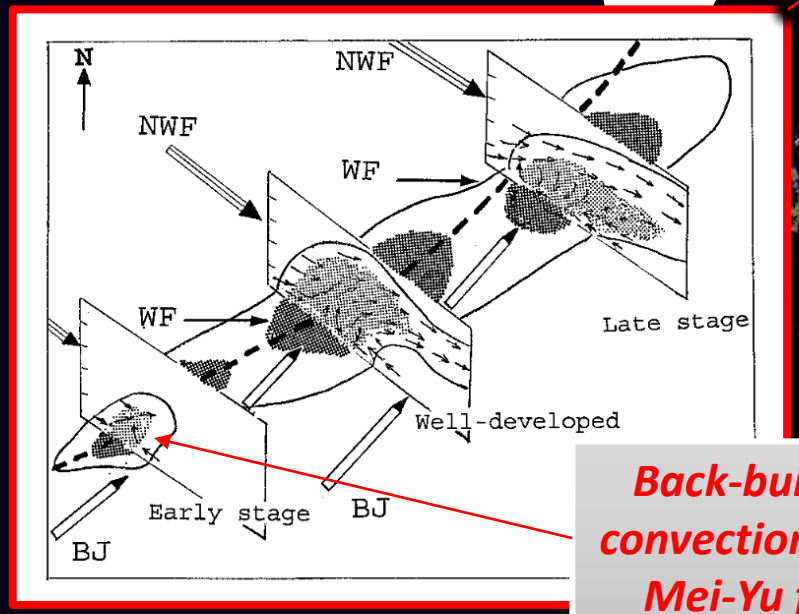


(Trier et al. 1997)



Courtesy: Richard Johnson

TAMEX Radar observations of convection along "Meiyu" front *(Trier et al. 1990; Lin et al. 1990, 1992; Wang et al. 1990; Chen and Chou 1993; Chen and Li 1995; Li et al. 1997; others)*

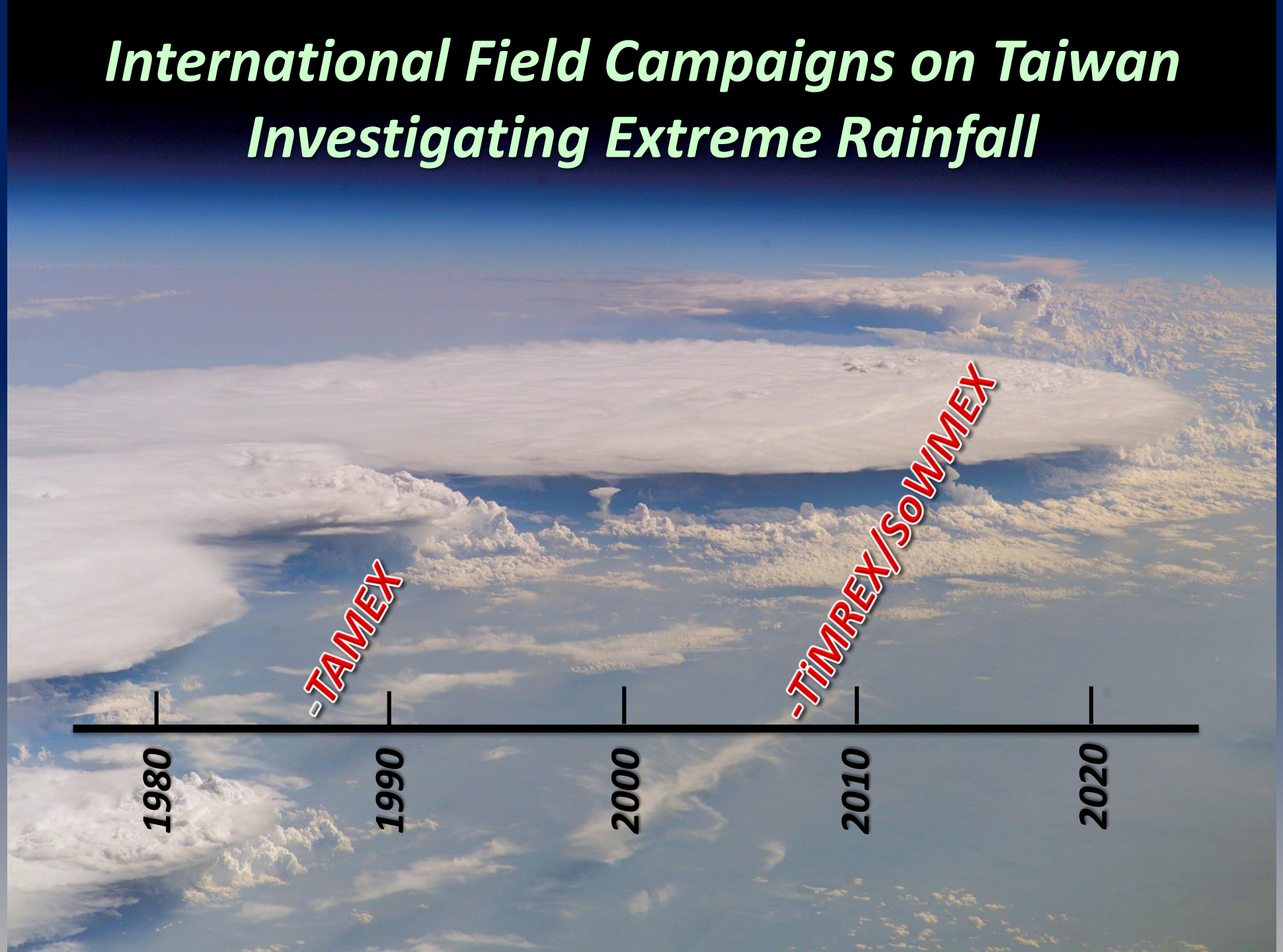


(Li, Chen and Lee 1997)

Back-building convection along Mei-Yu front

Courtesy: Richard Johnson

International Field Campaigns on Taiwan Investigating Extreme Rainfall



Southwest Monsoon Experiment

Terrain-influenced Monsoon Rainfall Experiment

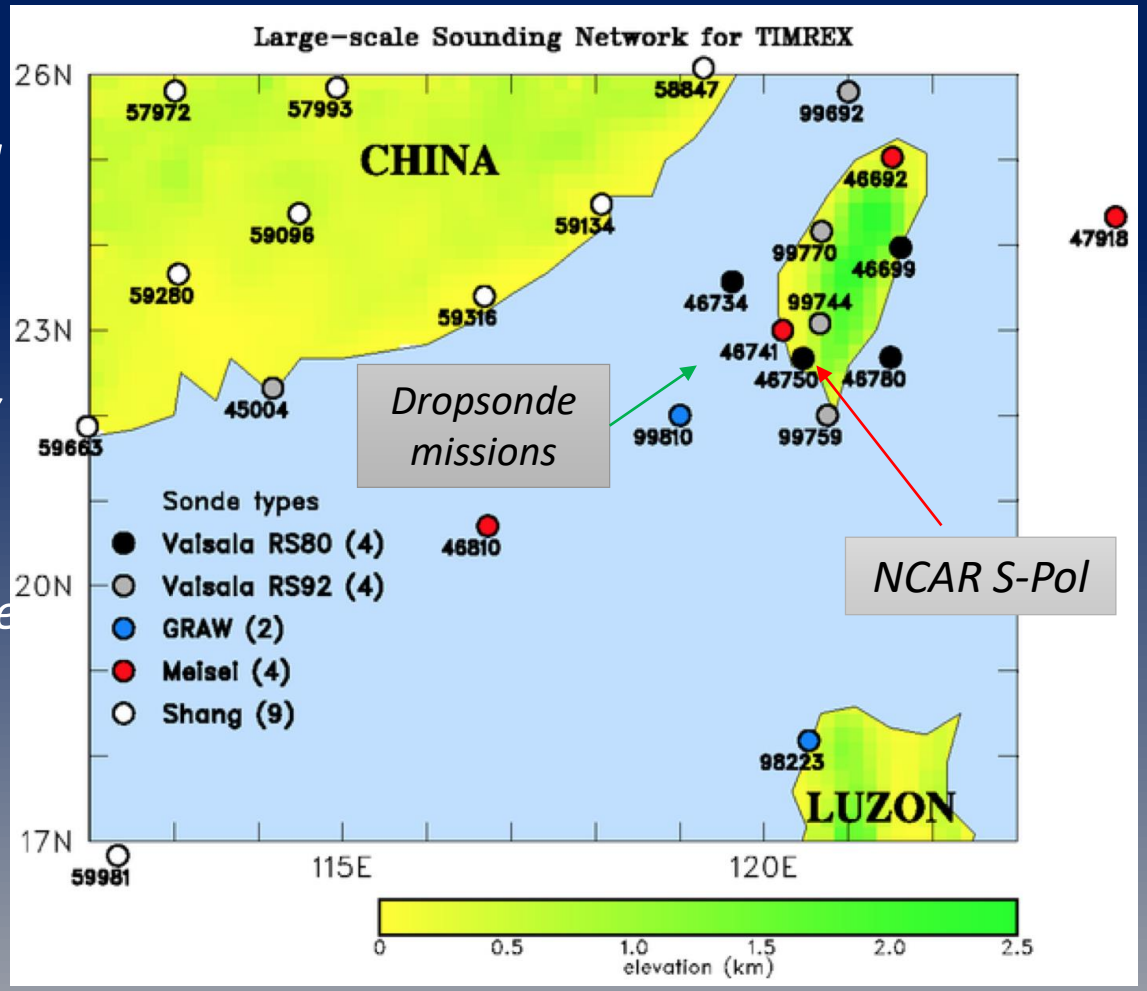
15 May – 30 June 2008

Scientific Objectives

- *Terrain effect on the flow and MCSs*
- *MCS dynamics, microphysics, and predictability*
- *Mesoscale data assimilation/ QPF*
- *Convective initiation/diurnal cycle/boundary layer processe*

Participants

- *Field phase: US-Taiwan*
- *Post-field phase activities/ workshops: Korea, Japan, Viet Nam, PRC*

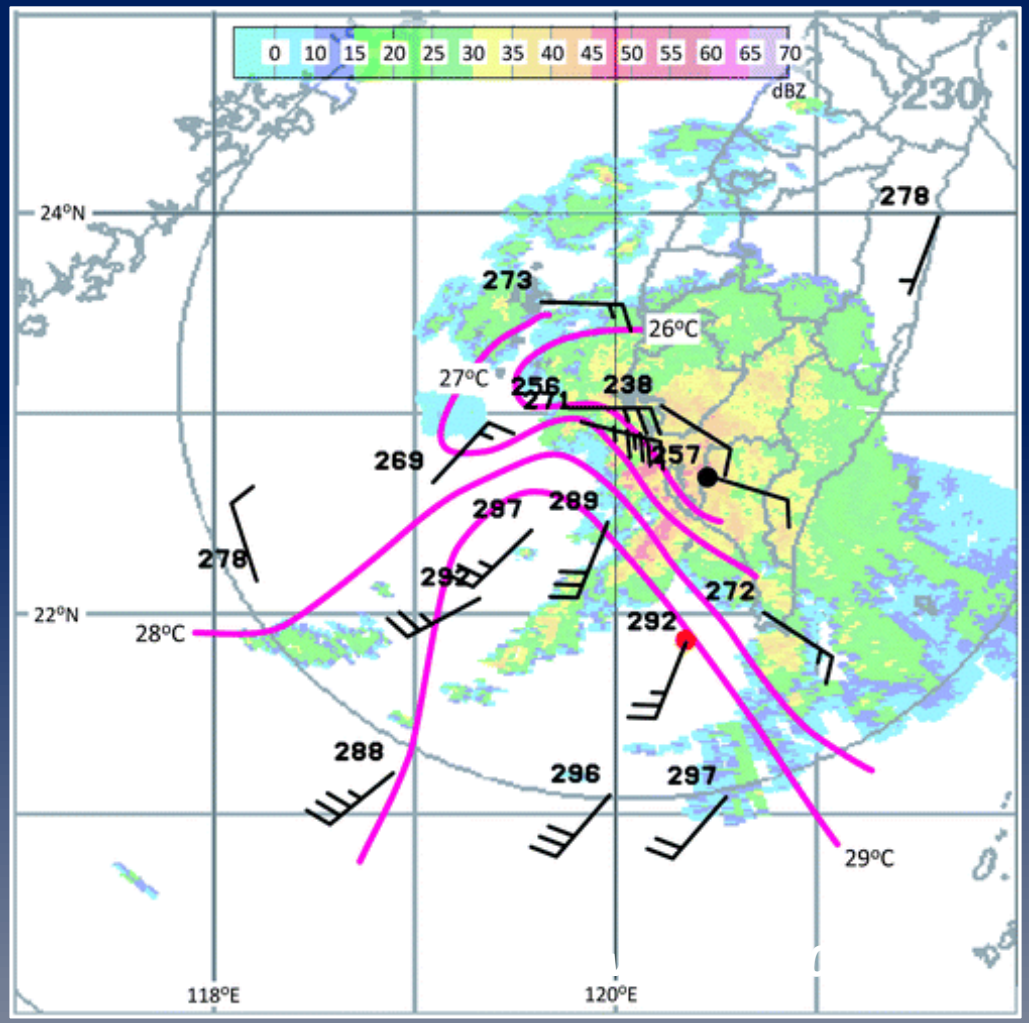


Courtesy: Richard Johnson

Observations of shallow fronts (Davis et al. 2012)

- *Despite shallowness and weak T gradient, impact on convection is significant*
- *T contrast reinforced by cool downdrafts over land*
- *Analogous to coastal fronts at higher latitudes*

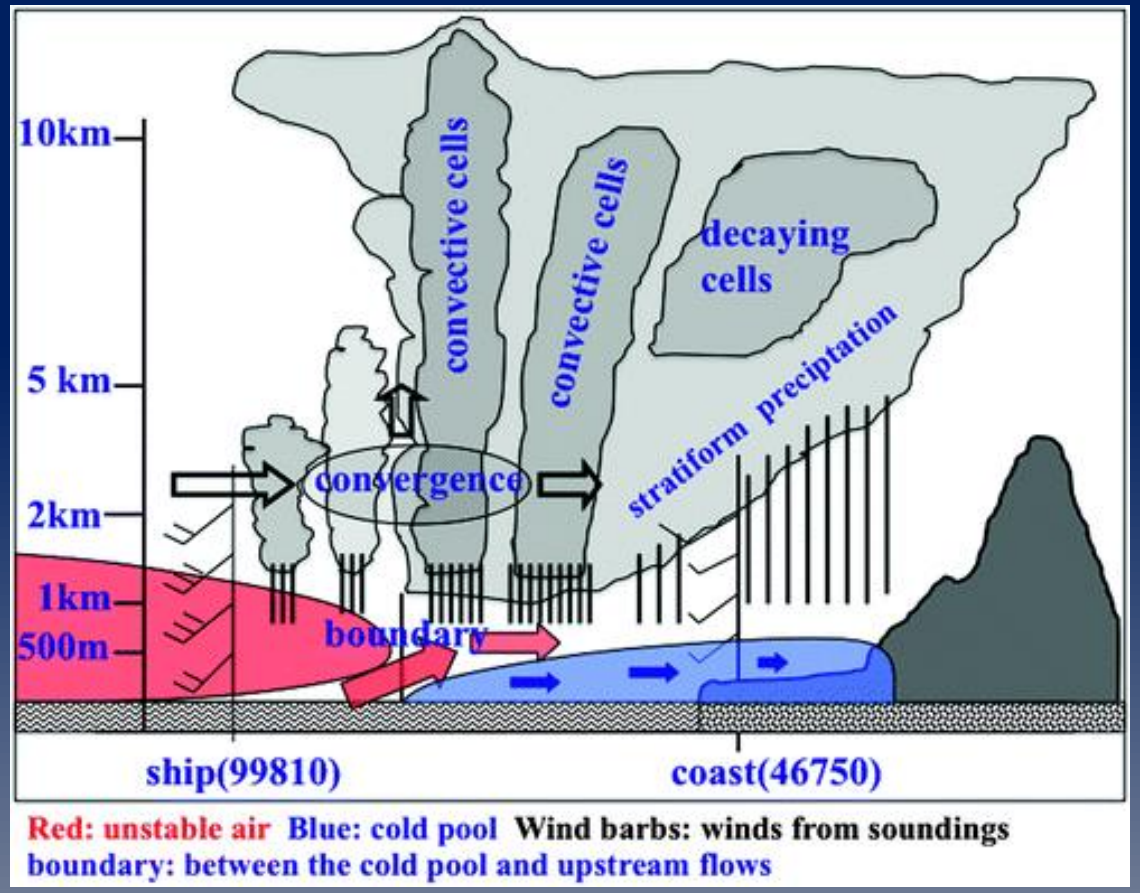
990 hPa wind, T_v at 06Z on 5 June 2008



Courtesy: Richard Johnson

Extreme rainfall 14-16 June 2008 (Xu et al. 2012)

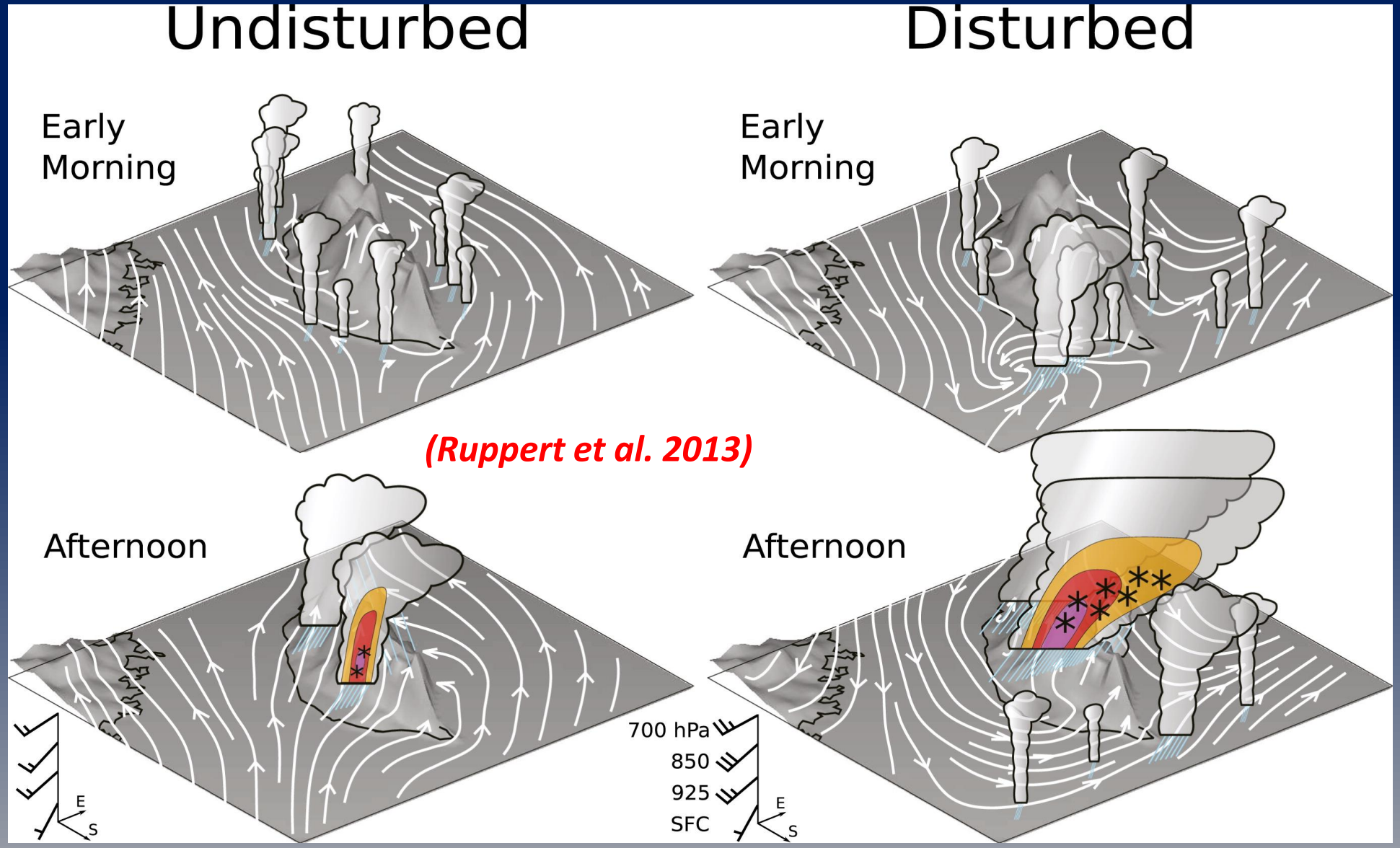
- *Convective cell triggering by low-level jet impinging on shallow cold pool*
- *Cold pool reinforced by continuous precipitation*
- *Cold pool trapped by terrain*
- *Virtual extension of island barrier to the southwest*



(Xu et al. 2012)

Diurnal Cycle of Convection during TiMREX

Courtesy: Richard Johnson



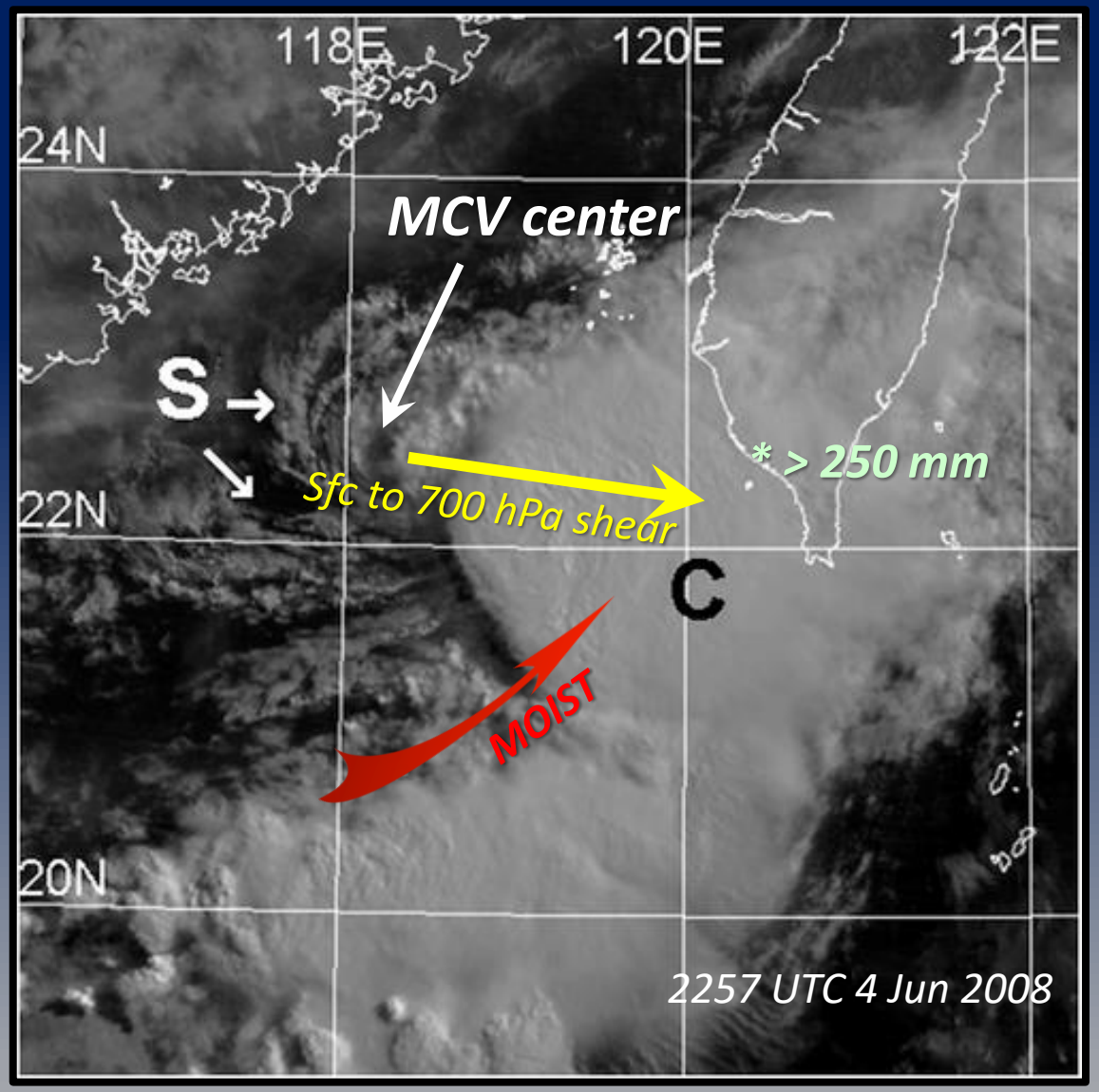
- *Morning rainfall offshore, afternoon maxima on coastal plain*
- *Dominant rainfall on at higher elevations over CMR in afternoon*

Mesoscale Convective Vortex (MCV) during TiMREX

4-5 June 2008 Heavy Rainfall
TiMREX/SoWMEX

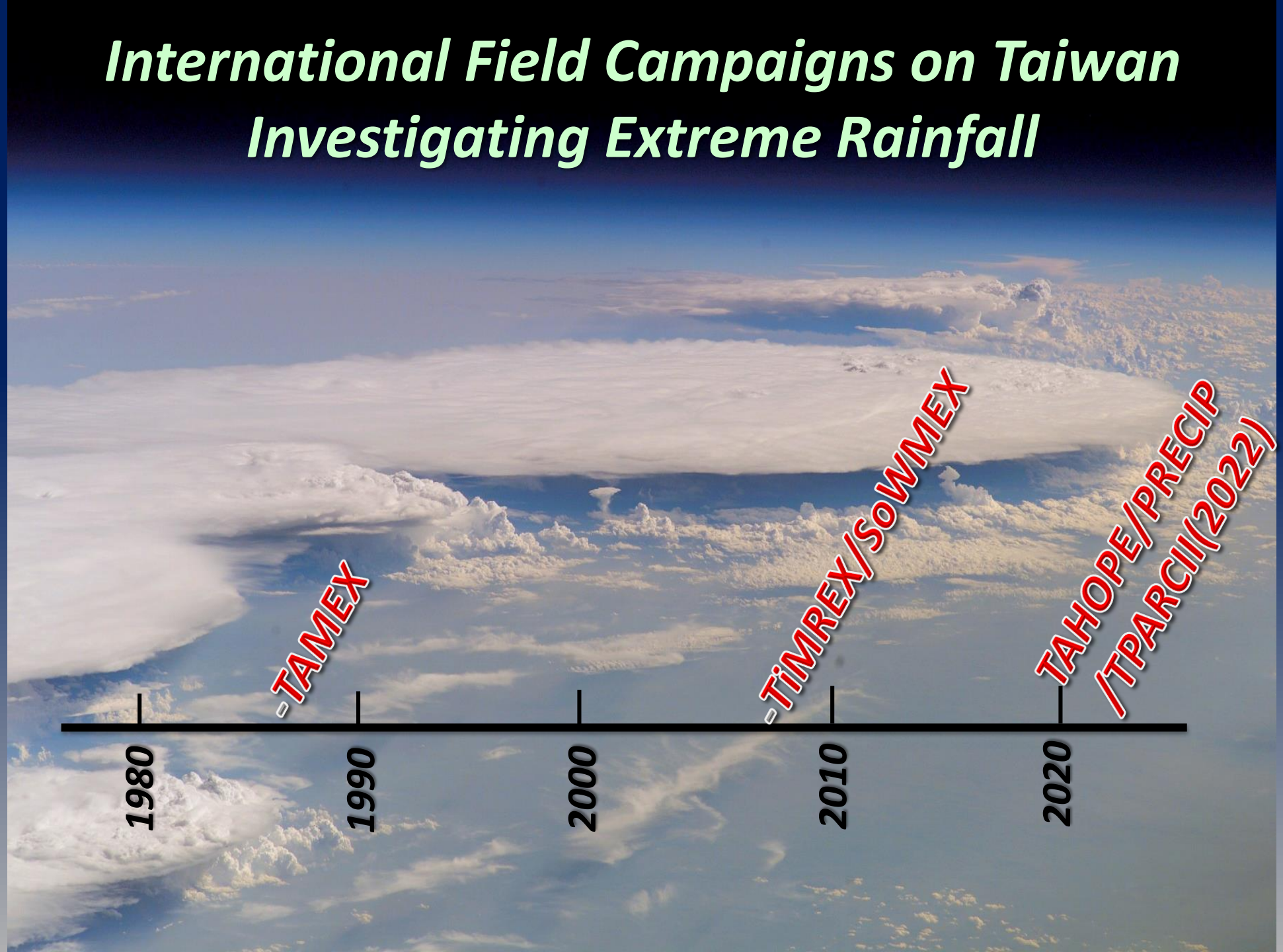
(Lai, Davis, and Jou 2011, MWR)

Heavy rain over southern Taiwan downshear of vortex center, aided by moist southwesterly flow



Courtesy: Richard Johnson

International Field Campaigns on Taiwan Investigating Extreme Rainfall

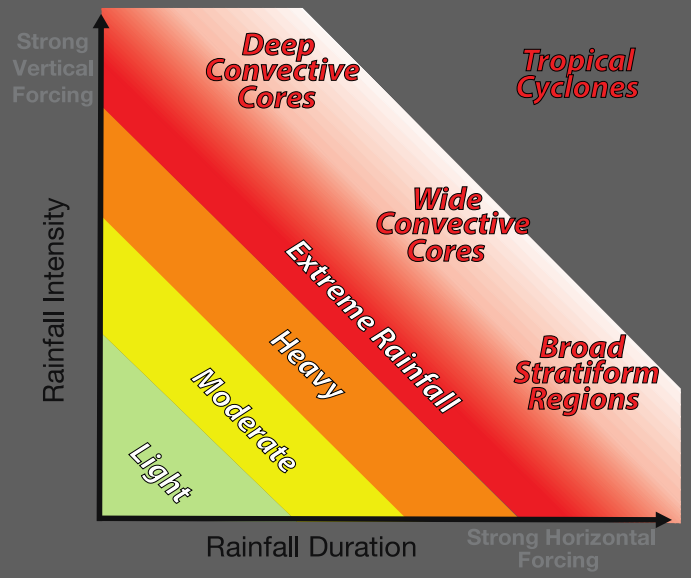


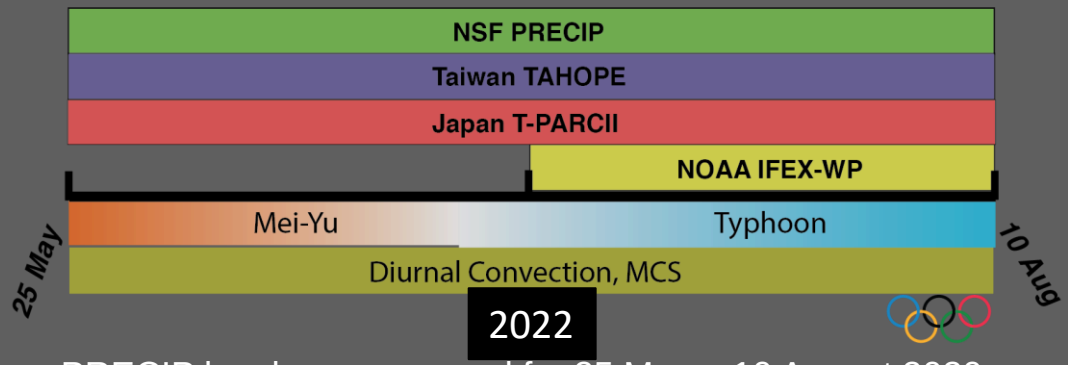
(Courtesy Michael Bell)

Prediction of Rainfall Extremes Campaign In the Pacific (PRECIP) ~~2020~~ 2022

Lead PIs: Michael M. Bell and Kristen L. Rasmussen

Colorado State University





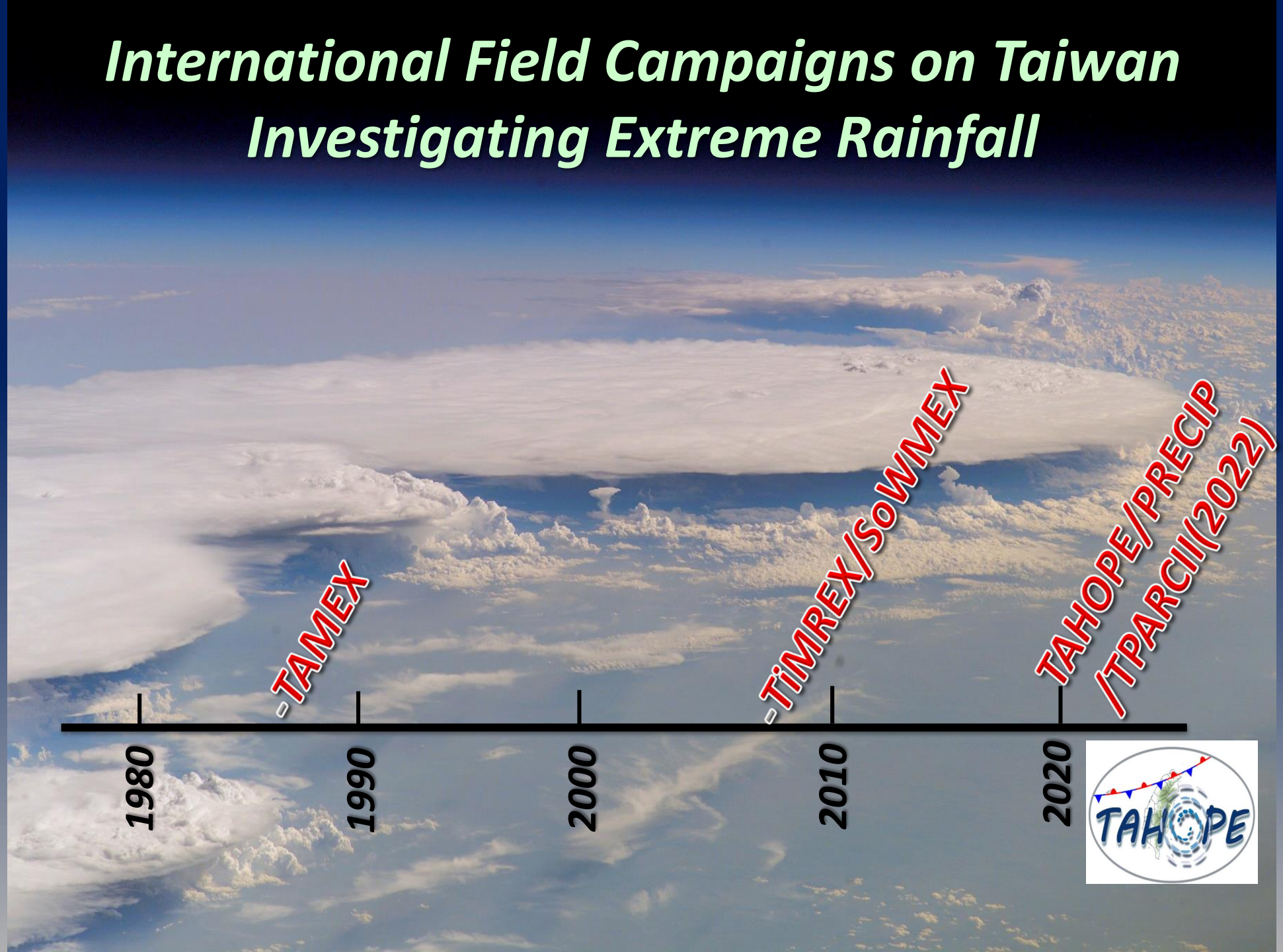
- PRECIP has been proposed for 25 May – 10 August ~~2020~~ 2022 to observe Meiyu front, MCSs, diurnal convection, and typhoons near Taiwan
- Part of an international effort to study extreme rainfall
  - Taiwan TAHOPE (Taiwan-Area Heavy rain Observation and Prediction)
  - Japan T-PARCII (Tropical cyclones-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts)
  - ~~NOAA IFEX-WP (Intensity Forecast Experiment – Western Pacific)~~

General Scientific Findings from TAMEX and SoWMEX/TiMREX

- *Moist, unstable conditions and weak CIN over Taiwan during onset of summer monsoon: convection is readily initiated by Meiyu front, cold pools, orography, flow blocking, SST gradients*
- *Extreme rainfall is often a result of a complex interplay among above processes*
- *MCS organization leading to extreme rainfall: many aspects similar to that observed elsewhere in the tropics and in the midlatitudes*

Courtesy: Richard Johnson

International Field Campaigns on Taiwan Investigating Extreme Rainfall



Focus on…

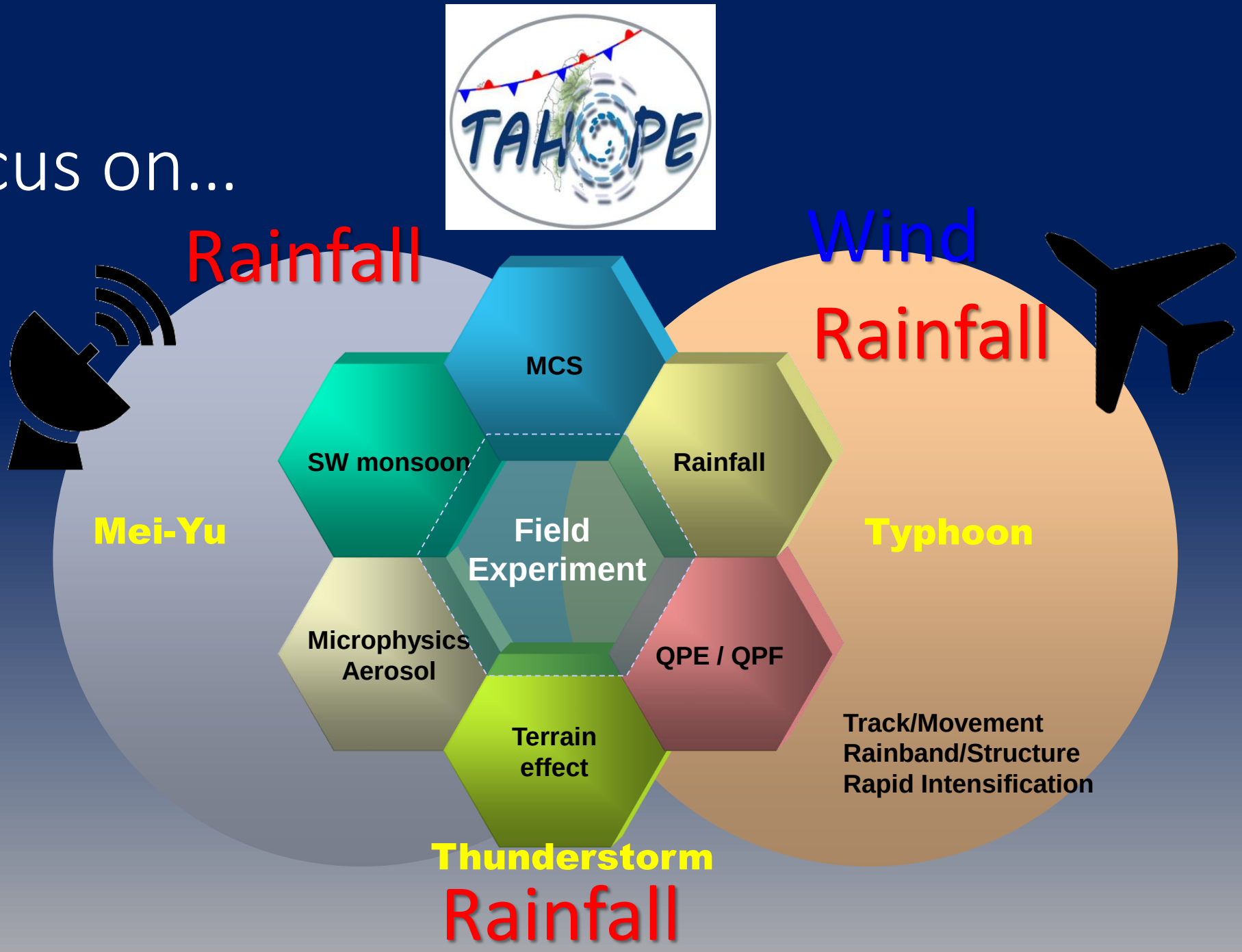

Rainfall
Wind
Rainfall
MCS
SW monsoon
Rainfall
Mei-Yu
Field
Experiment
Typhoon
Microphysics
Aerosol
QPE / QPF
Terrain
effect
Track/Movement
Rainband/Structure
Rapid Intensification
Thunderstorm
Rainfall

Table 1.1 *Atmospheric scale definitions. (Adapted after Thunis and Bornstein 1996.)*

Horizontal Scale	Lifetime	Stull (1988)	Pielke (2002)	Orlanski (1975)	Thunis and Bornstein (1996)	Atmospheric Phenomena
10 000 km	1 month	Macro	Synoptic Regional	Macro-α	Macro-α	General circulation, long waves
2000 km	1 week			Macro-β	Macro-β	Synoptic cyclones
200 km	1 day			Meso-α	Macro-γ	Fronts, hurricanes, tropical storms, short cyclone waves, mesoscale convective complexes
20 km	1 h	Meso	Meso	Meso-β	Meso-β	Mesocyclones, mesohighs, supercells, squall lines, inertia-gravity waves, cloud clusters, low-level jets thunderstorm groups, mountain waves, sea breezes
2 km				Meso-γ	Meso-γ	Thunderstorms, cumulonimbi, clear-air turbulence, heat island, macrobursts
200 m	30 min	Micro	Micro	Micro-α	Meso-δ	Cumulus, tornadoes, microbursts, hydraulic jumps
20 m	1 min			Micro-β	Micro-β	Plumes, wakes, waterspouts, dust devils
2 m	1 s	Micro δ		Micro-γ	Micro-γ	Turbulence, sound waves
					Micro-δ	

Source:
"*Mesoscale Dynamics*"
Textbook by Lin (2007)

Orlanski (1975; BAMS)

PI: Ming-Jen Yang
Taiwan

PI: Michael Bell
USA

PI: Kazuhisa Tsuboki
Japan

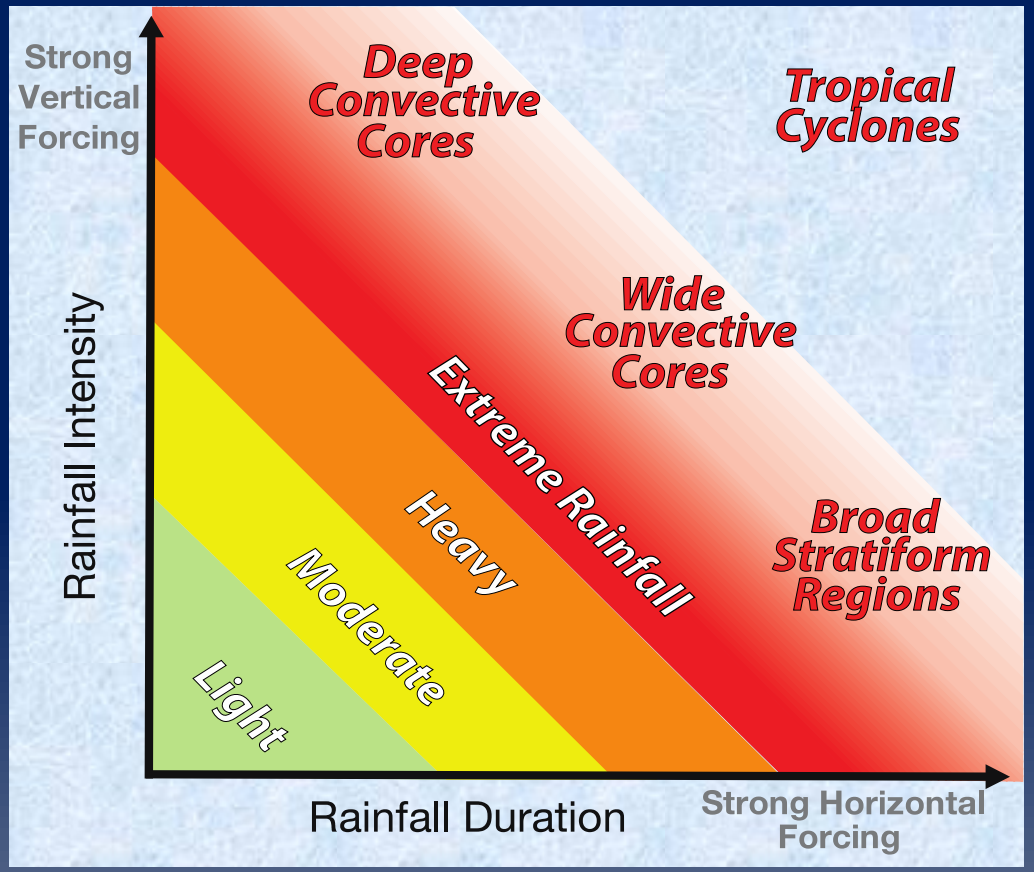
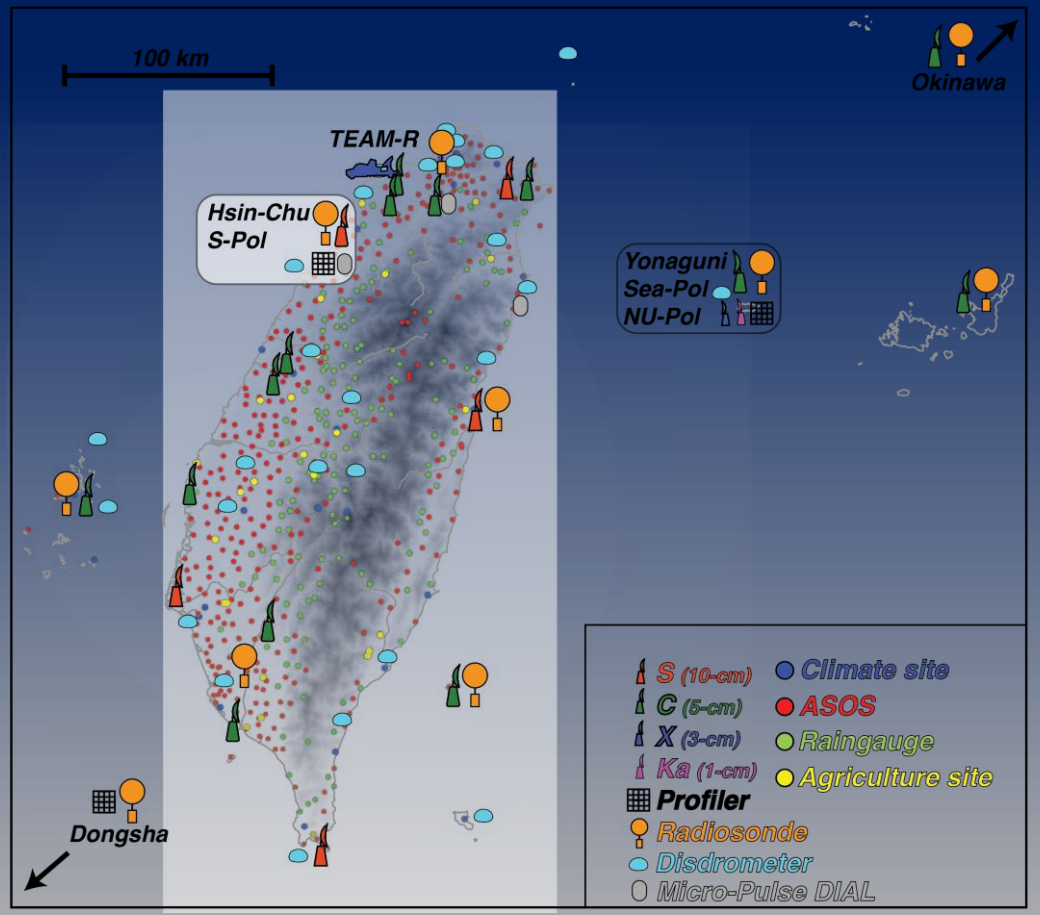


Figure from Michael Bell

- ***Primary objective*** is to simplify complexity of multi-scale interactions by identifying key ingredients and processes in the two limiting cases of high intensity and long duration events in a ***moisture-rich environment***

TAHPOPE/ PRECIP/ T-PARCII 2022



Slide from
Michael Bell

TAHOPE/PRECIP 2022
S-Pol Radar Antenna Assembly

Video from Dr. Wen-Chau Lee at NCAR

TAHOPE/PRECIP 2022
S-Pol Radar Observation

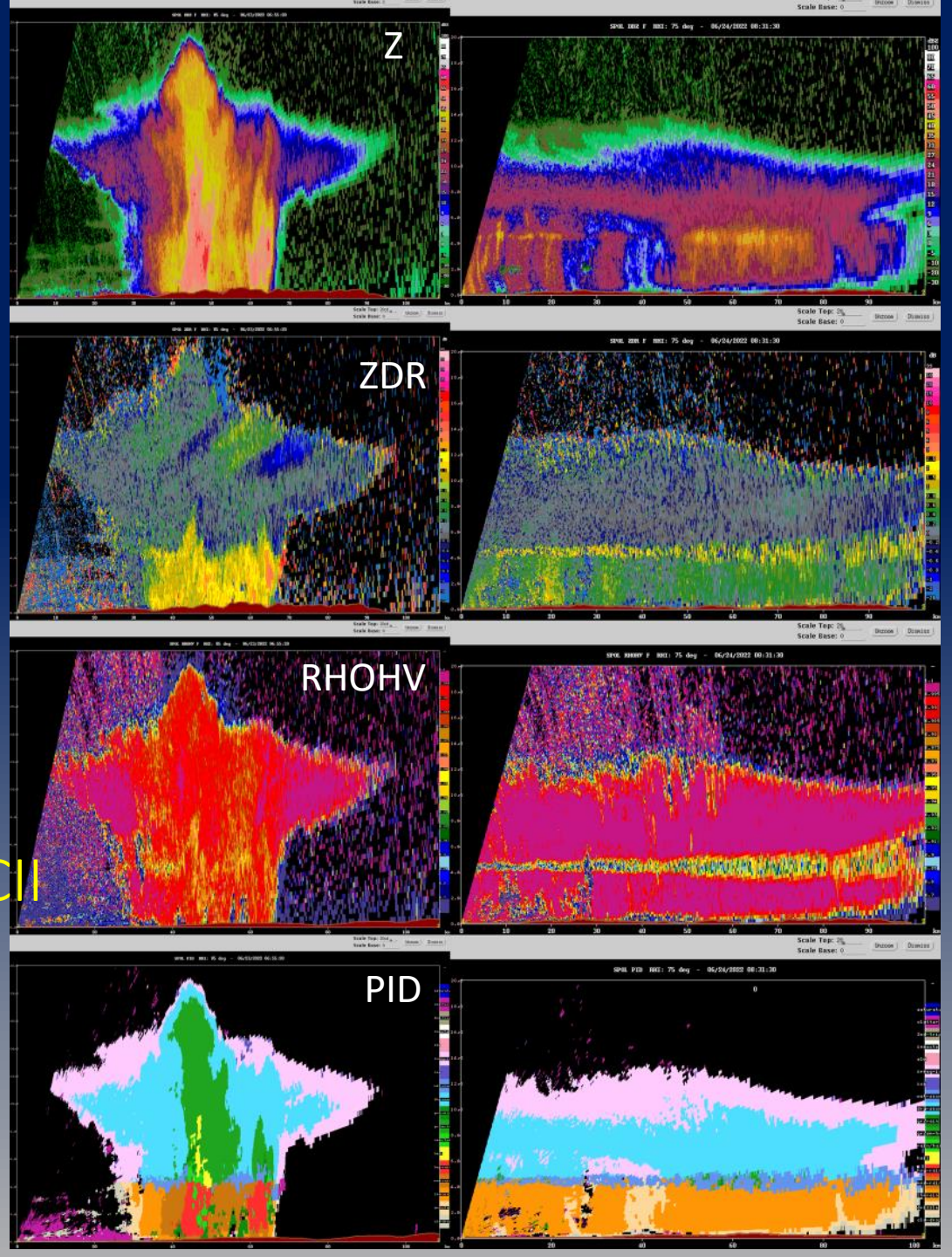
Video from Hsinchu County Government

TAHOPE/PRECIP 2022
Sounding Release on Pengjiayu Island

Video from Prof. Jou-Ping Hou at
National Defense University

Over 286,000 RHI scans in 2022

- S-Pol operated from 5/25 – 8/10 (78 days)
  - Over 176,000 RHIs
- SEA-POL operated from 6/10 – 8/22 (74 days)
  - Over 100,000 RHIs
- TEAM-R operated from 5/15 – 7/31 (78 days)
- 3 MPDs operated from 5/28 – 8/10 (75 days)
- 1,341 soundings from TAHOPE/PRECIP/T-PARCII
- 11 Intensive Observing Periods (IOPs) & 8 Special Observation Periods (SOPs)



List of IOPs & SOPs during TAHOPE 2022 (5/25 to 8/10 : 11 IOPs totally)

	Period	Description
SOP1	5/25 00Z – 5/26 00Z	Mei-Yu front and MCS
IOP1	5/26 00Z – 5/28 00Z	Mei-Yu front and MCS (Backbuilding MCS on 5/26)
IOP2	5/31 00Z – 5/31 12Z	Afternoon thunderstorm (Thunderstorms with seep echo top of 16-km over Yilan)
IOP3	6/06 06Z – 6/12 12Z	Quasi-stationary Mei-Yu front on Taiwan (Backbuilding MCS over Miaoli; a squall line approaching northern Taiwan on 6/10)
IOP4	6/15 00Z – 6/16 00Z	Prefrontal southwesterly in a weakening Mei-Yu front (Dry air intrusion at low level over northern Taiwan)
SOP2	6/23 00Z – 6/24 00Z	Afternoon thunderstorm
SOP3	6/24 00Z – 6/25 00Z	Afternoon thunderstorm (Hail case at Taipei Basin)
IOP5	6/25 00Z – 6/25 15Z	Afternoon thunderstorm (Intense thunderstorms over Taipei, Taoyuan, and Miaoli)
SOP4	6/29 00Z – 6/30 00Z	Afternoon thunderstorm
IOP6	7/01 00Z – 7/04 00Z	Rainfall associated with TC Chaba and TC Aere (Heavy rainfall on eastern and southern Taiwan)

List of IOPs & SOPs during TAHOPE 2022 (5/25 to 8/10 in Year 2022: 11 IOPs totally)

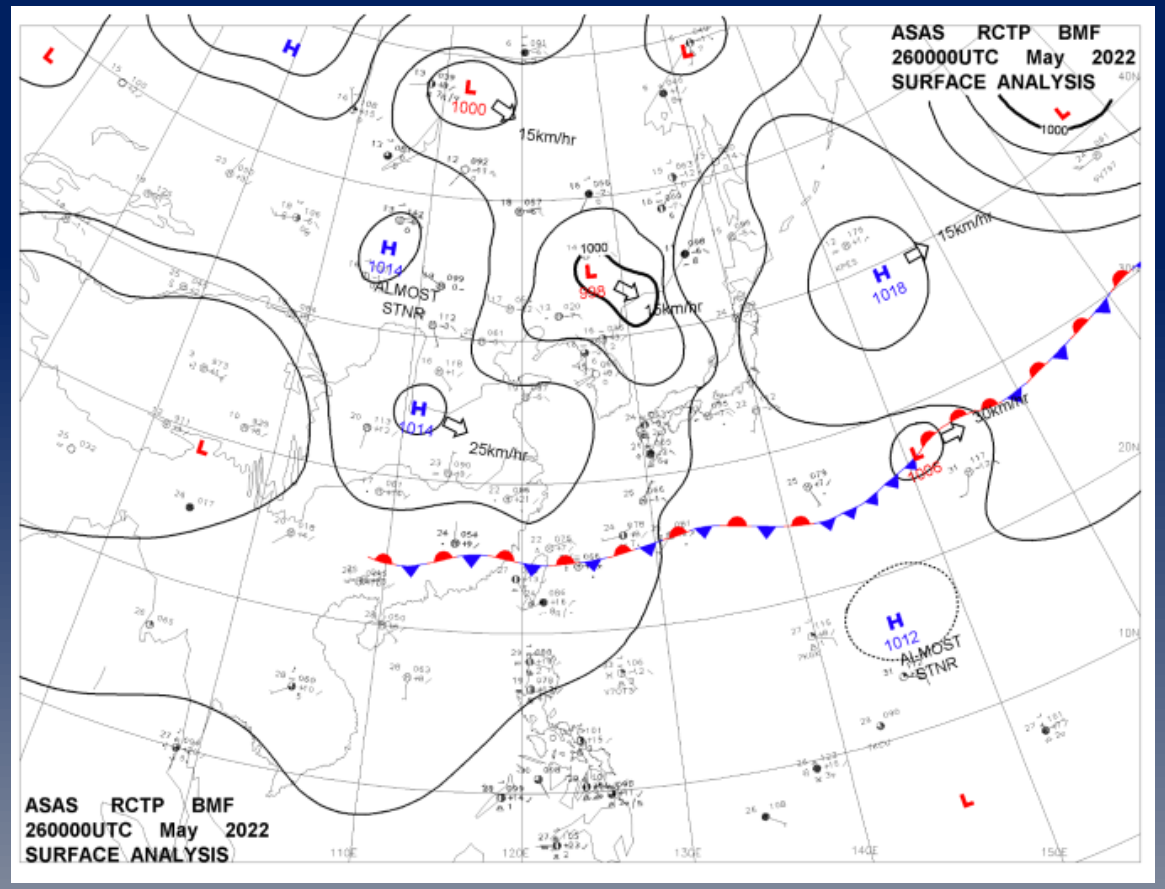
IOP7	7/05 00Z – 7/05 04Z	Typhoon Aere approaching Kyushu with dropsondes observation (Heavy rainfall over Kyushu and Honshu)
SOP5	7/05 00Z – 7/06 00Z	Afternoon thunderstorm at Taipei Basin
SOP6	7/06 00Z – 7/07 00Z	Afternoon thunderstorm at Taipei Basin
IOP8	7/13 06Z – 7/16 06Z	Rainfall associated with TD 90W (Heavy rainfall on eastern and southern Taiwan)
SOP7	7/19 00Z – 7/20 00Z	Afternoon thunderstorm at Taipei Basin
SOP8	7/20 00Z – 7/21 00Z	Afternoon thunderstorm at Taipei Basin
IOP9	7/29 00Z – 7/29 12Z	Moisture transport by low pressure and afternoon thunderstorm (Heavy rainfall in the evening; thunderstorms and lightning over northern Taiwan)
IOP10	8/01 00Z – 8/03 18Z	Moisture transport by low pressure (Heavy rainfall in Taipei Basin, central and southern Taiwan)
IOP11	8/04 00Z – 8/04 12Z	Afternoon thunderstorm (Thunderstorms in Taipei Basin)

備註：

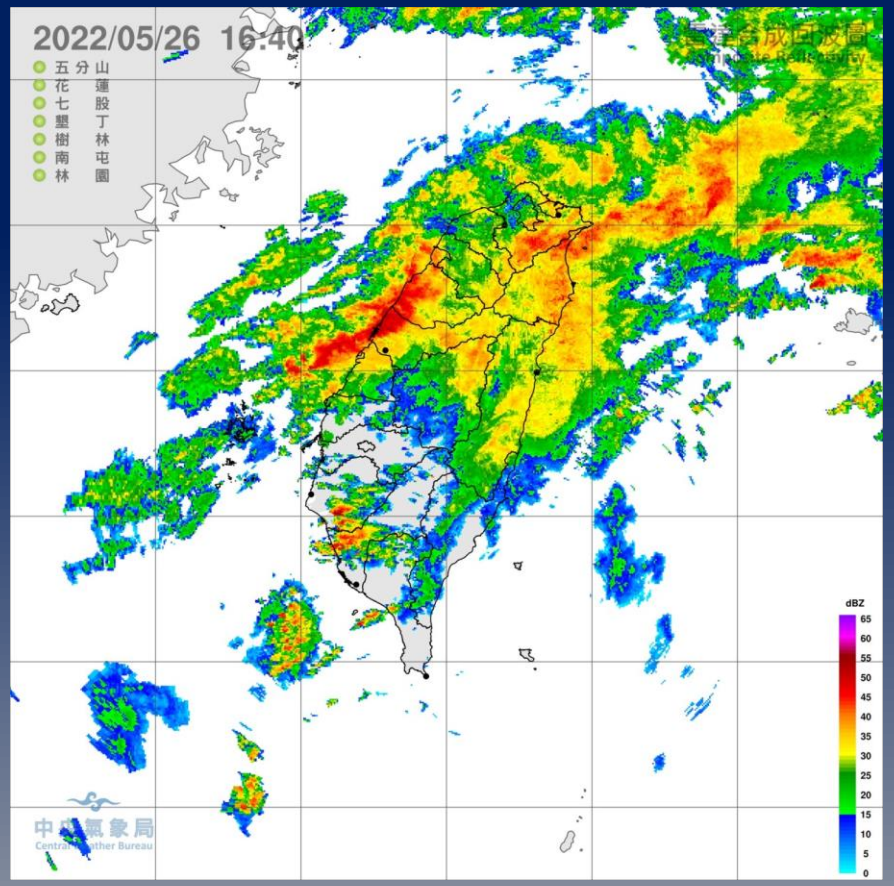
IOP (intensive observation periods)為有劇烈降水天氣且有額外密集觀測之個案。

SOP (special observation periods)為有劇烈降水天氣，但沒有額外密集觀測之個案(無探空加放)。

IOP1 weather feature: Backbuilding MCS along a Mei-Yu front

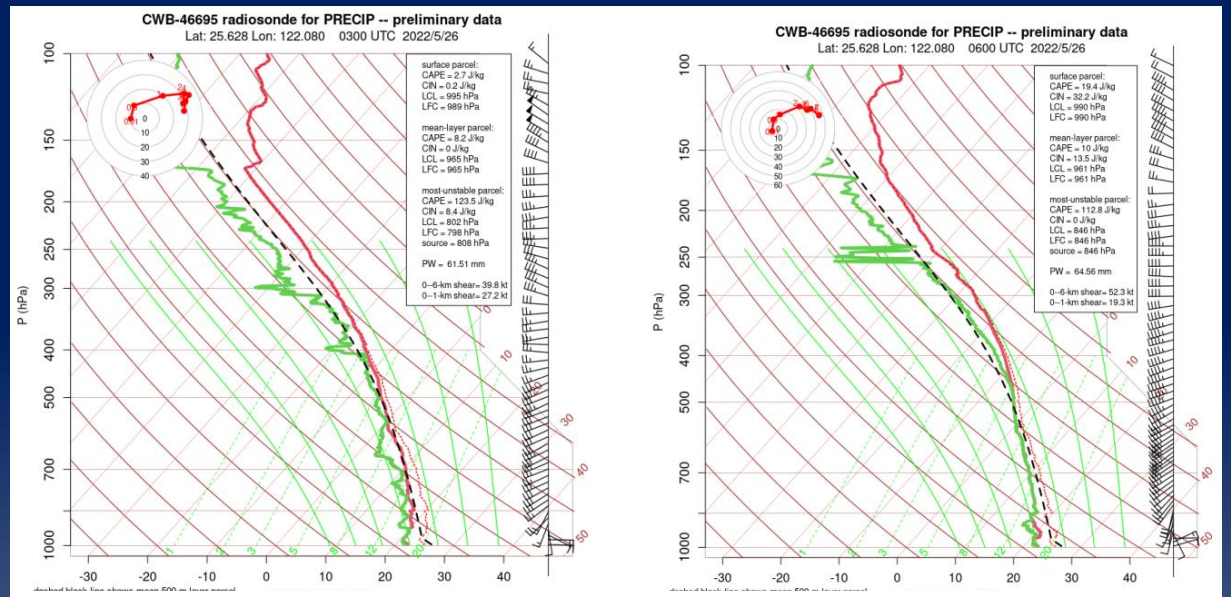


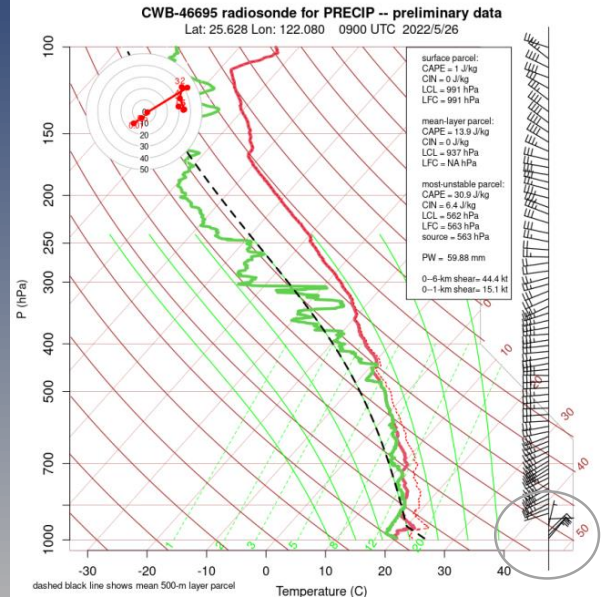
Surface weather map on 00 UTC 26 May: A May-Yu front is approaching from southeastern China to Taiwan

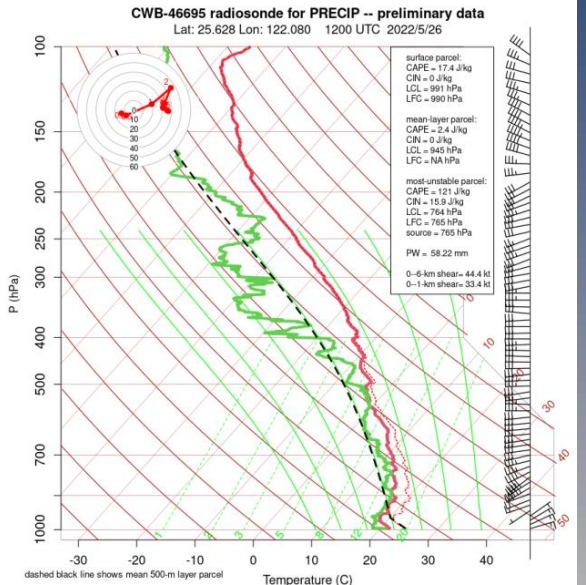


An MCS with backbuilding structure on 26 May for IOP 1

3-hourly Pengjiayu soundings at 03, 06, 09 and 12 Z on May 26

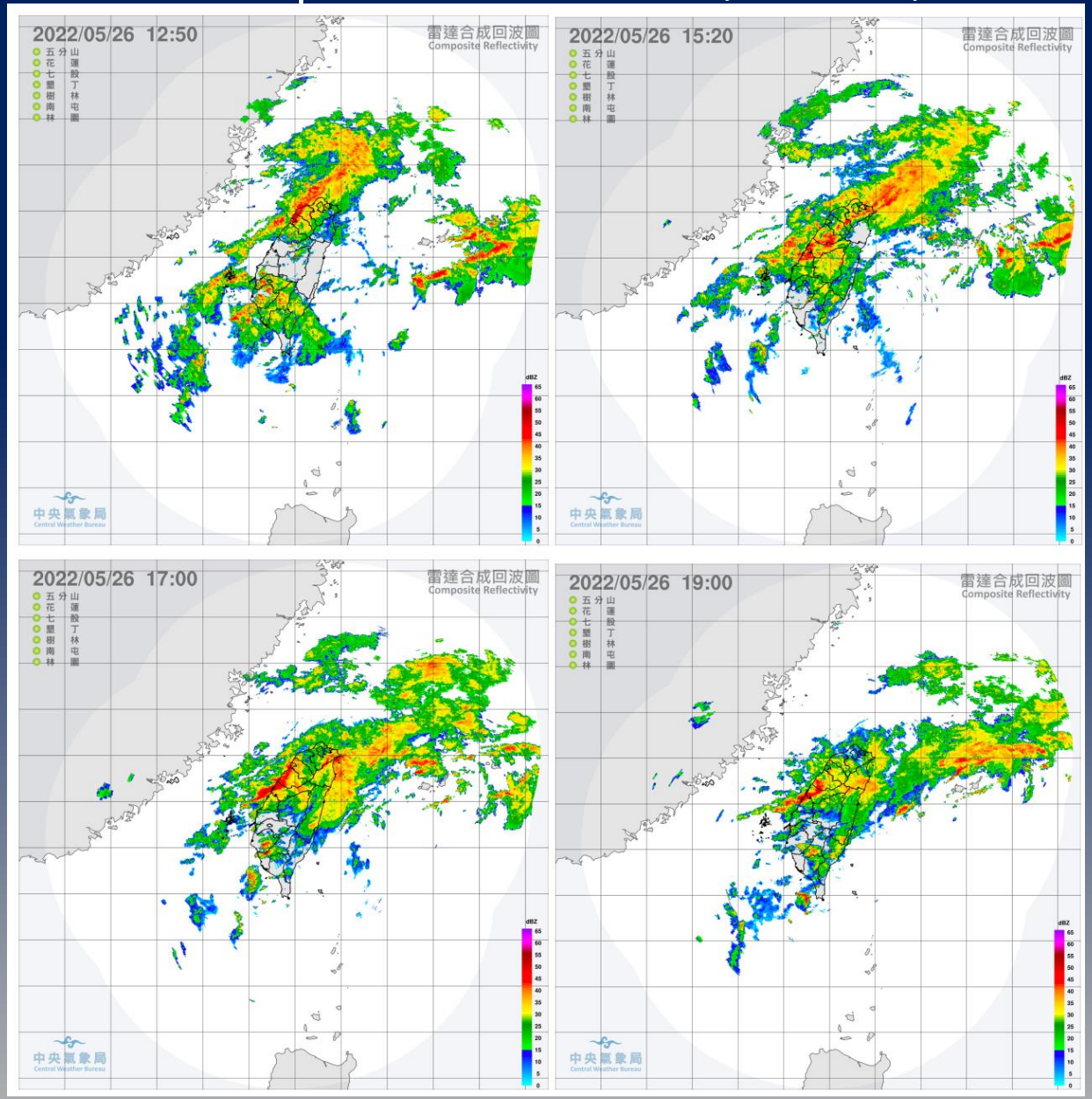






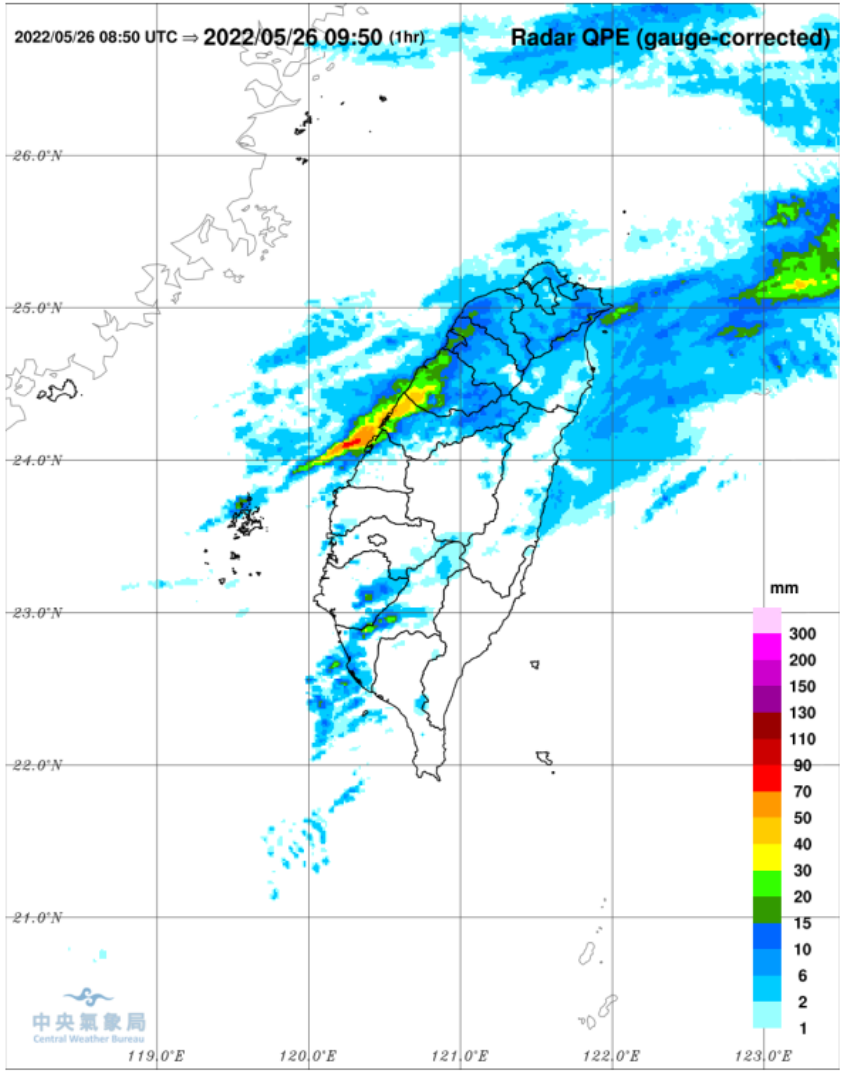
Pengjiayu surface wind turned to northerly at 09 UTC, indicating the passage of the Mei-Yu front.

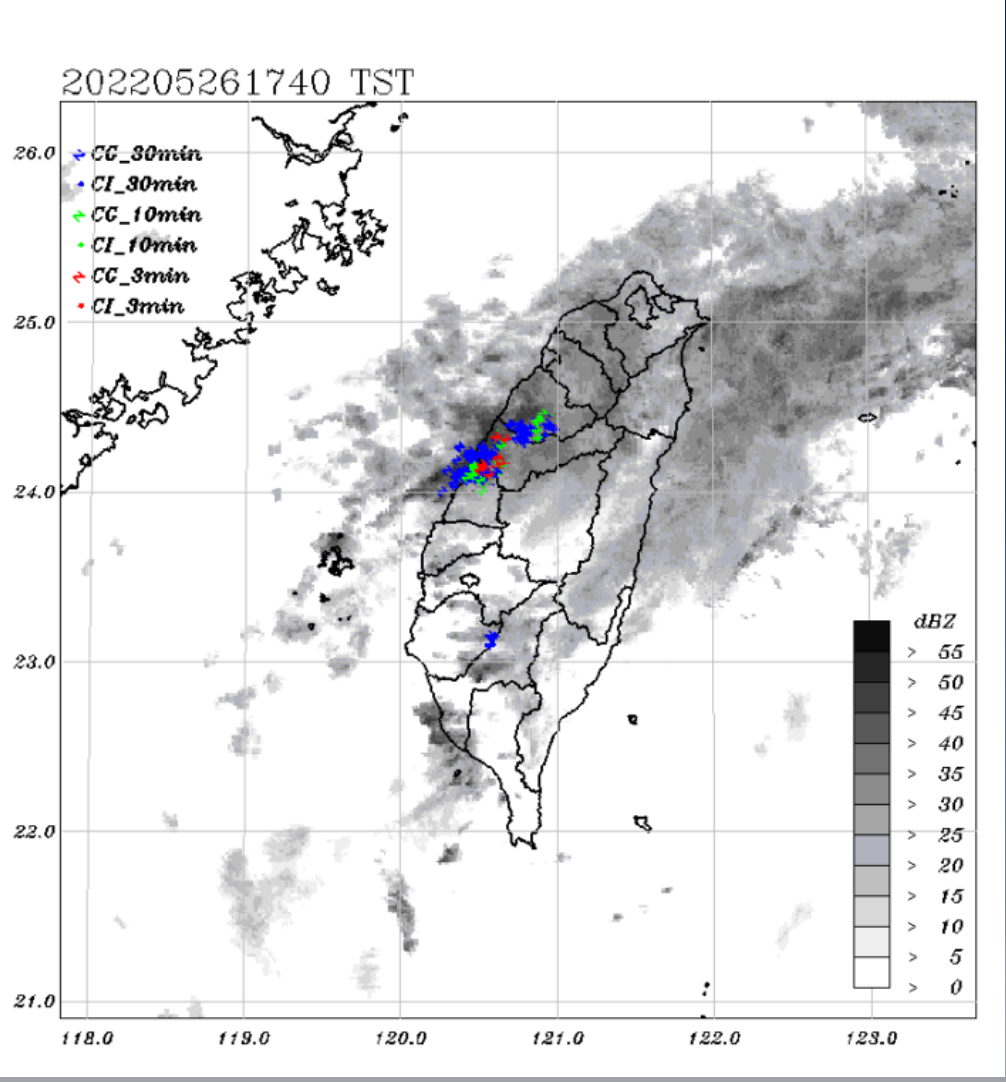
CWB radar composite at 1250, 1520, 1700 and 1900 LST on May 26



Radar composites highlight the movement of a NE-SW rainband over the western Taiwan, with new cells forming on the upstream side of this rainband, a signature of back-building MCS.

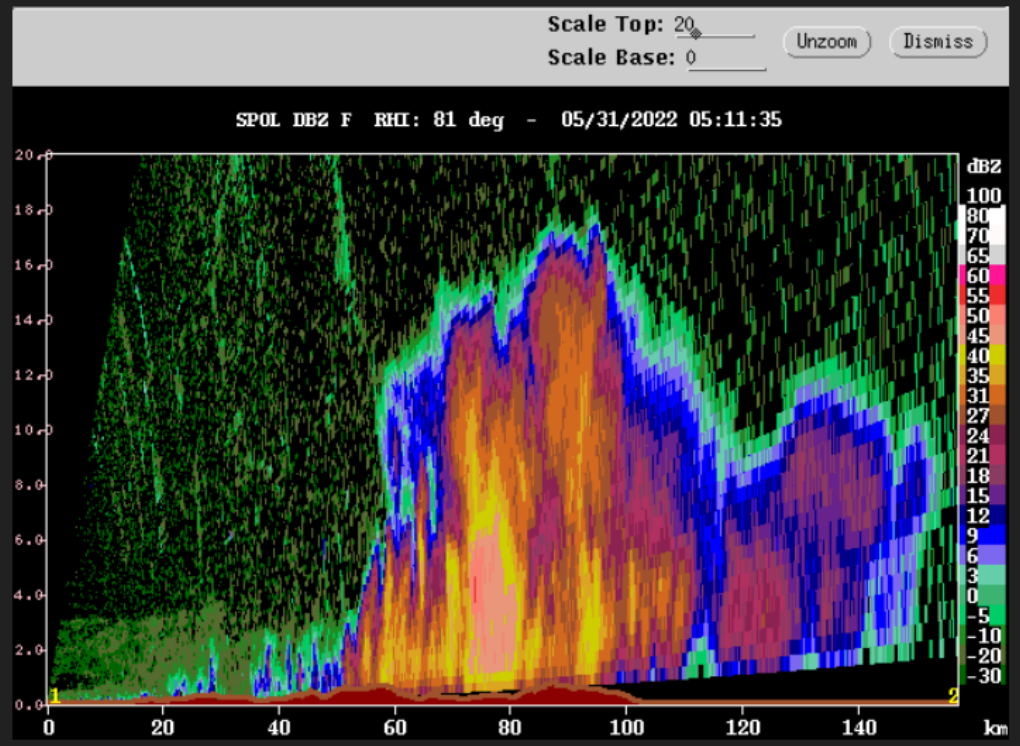
Notable period of 1-h radar-estimated rainfall and lightning at 1740 LST on May 26



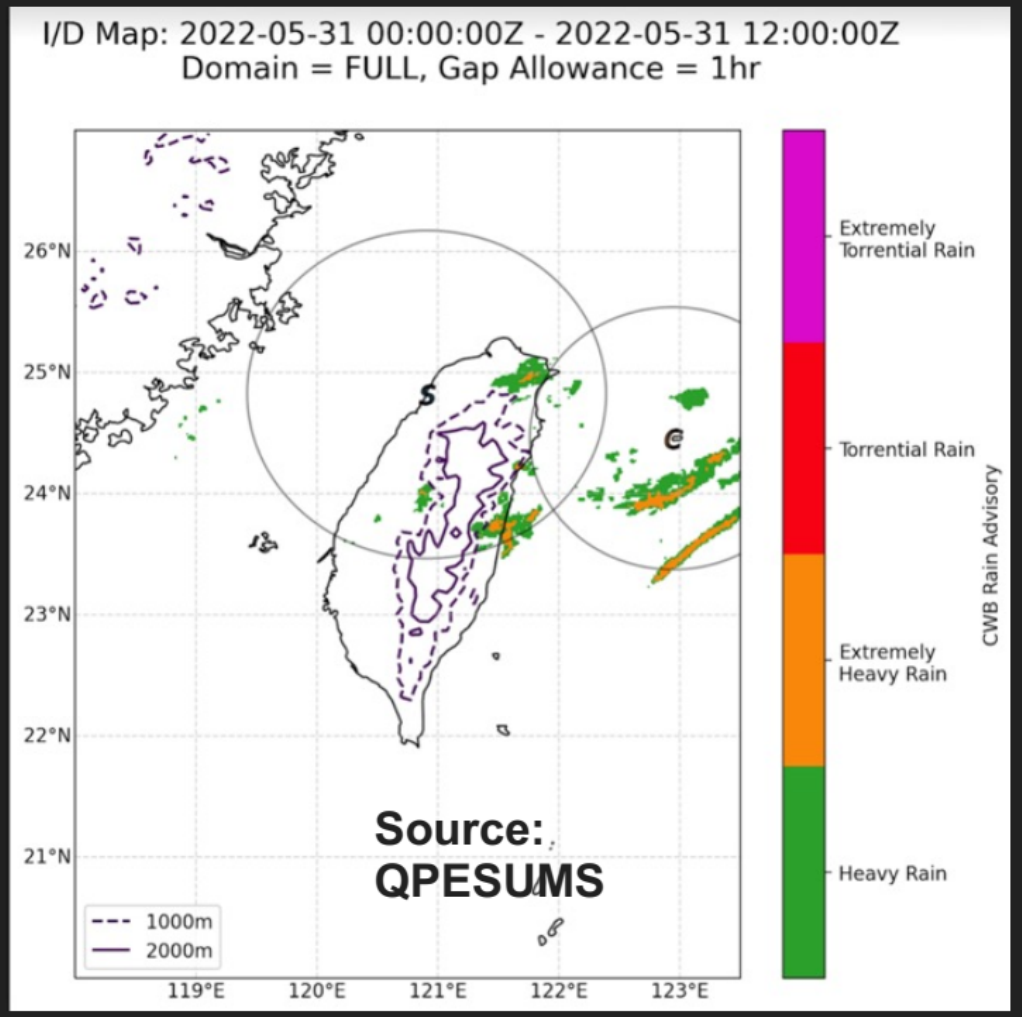


Hourly rainfall > 70 mm/h and intense lightning over central Taiwan.

PRECIP/TAHOPE observations – IOP2

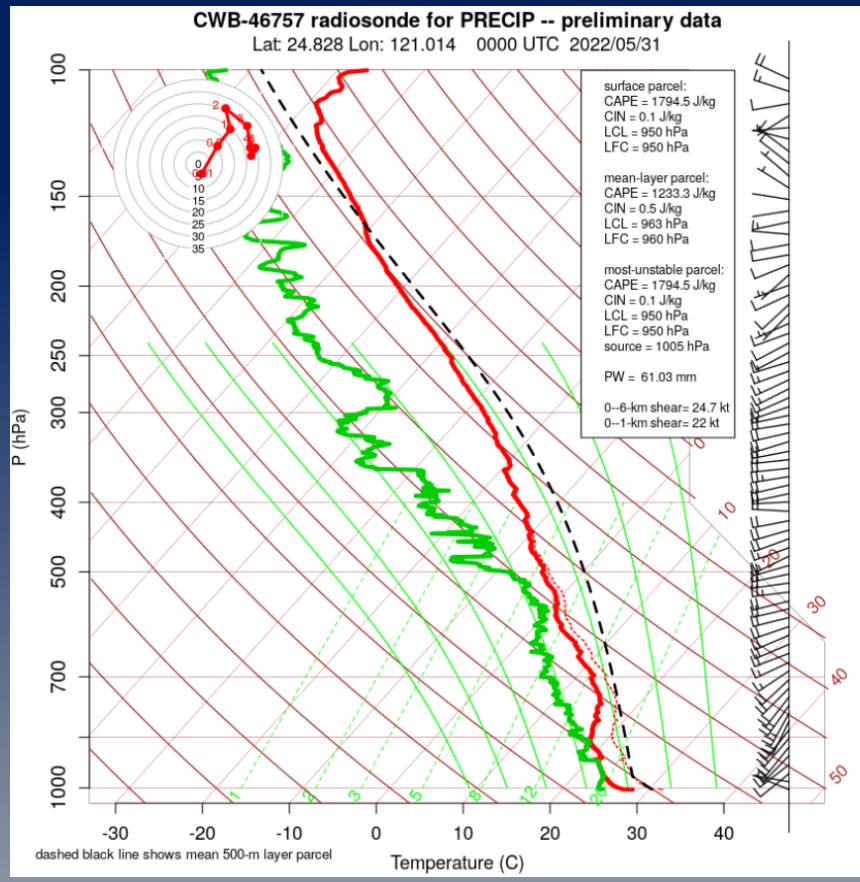


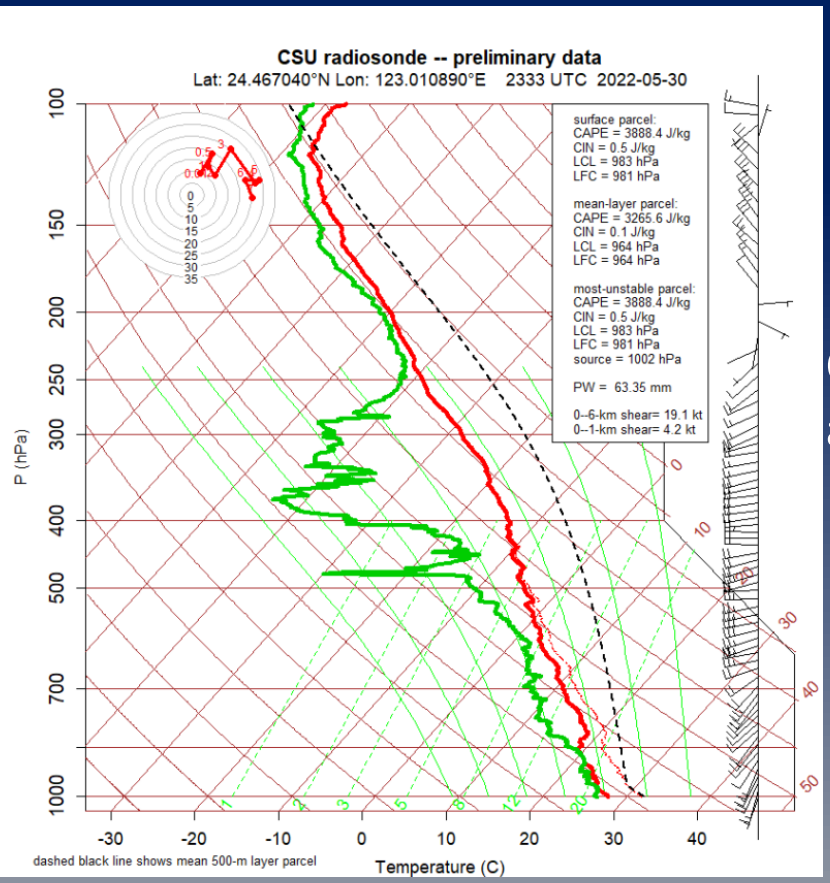
S-Pol (05 UTC 31 May)



Strong convective instability indicated by 00 UTC soundings at Hsinchu (left) and Yonaguni (right)

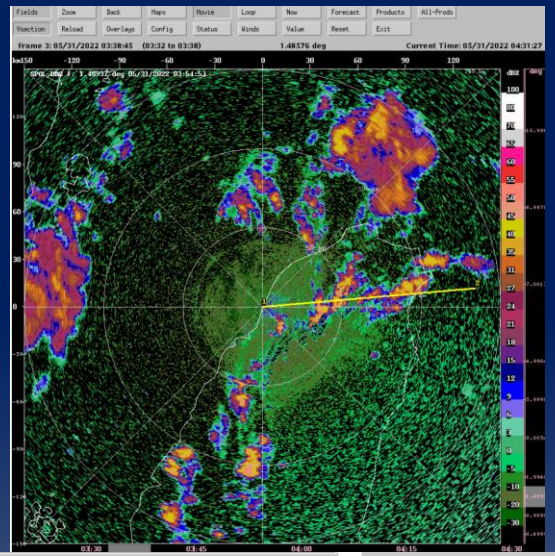
CAPE ~ 1800 J/kg at Hsinchu



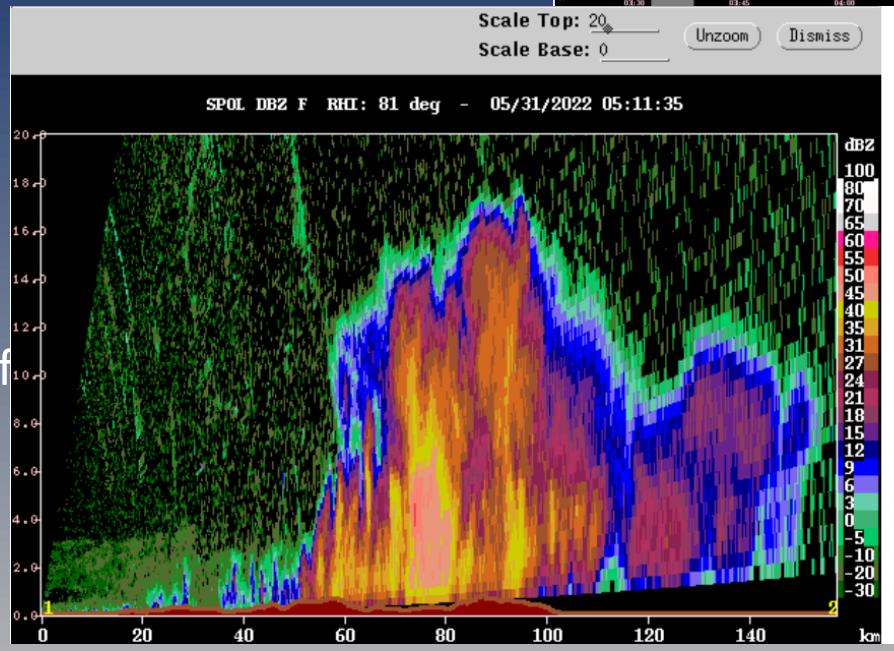


CAPE ~ 3900 J/kg at Yonaguni Island

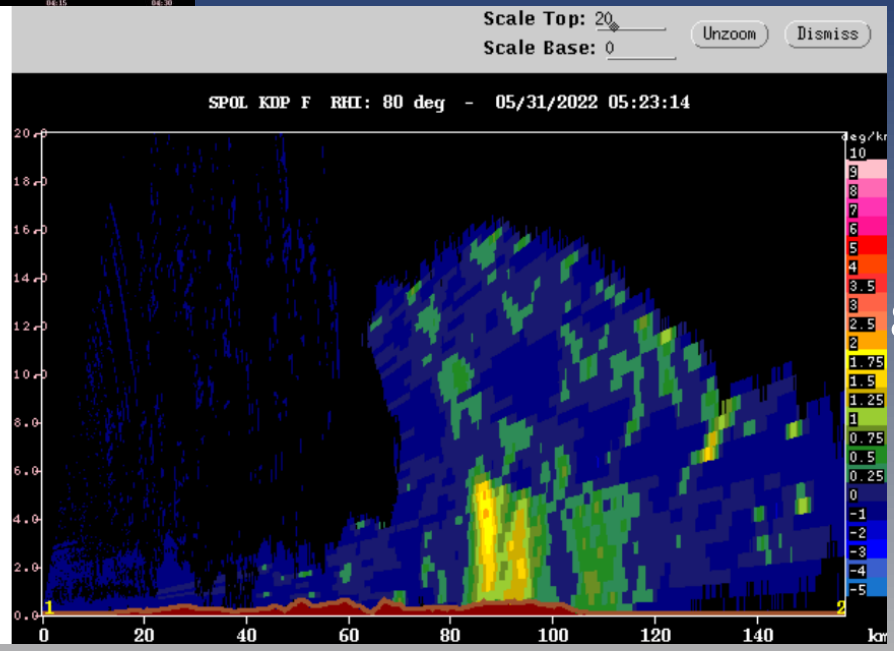
S-Pol radar observations of deep convective cells for the IOP2 afternoon thunderstorms



Reflectivity PPI at 0431 UTC

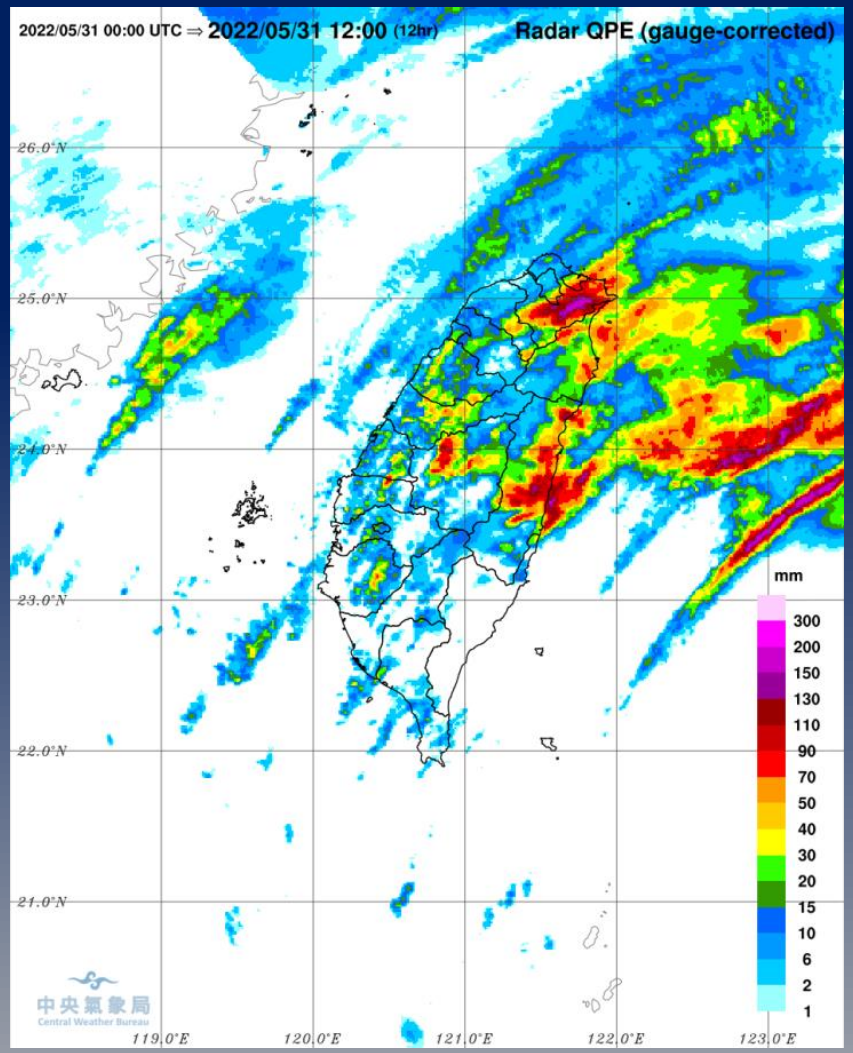


81-degree RHI of Z echo top ~ 16 km at 0511 UTC



81-degree RHI of KDP at 0511 UTC

Intense rainfall for the IOP2 afternoon thunderstorms



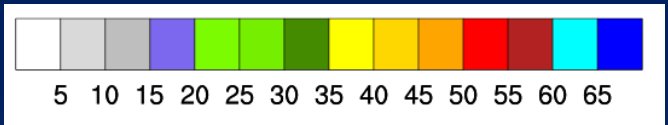
12-h radar-estimated rainfall > 150 mm over NE and eastern Taiwan for IOP2 event

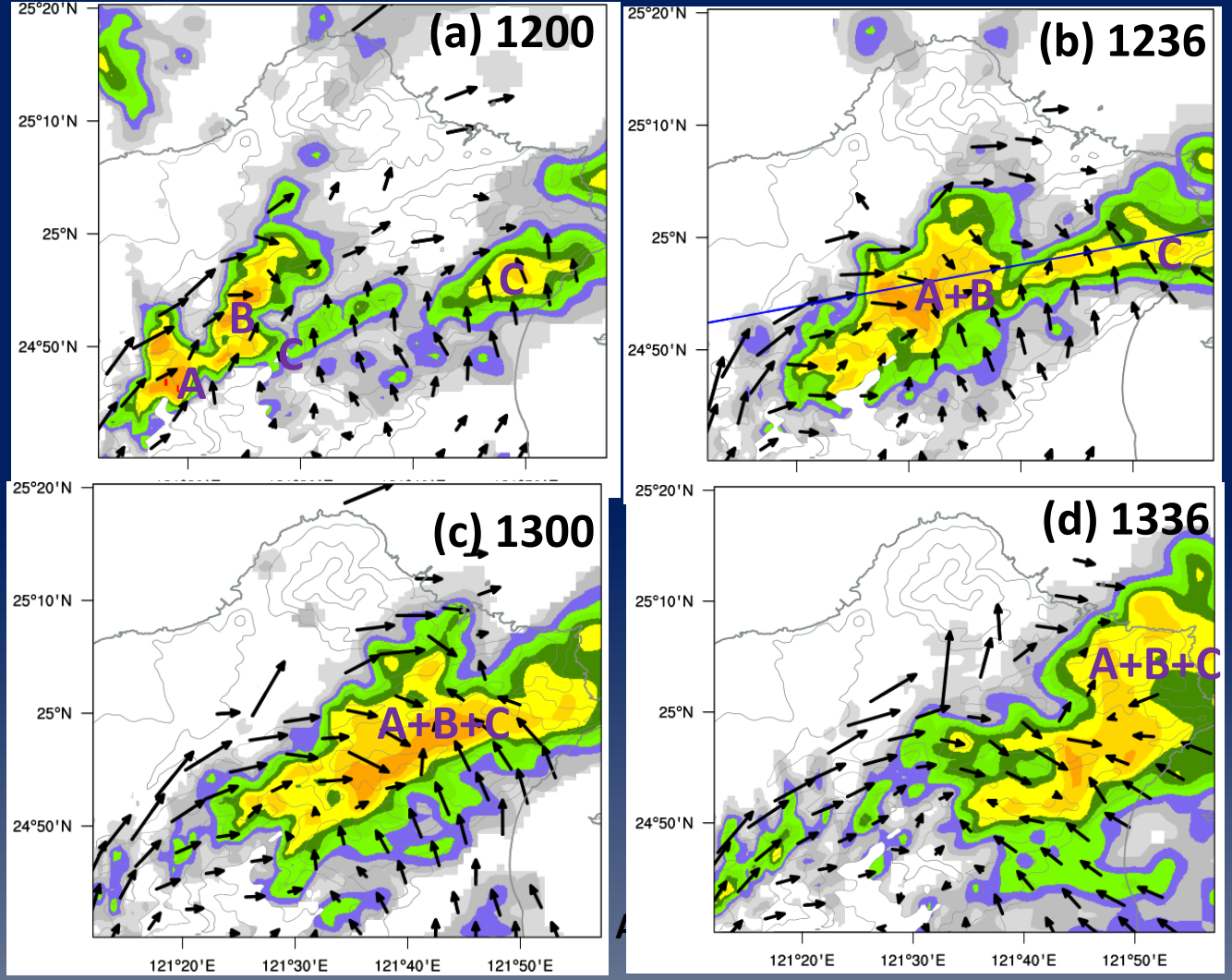
⇒ meets the CWB Heavy Rain Warming criteria

⇒ Heavy rain alert and flash flood alert were issued by CWB at 0431 and 0531 UTC

Source: Jack Miao

horizontal wind (vector) at Z=1.5 km, and ZH (colored) at Z=1.5 km

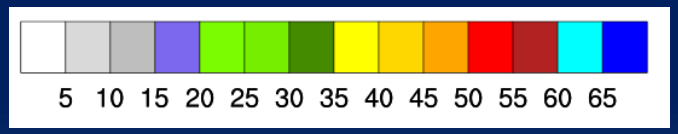


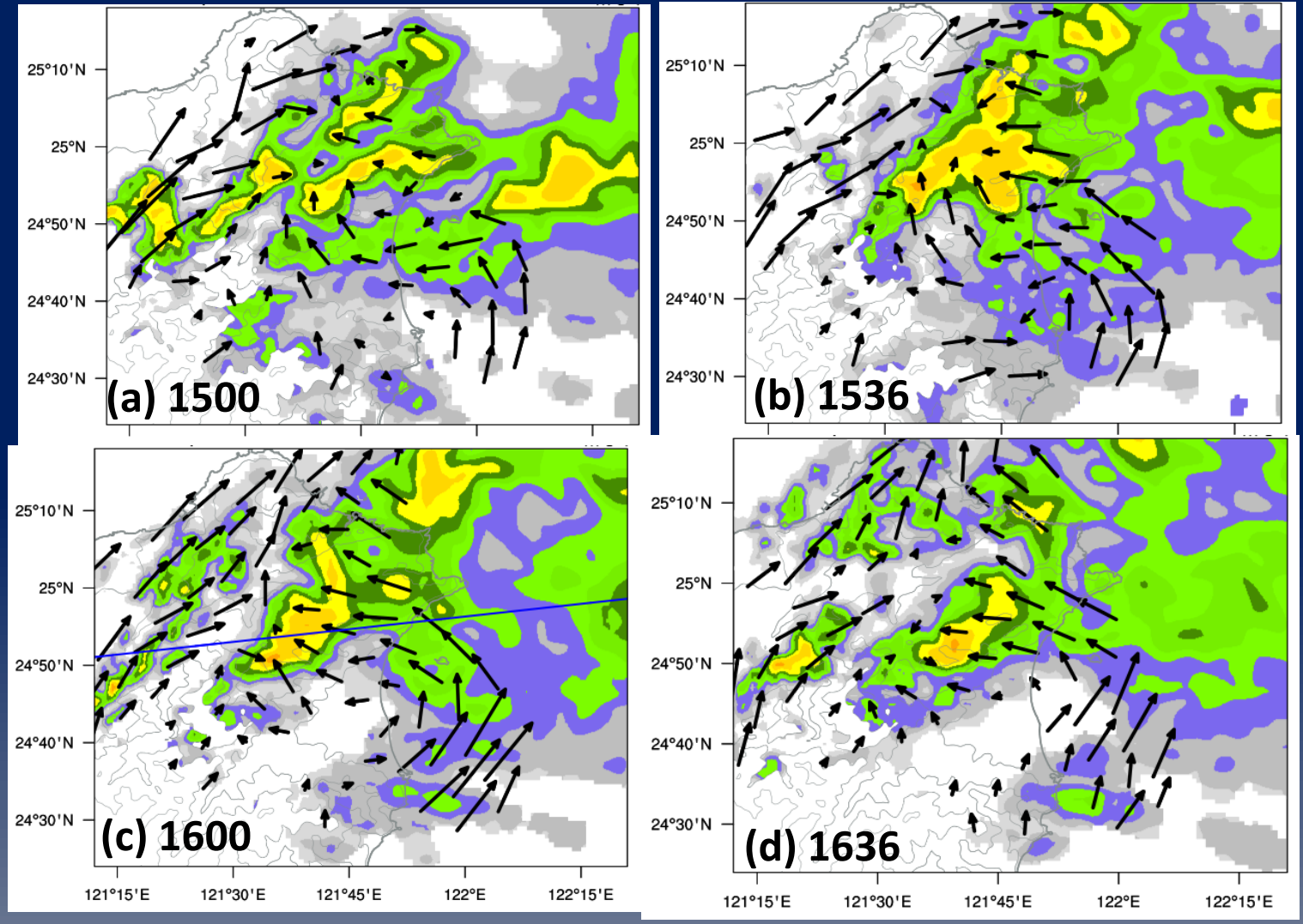


- 1209-1231 LST: cells A and B merge to form cell A+B, while the mid-level updrafts (2 m/s) do not merge => discrete updraft structure
- The difference in environmental wind speed near cells A and B suggests that the physical mechanism of cell A+B merger may be a rear-end collision due to the different propagation speeds (Miao and Yang 2018).

Source: Jack Miao

horizontal wind (vector) at Z=1.5 km, and ZH (colored) at Z=1.5 km



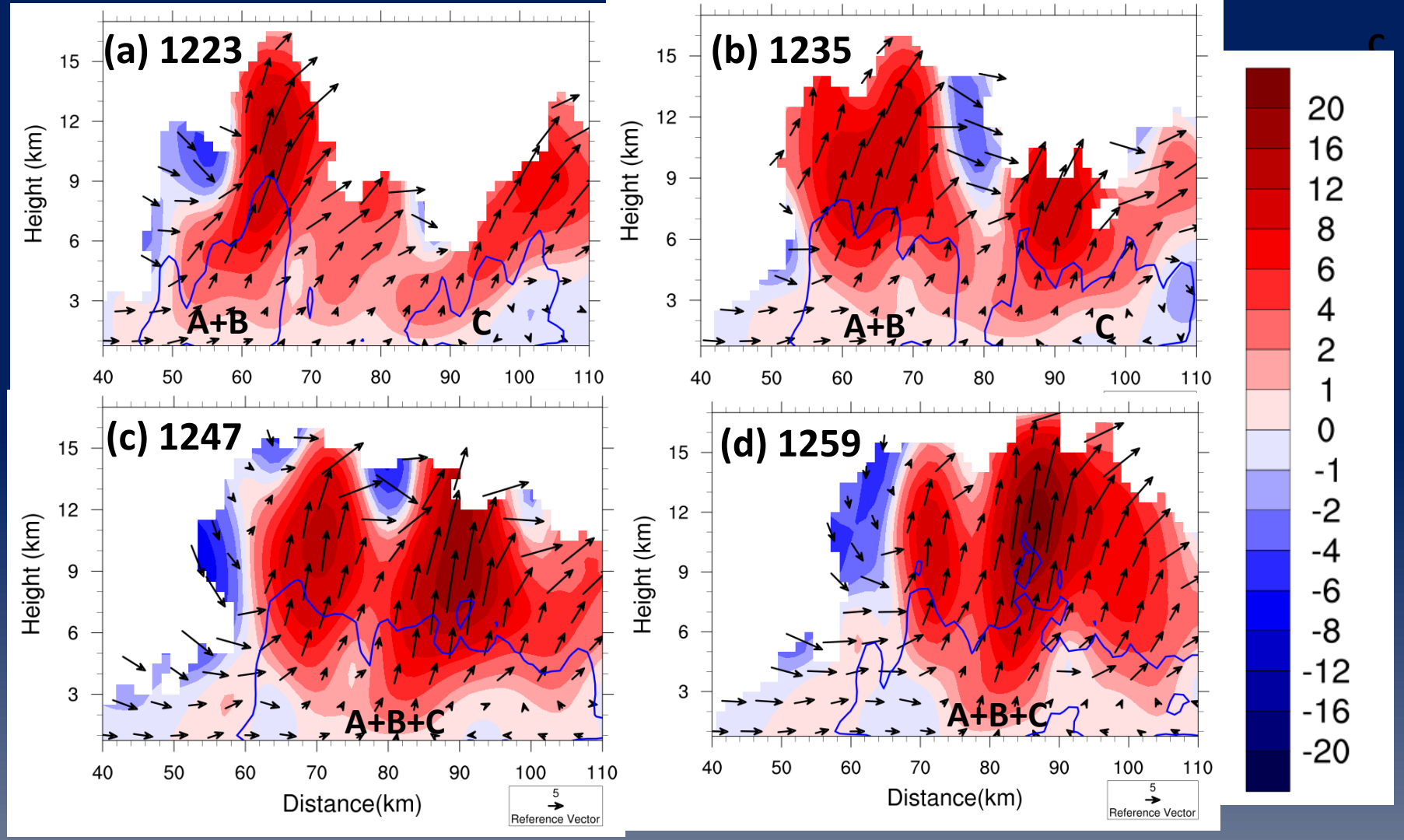


- 1500-1636 LST: Convective cells were isolated and weaker; easterly winds north of a mesoscale vortex over Yilan prevailed over the Snow Mountain Range, which resulted in the subsidence evaporation associated with the easterly downslope wind.

Source: Jack Miao

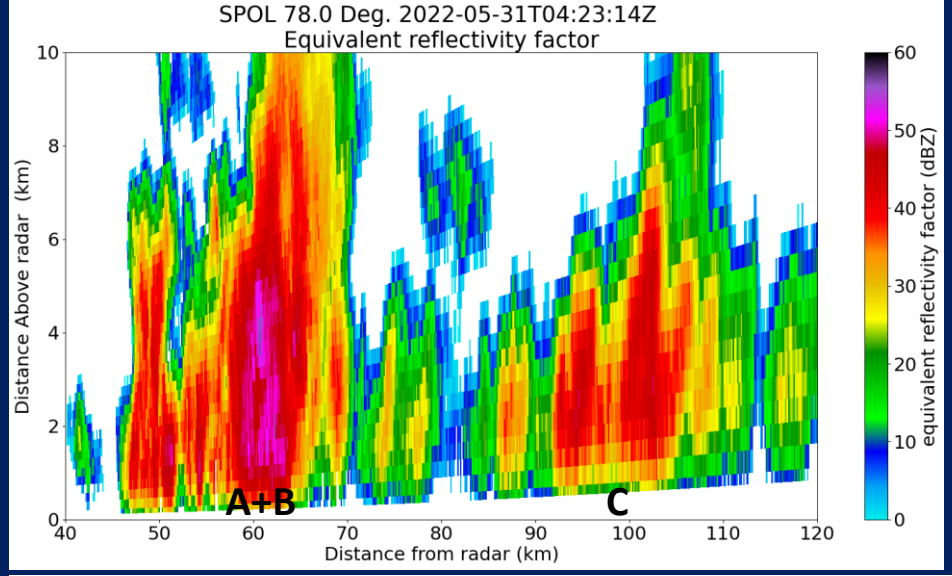
Vertical velocity (colored), and 35-dBZ contour (blue line)

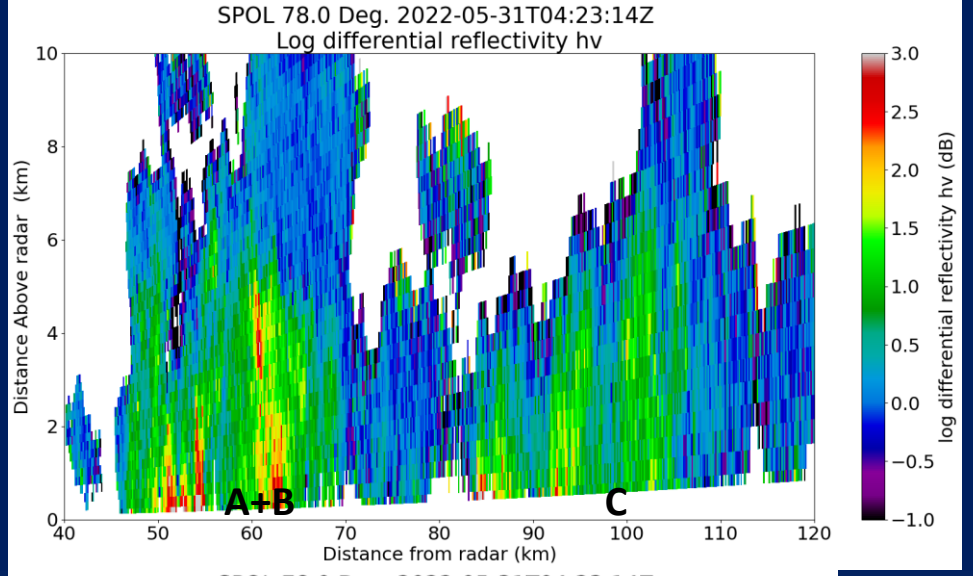
Multiple Cell Merger

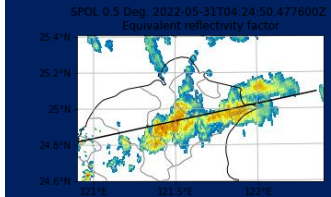


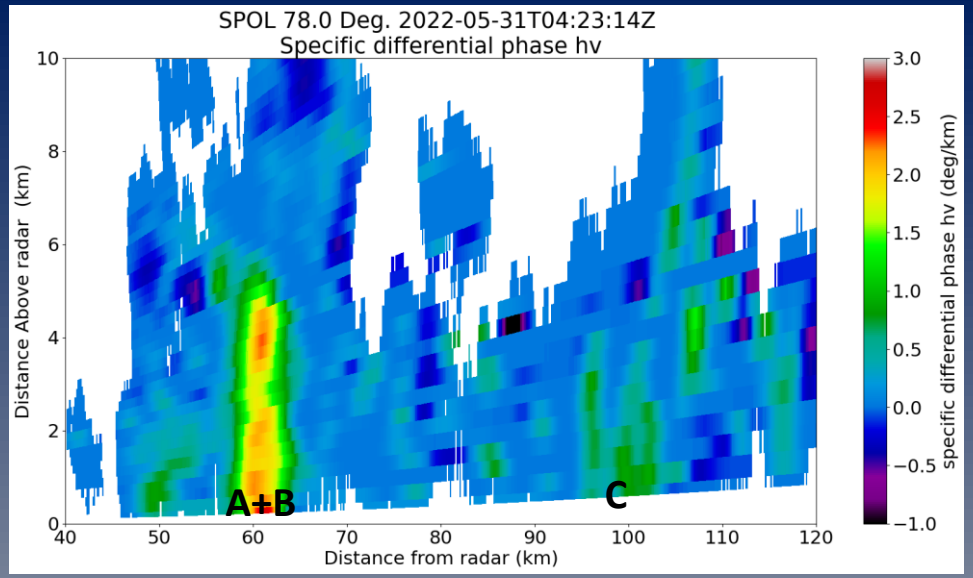
- 1209-1231 LST: cells A and B merge to form cell A+B, while the mid-level updrafts (2 m/s) do not merge => discrete updraft structure
- 1231-1300 LST: cells A+B and C merge to form cell A+B+C, with stronger updrafts and wider storm, similar to those in previous modeling studies (Miao and Yang 2018; Miao and Yang 2020; Miao and Yang 2022)

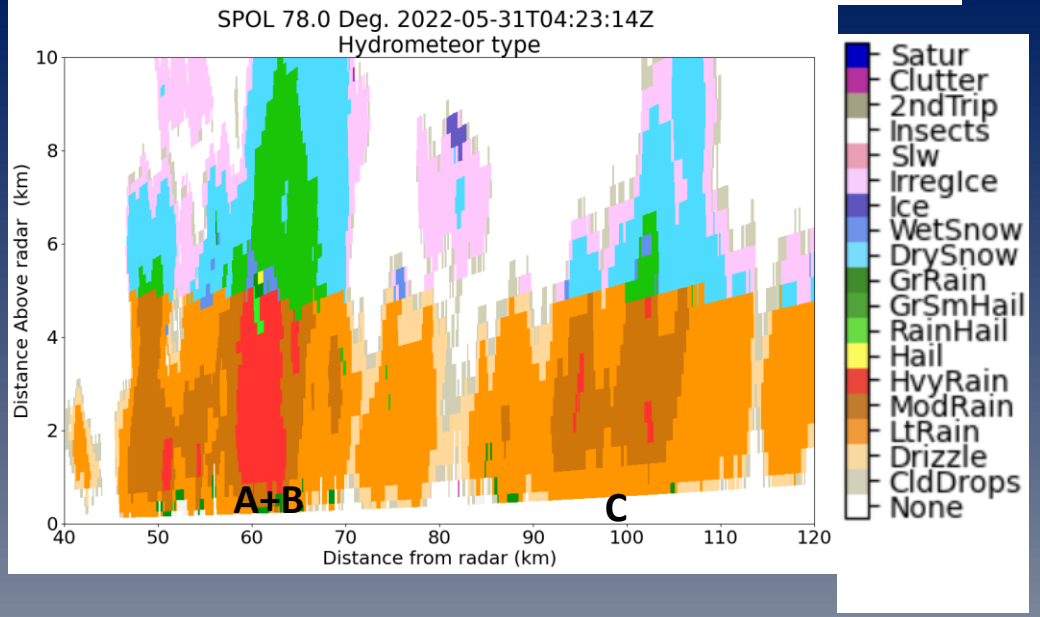
Source:
Jack Miao





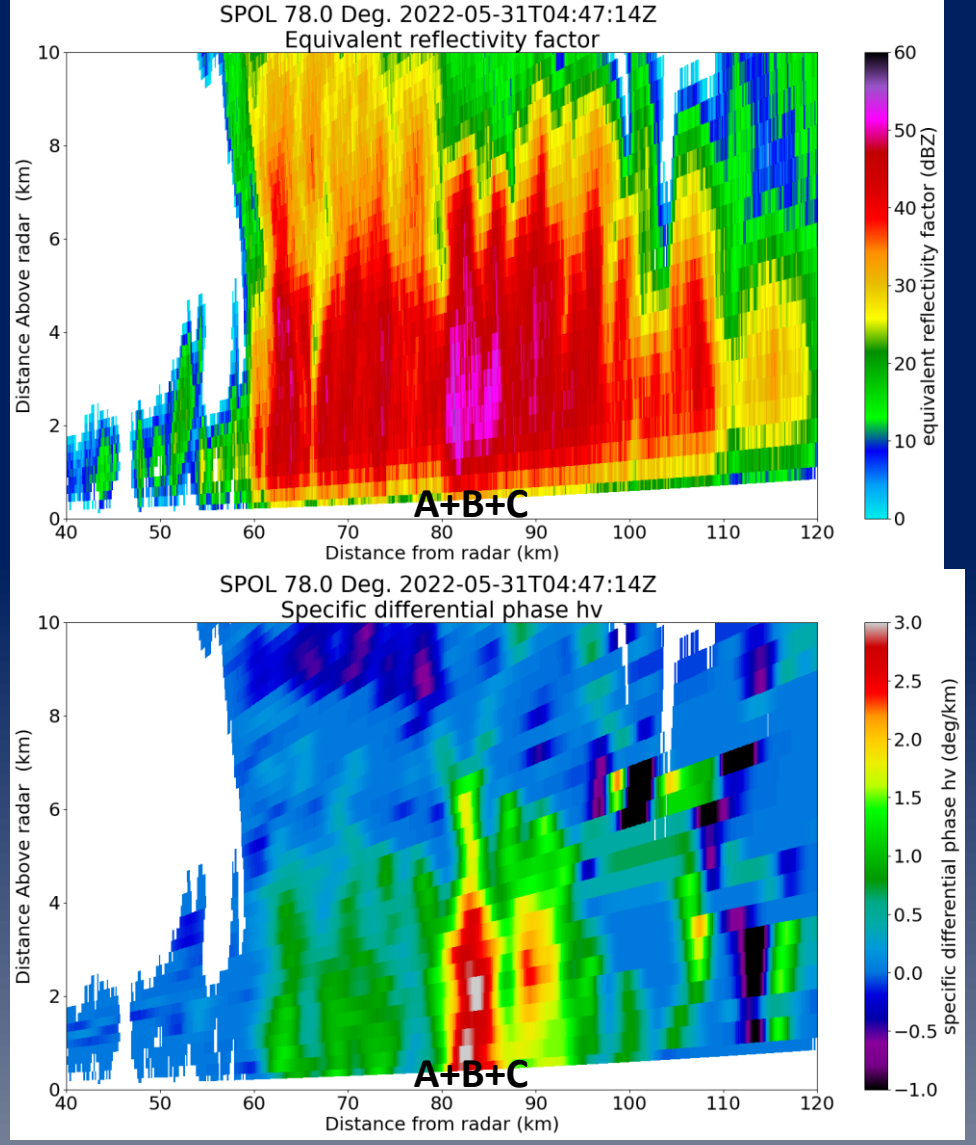


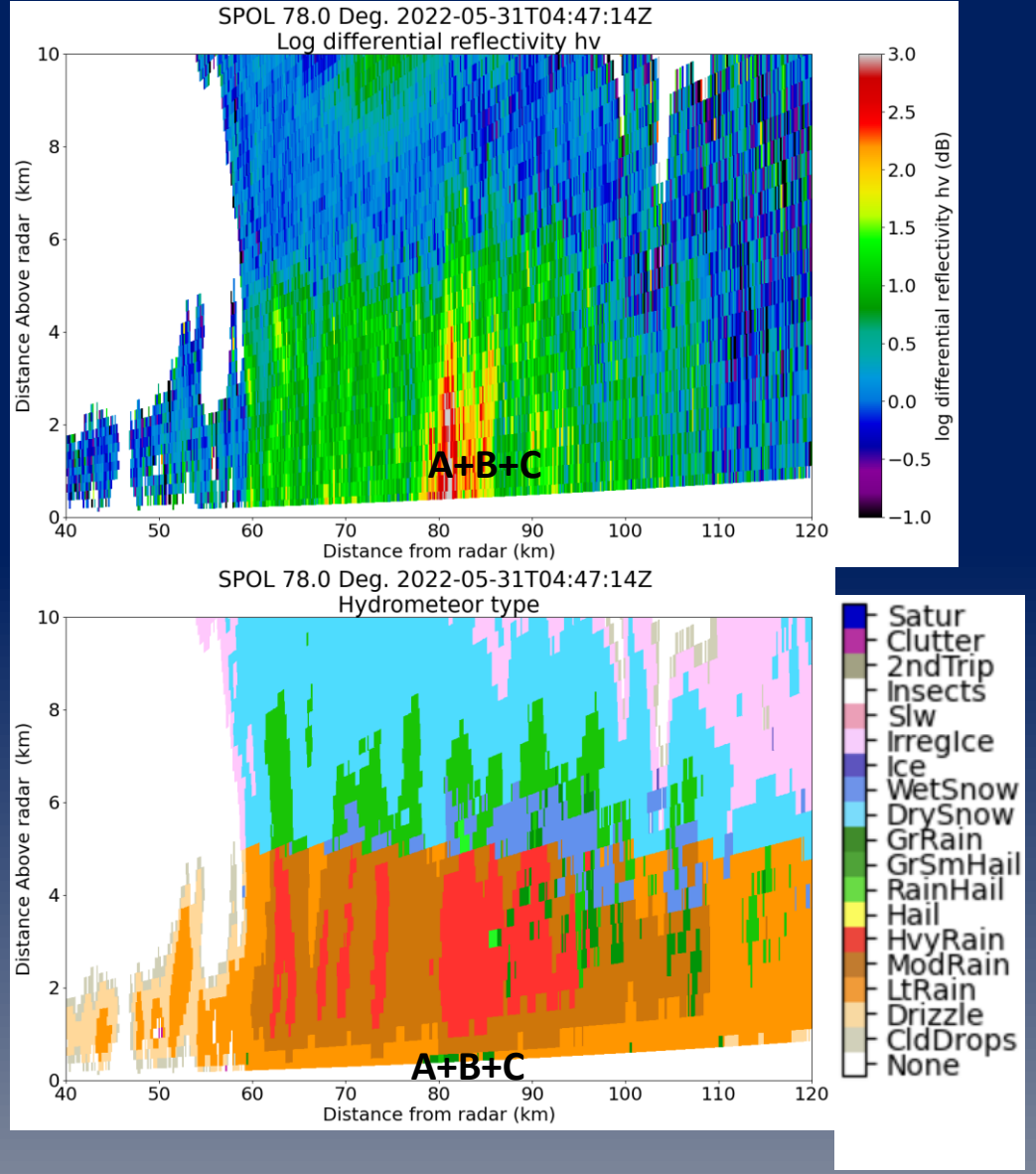




- 1223 LST (cell A+B and cell C): ZDR columns (>1dB) at x=60 km and 100 km with heights reaching 6 km => updrafts.
- The ZDR values within the ZDR column of cells A+B (x~60 km) are relatively large, with local maxima located at the middle (3-5 km) and low levels (0.5-2.5 km). The area of maximum ZDR values at middle levels corresponds to graupel/rain and hail/rain mixture, with a reduced correlation coefficient of ~0.94, indicating the presence of mixed-phase processes

Source:
Jack Miao

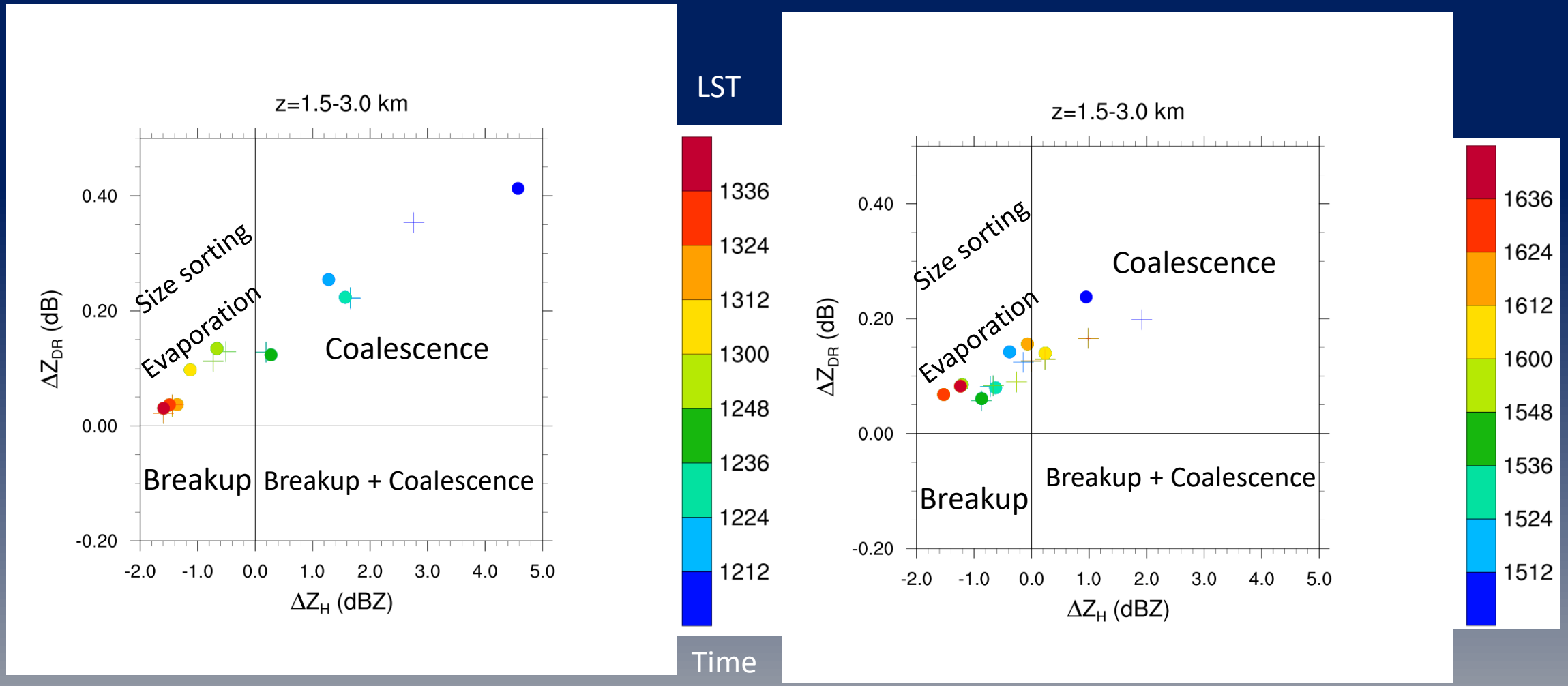




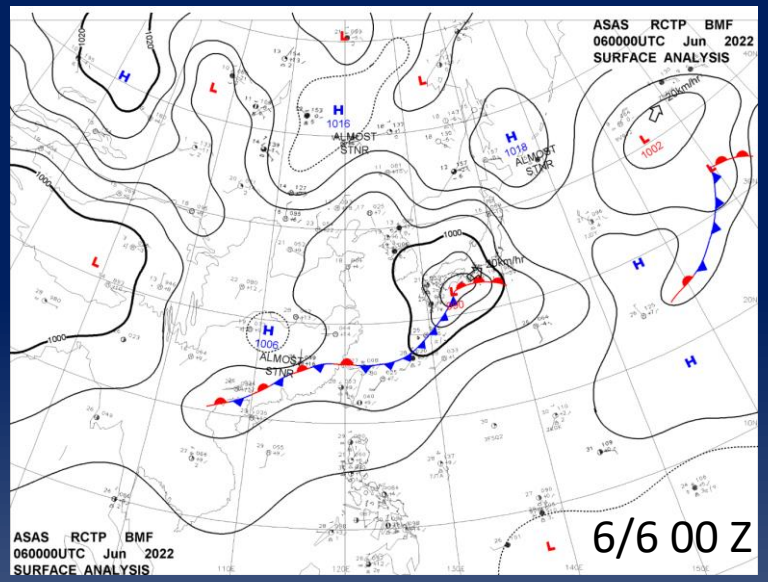
- 1247 LST (A+B+C cell merger): ZDR column (x=84km) with a height of 7km. **Wider ZDR column => wider updraft**
- KDP column above the melting layer was composed of graupel and rain/hail mixture. A reduced correlation coefficient (~0.92) at 4-6 km height indicated an more active mixed-phase process.

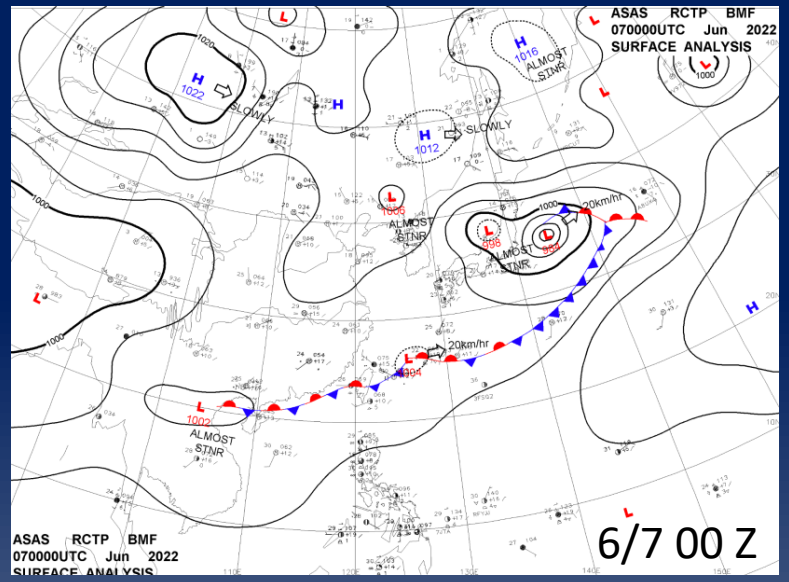
Source:
Jack Miao

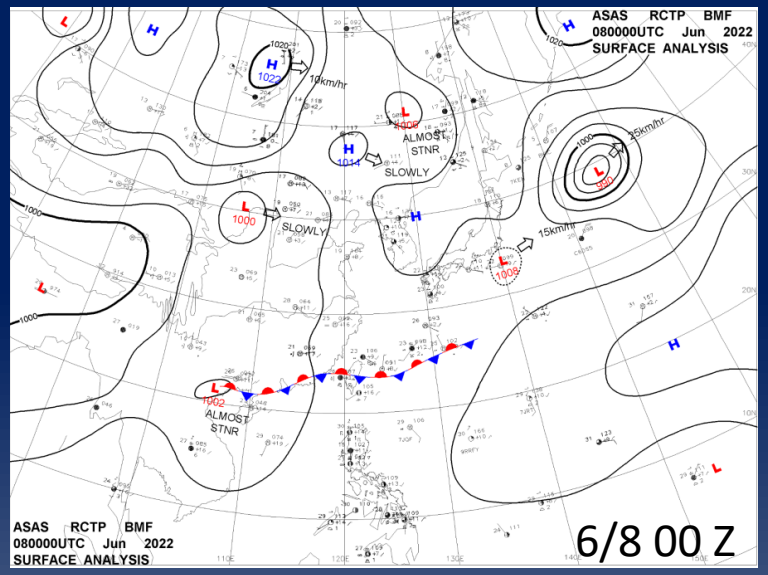
Phase Diagram for Microphysical Processes

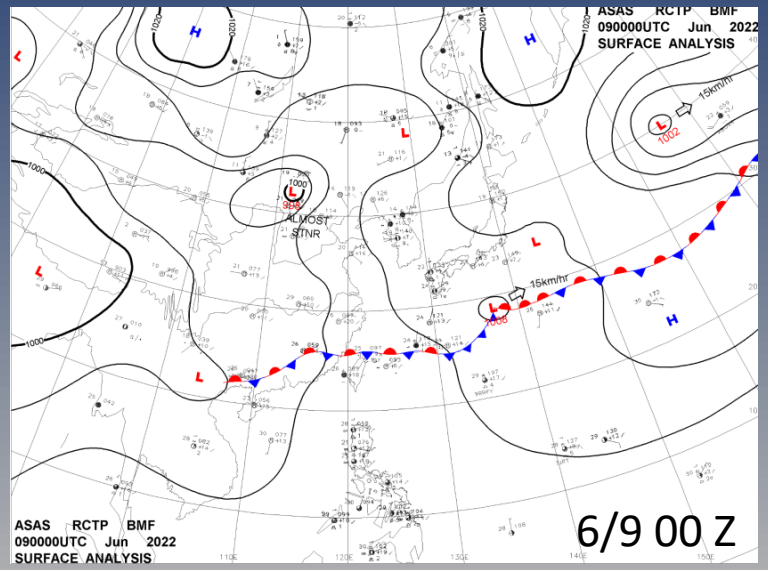


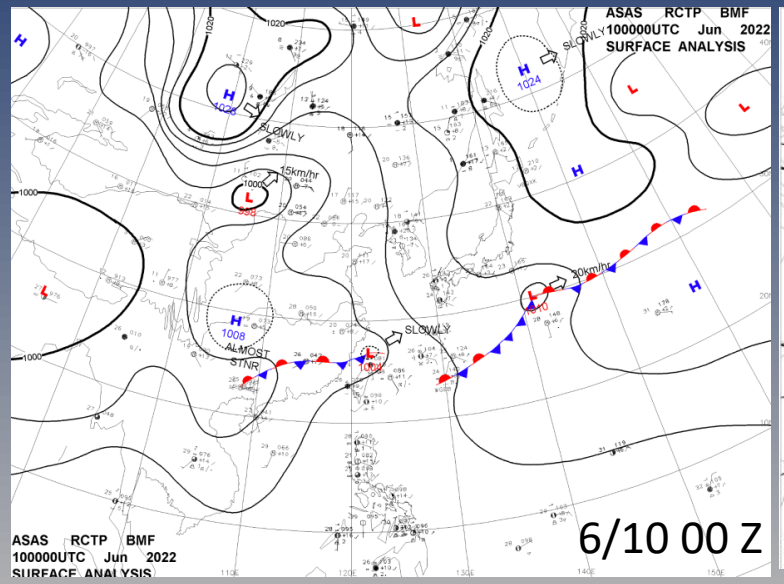
IOP3: Passage of a quasi-stationary Mei-Yu front with embedded MCSs and squall lines

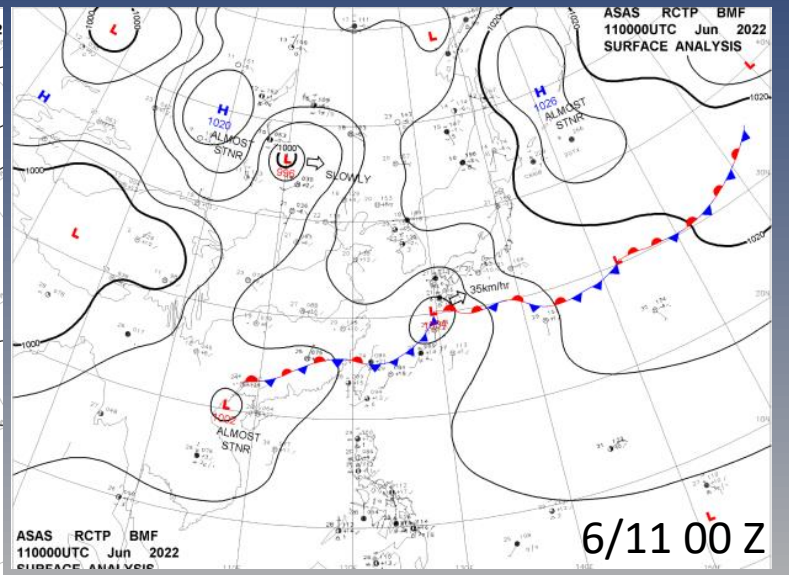




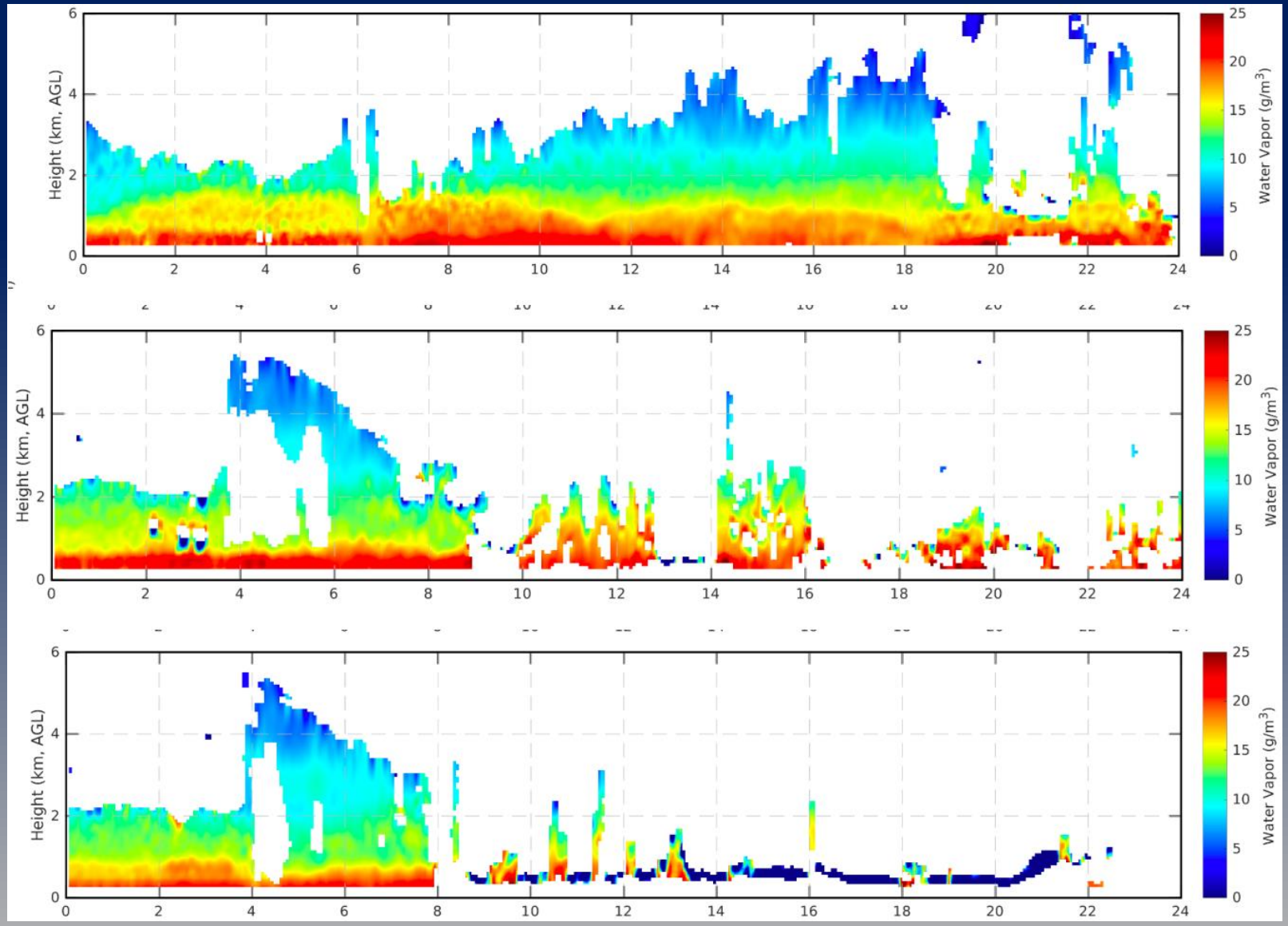






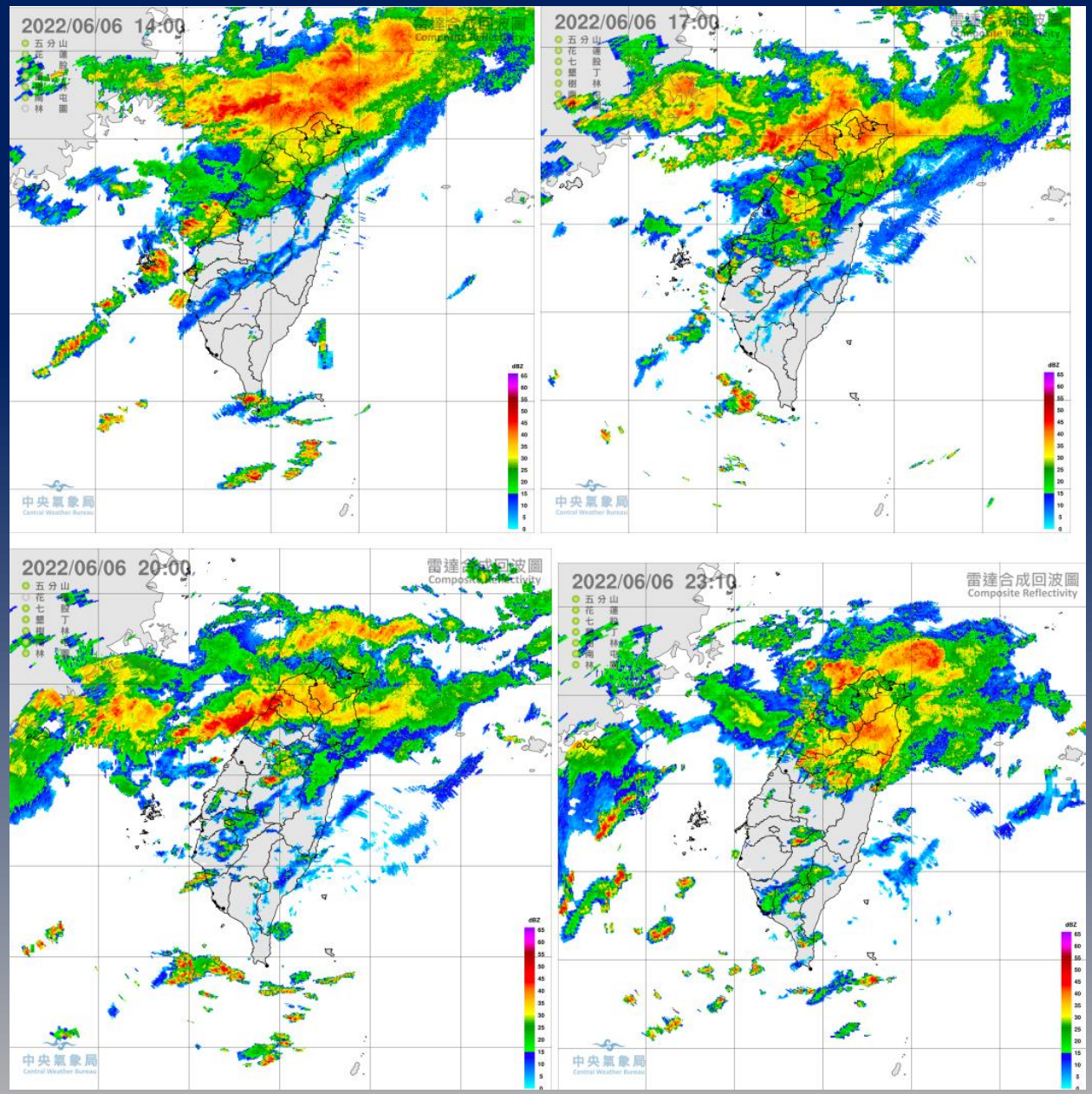


Water vapor time series on June 6 from MPDs at Yilan (upper), Hsinchu (middle), and NCU (bottom) stations



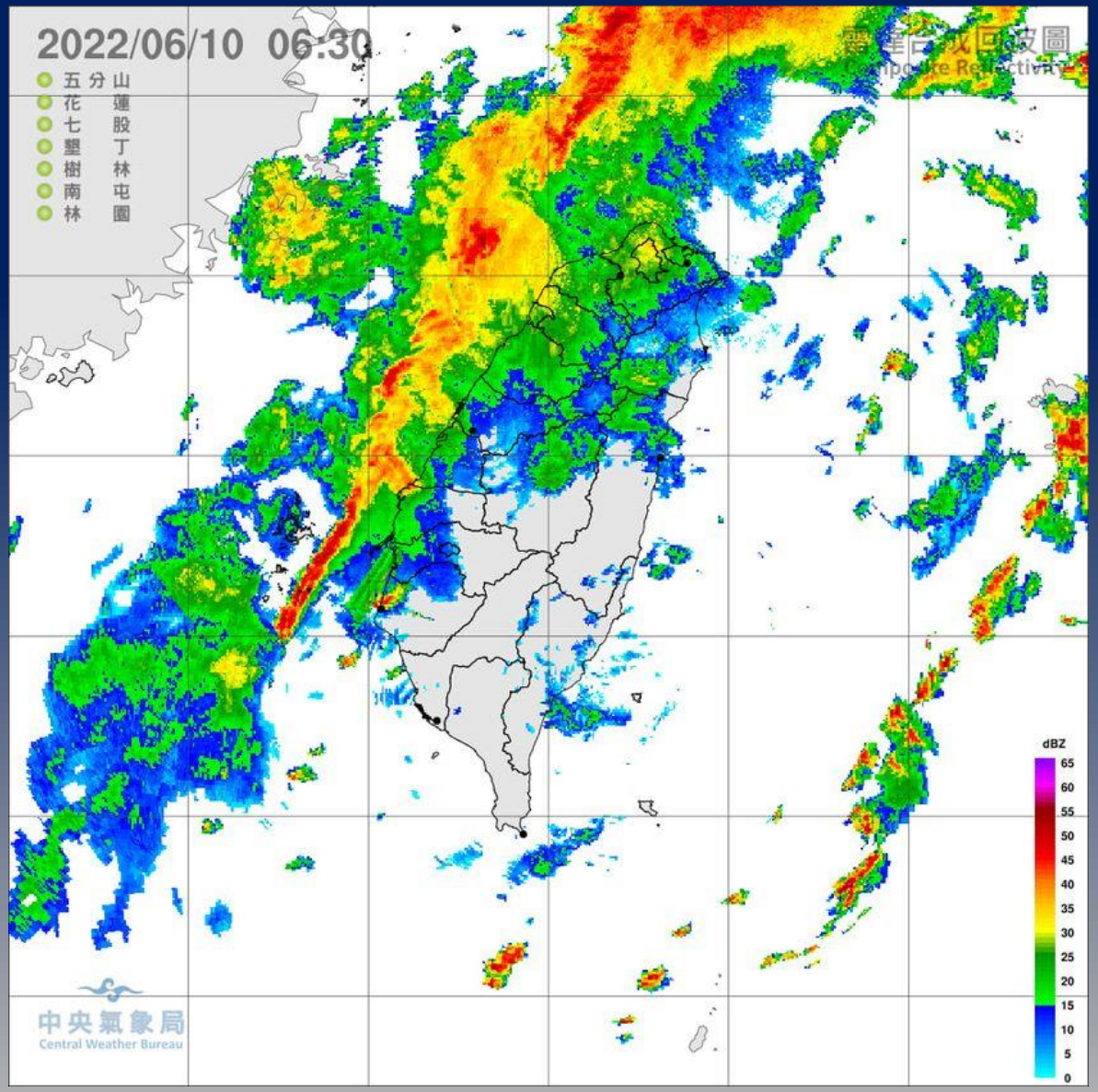
Low-level moisture is increasing with time, particularly after 06 UTC, leading to precipitation at Hsinchu and NCU at 08 UTC.

Radar composite images at 14, 17, 20, and 23 LST on June 6 during IOP3

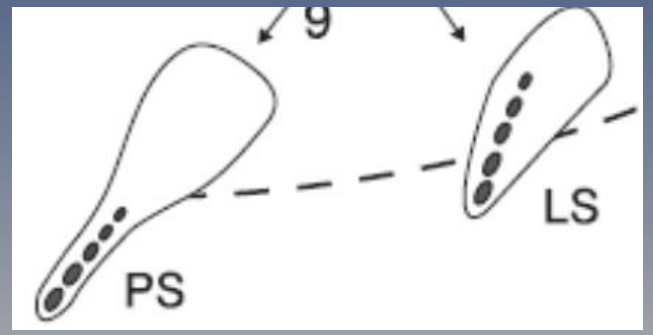


Deep convective cells within broader stratiform precipitation over northern and central Taiwan on June 6.

IOP3: Leading-stratiform and parallel-stratiform MCSs on June 10

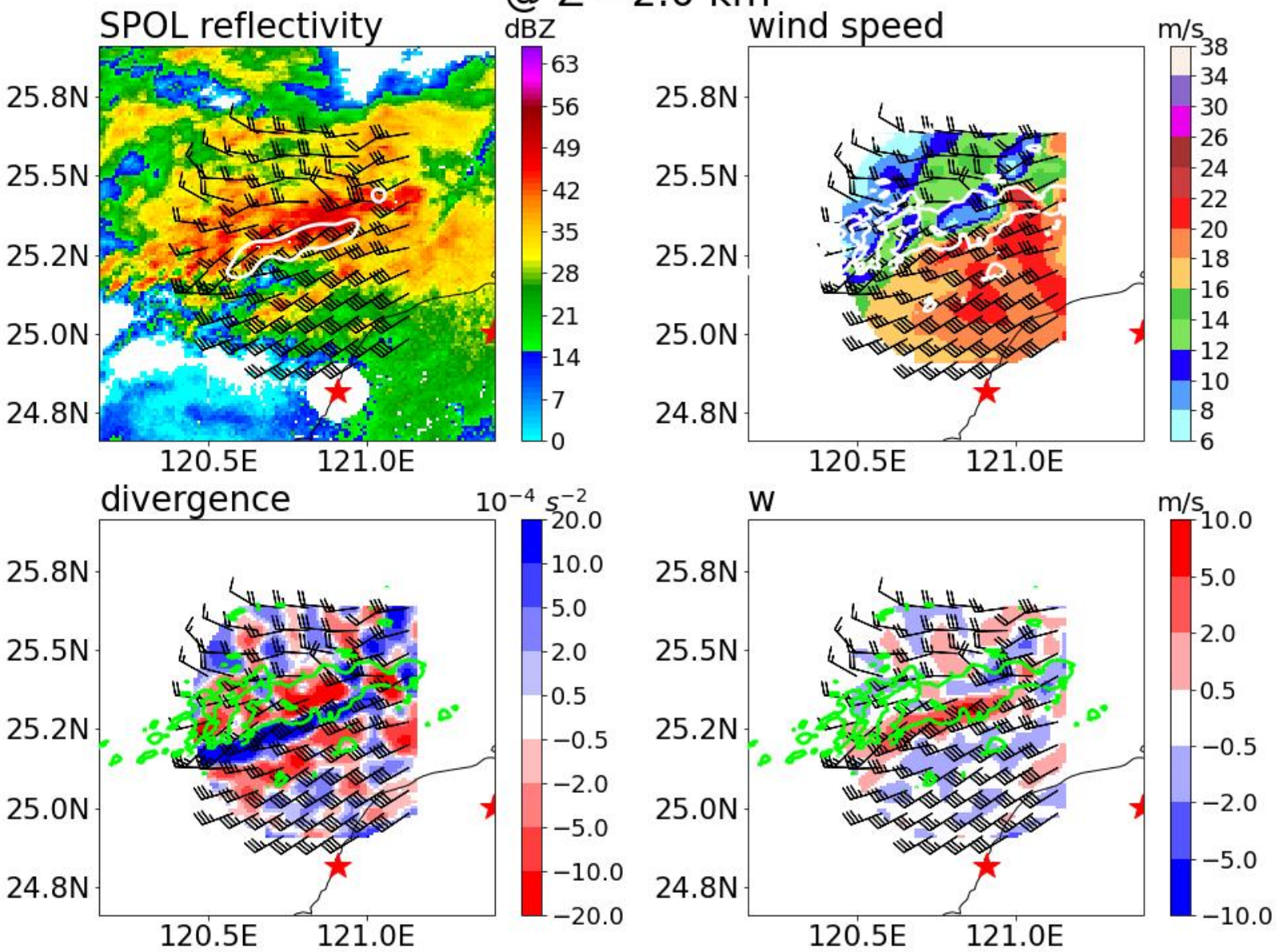


For IOP 3, Leading-stratiform (LS) and parallel-statiform (PS) MCSs occurred over the Taiwan Strait on 10 June.



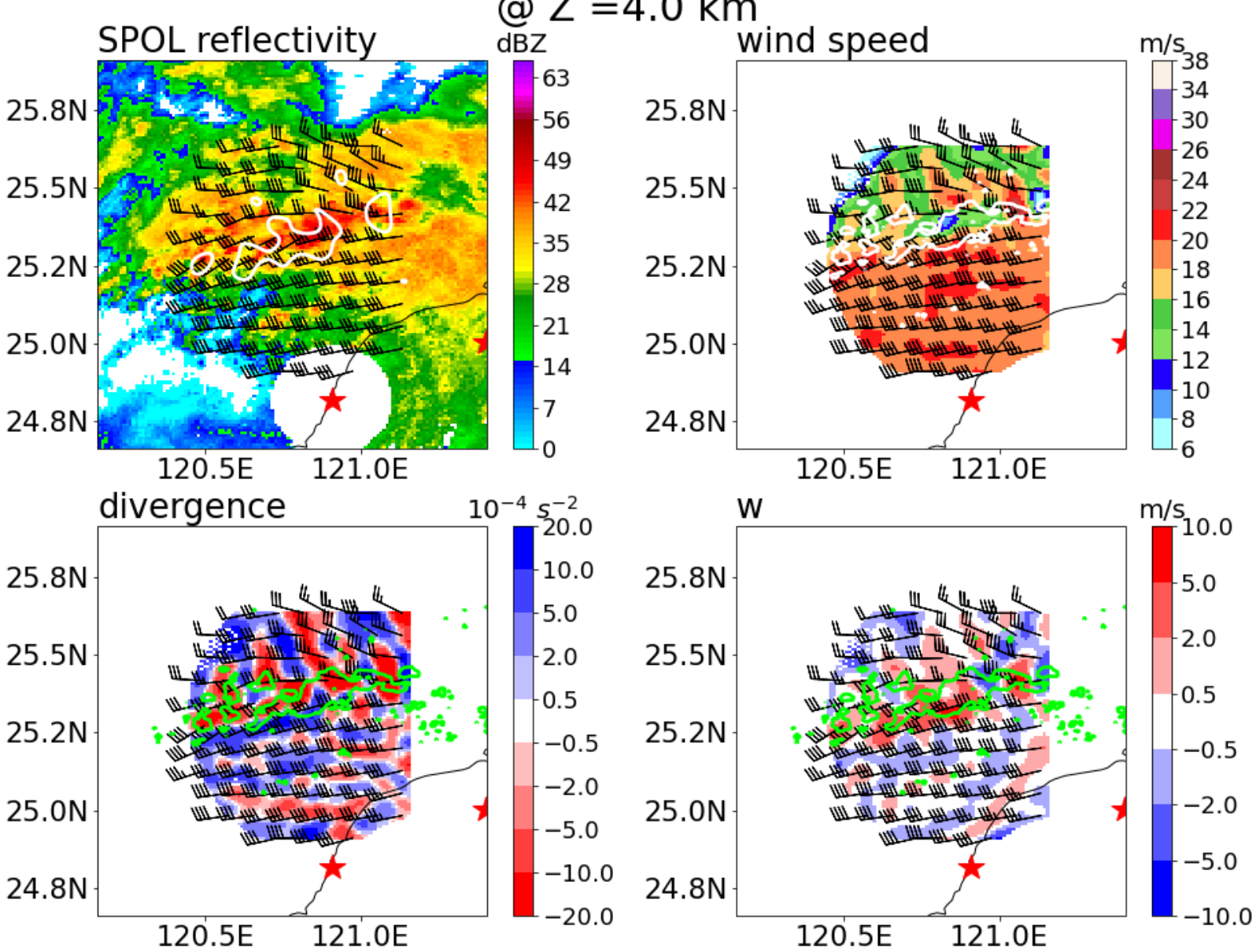
Parker and Johnson (2000)

Source:
Chiu-Lin Liao

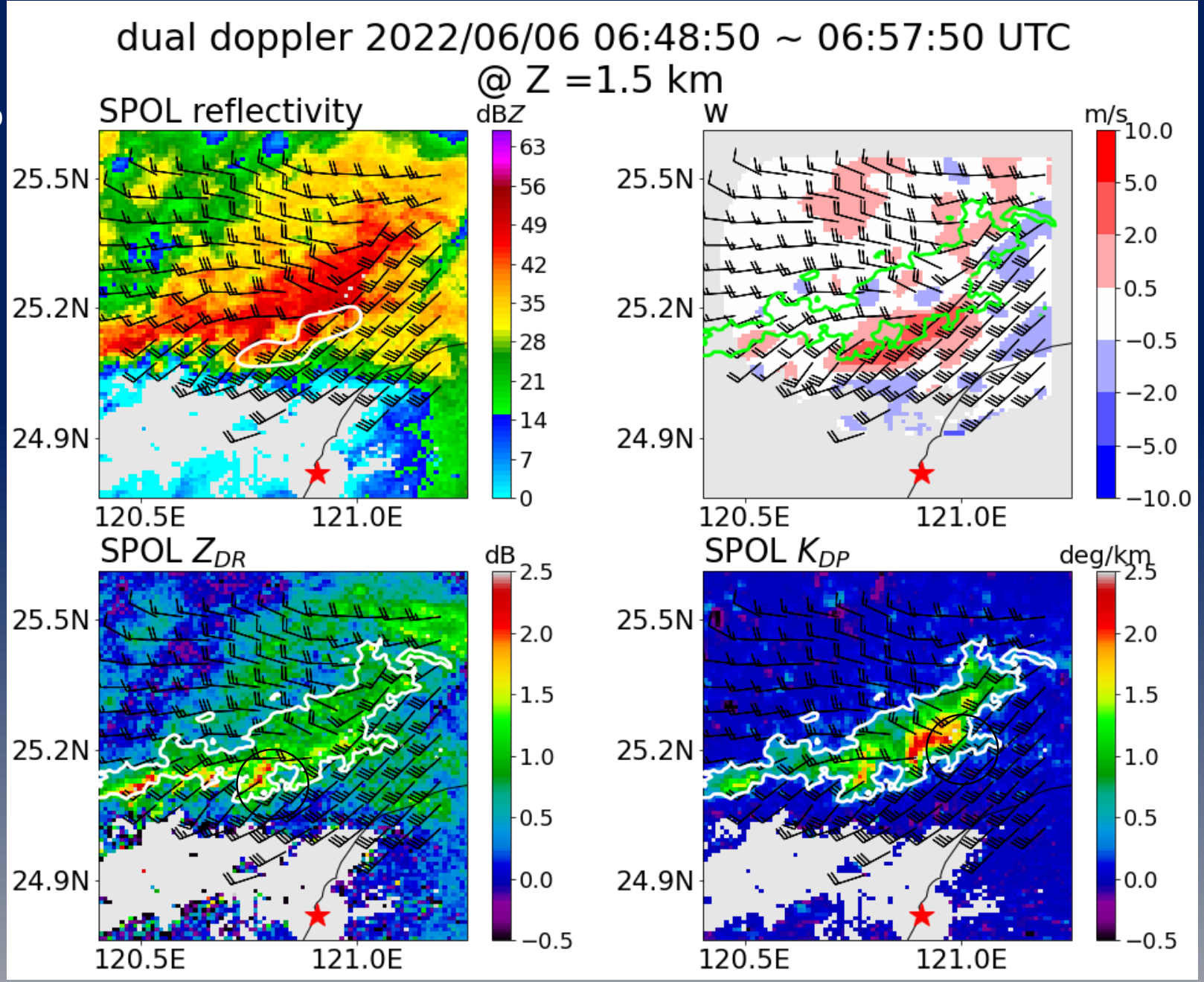


Barrier Jet/
Low-Level Jet

Source:
Chiu-Lin Liao



Source:
Chiu-Lin Liao



Hydrometeor Size-sorting

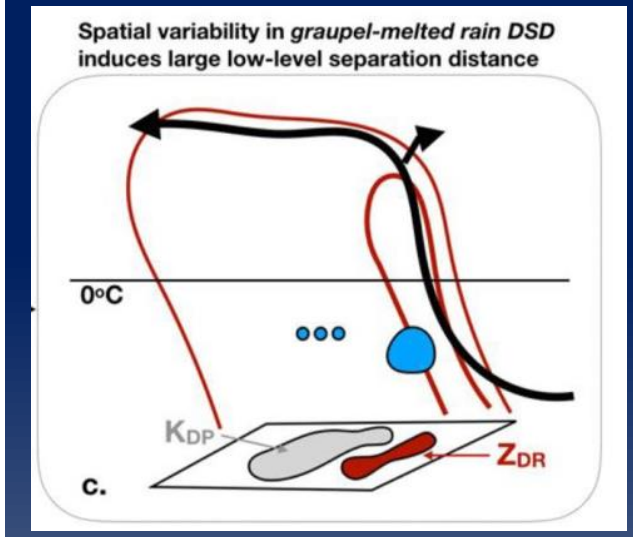
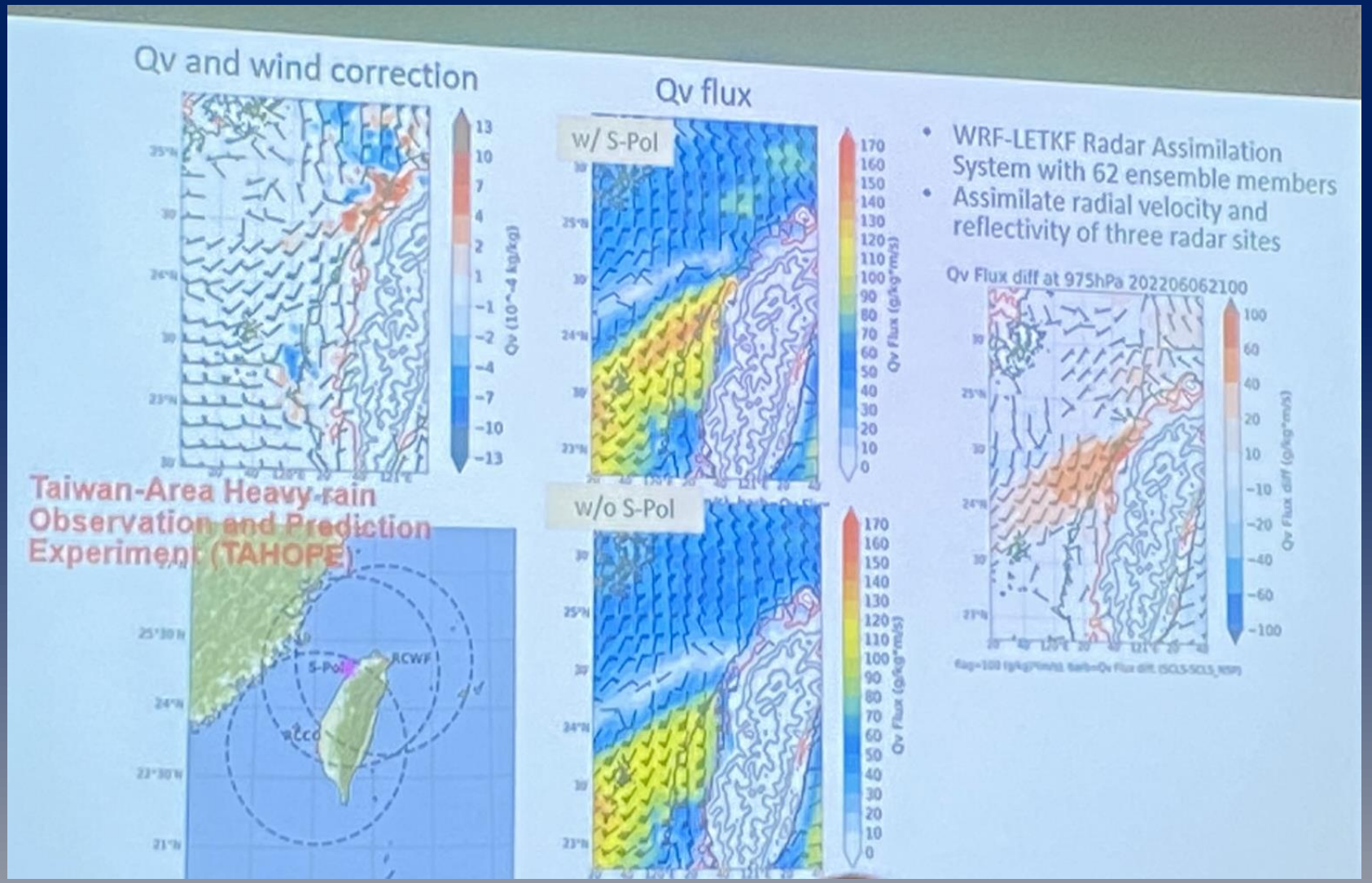


Fig. 17c of Tam, Yang, and Lee for an PECAN MCS in Oklahoma (2022; JGR)

Source:
Shu-Chih Yang



Assimilating the S-Pol radar data enhances the low-level moisture transport!

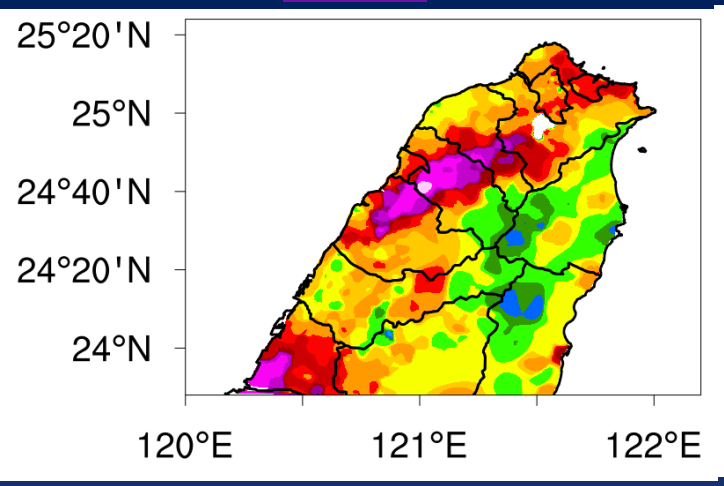
Results of forecast (forecast from 0600 UTC)

Accumulated rainfall

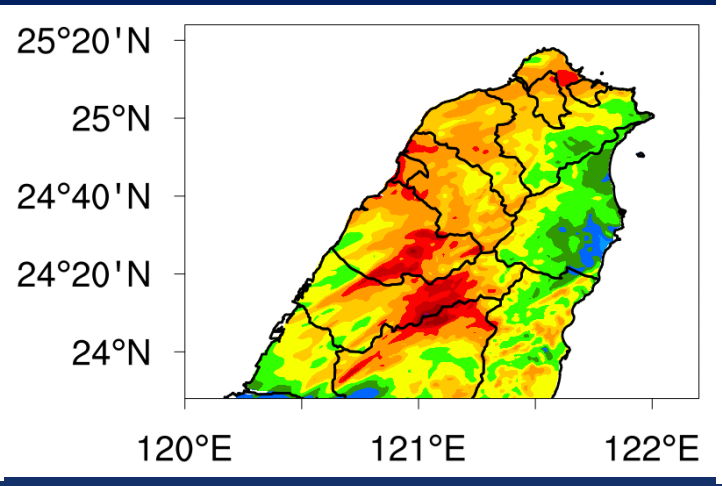
Source:
Kao-Shen Chung

3h

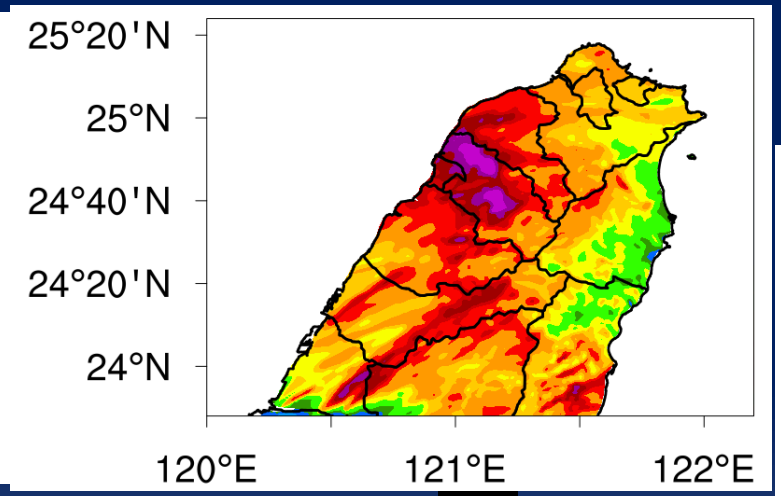
OBS

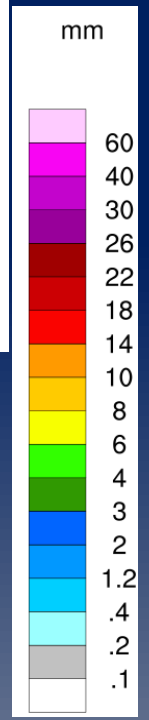


3Rad

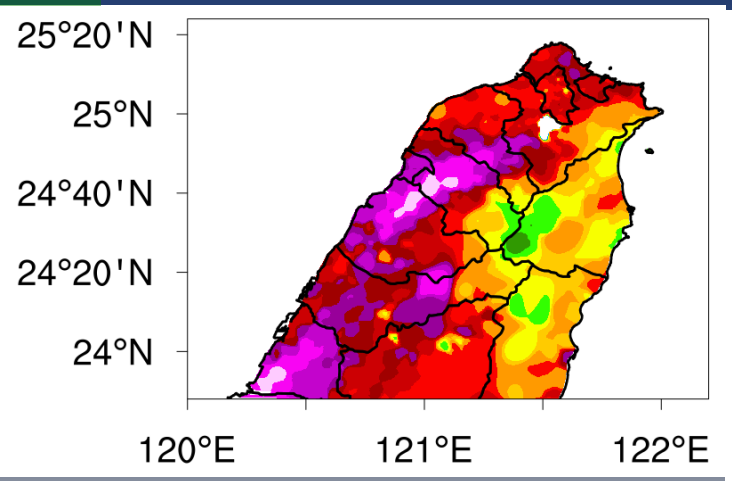


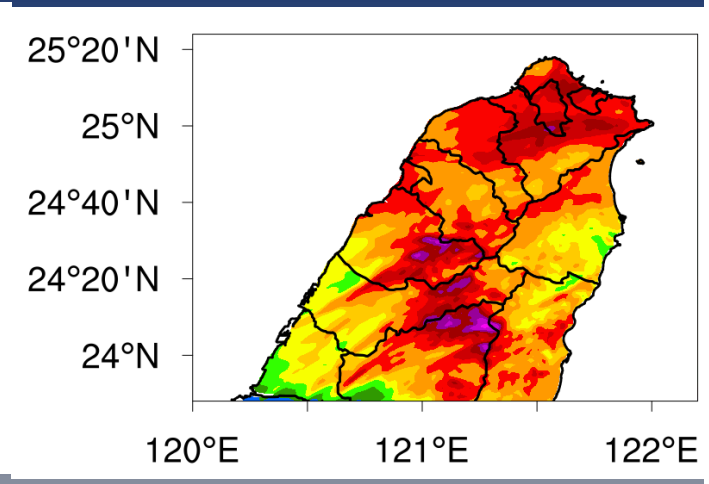
3Rad_Qv

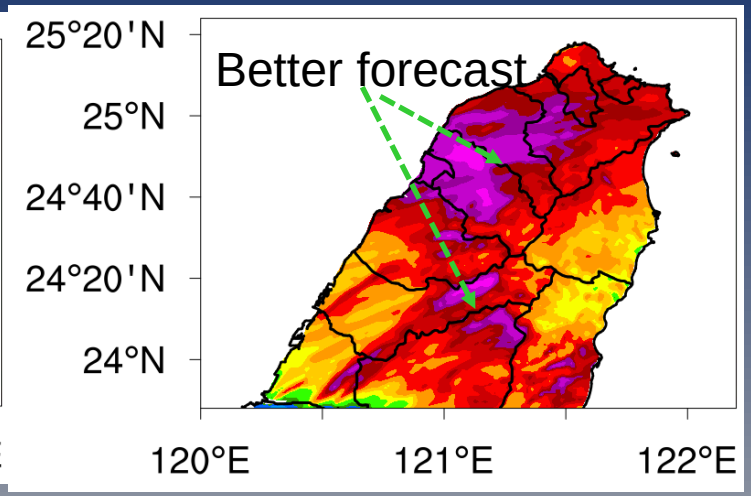




6h

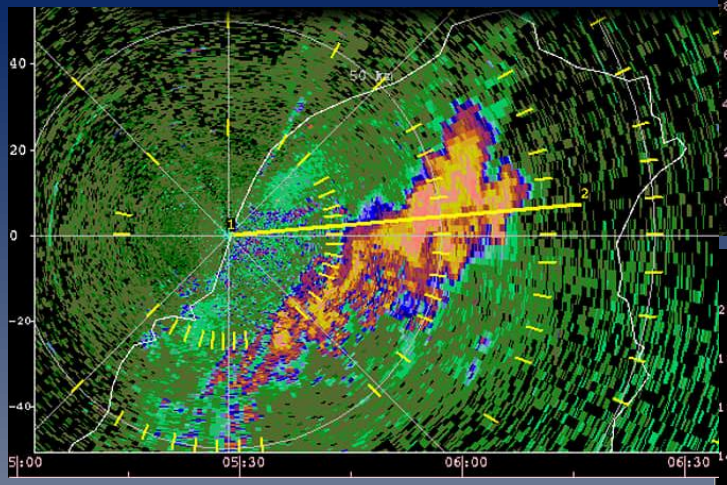


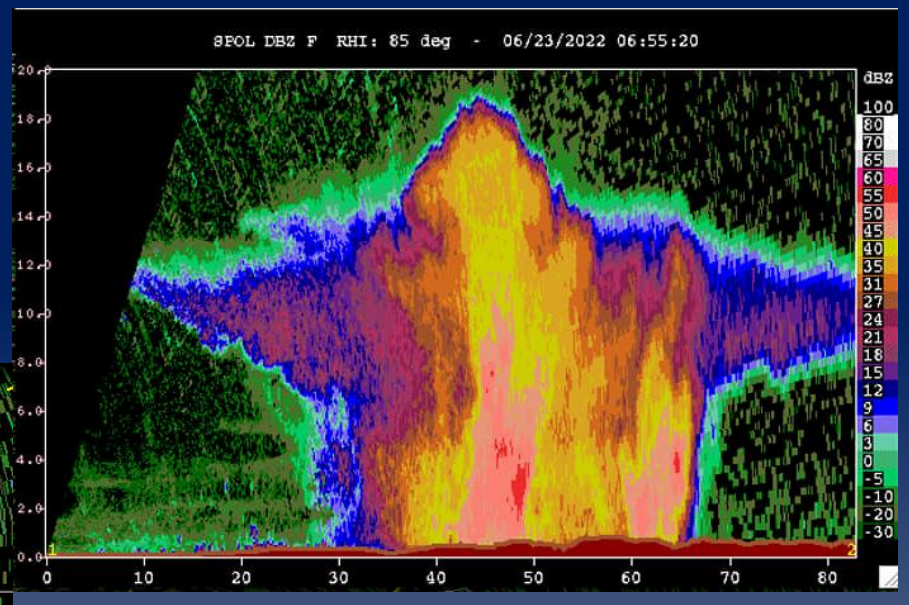


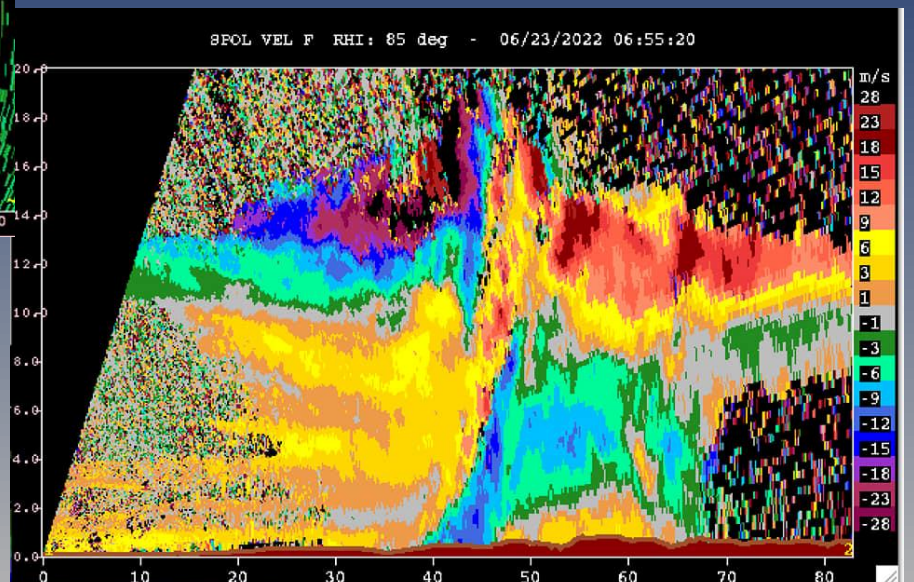


- Assimilate 3 radars (S-Pol, TEAM-R, and RCWF)
- Observation errors: 5 dBZ for Z, 3 m/s for V_r, 1 g/kg for Qv
- Horizontal localization: 12 km for updating Qv

Special Observation on June 23: S-Pol radar observations

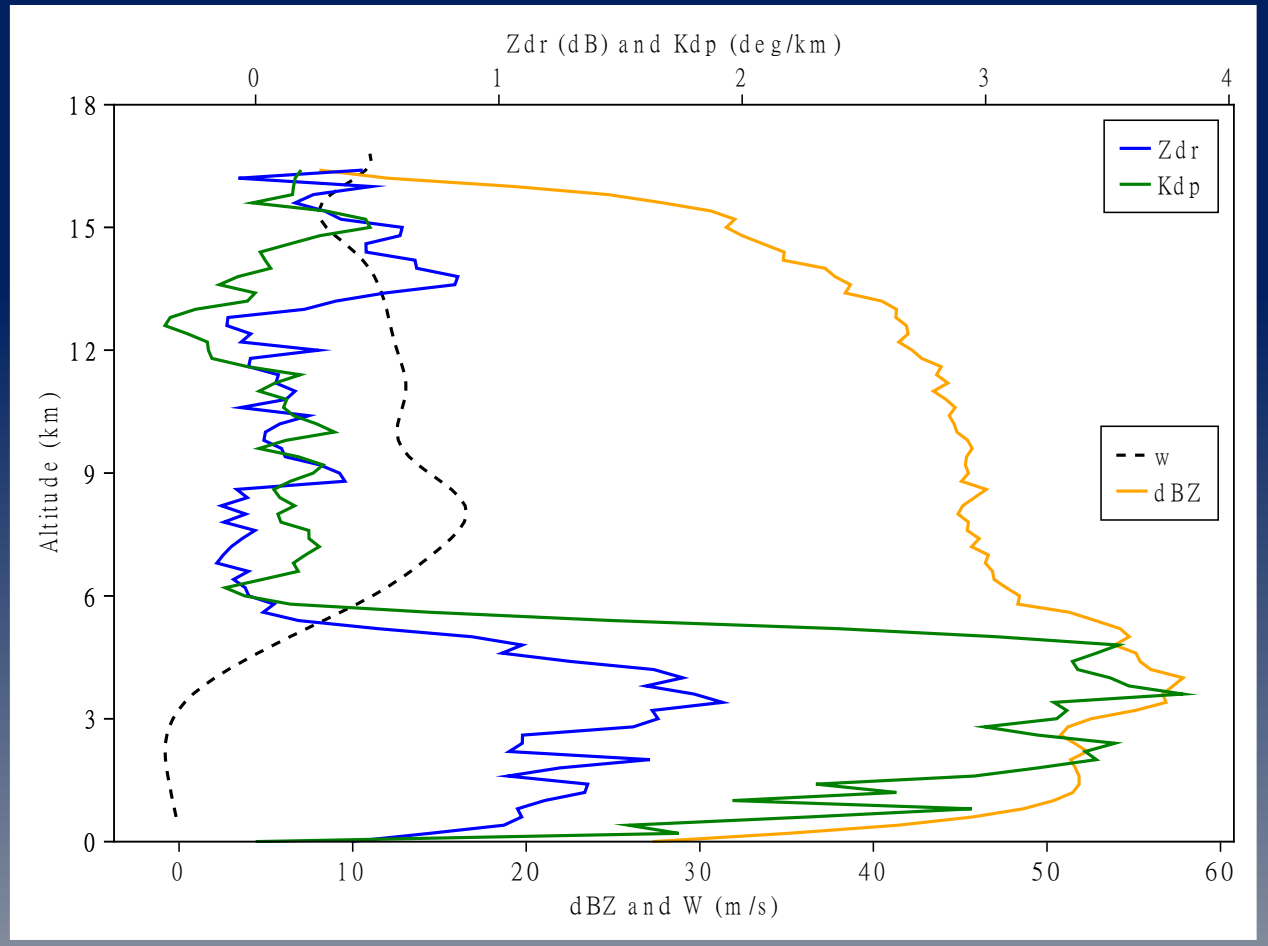




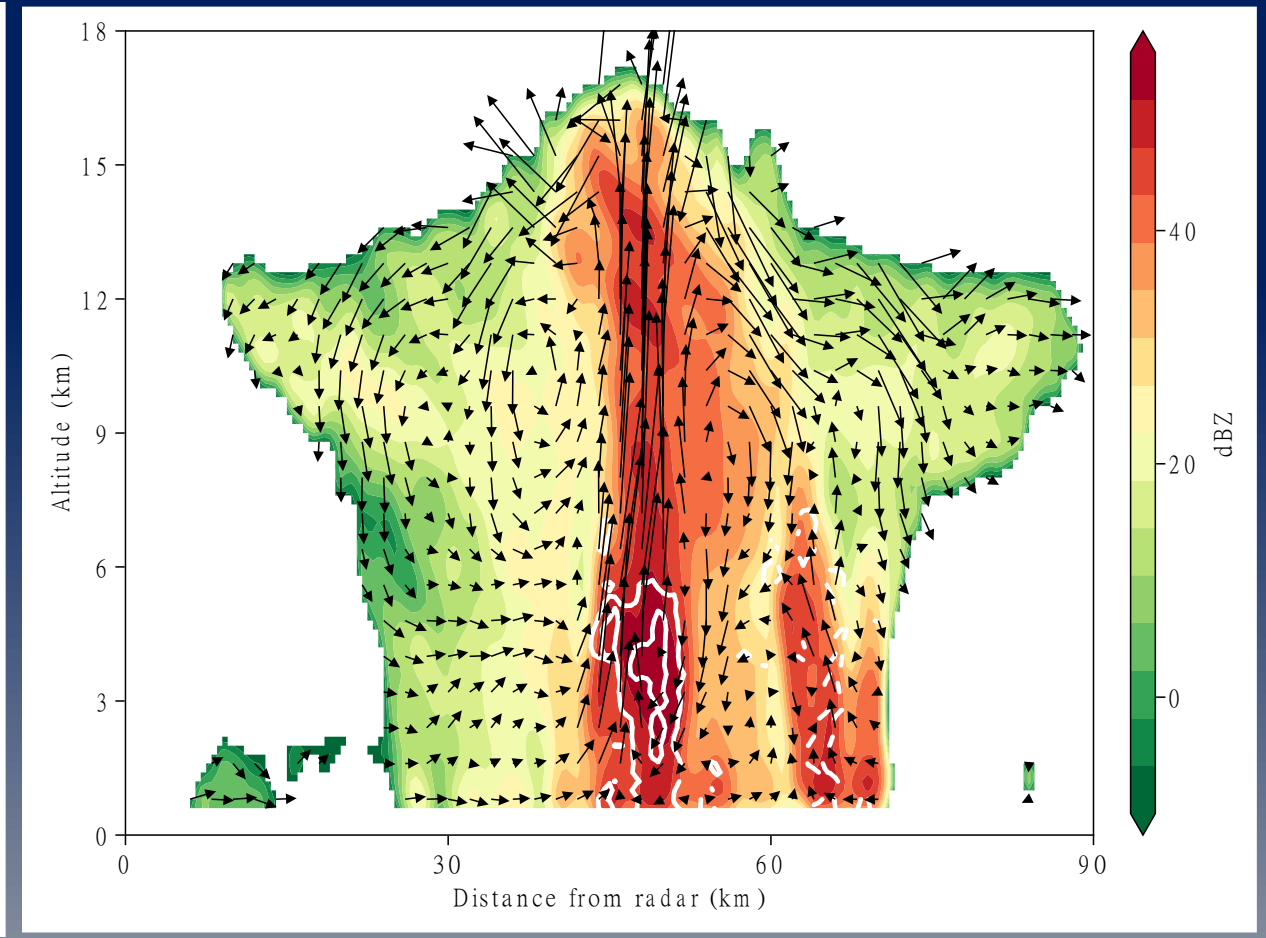


Deep convection with overshooting cloud top and anvils (with low-level convergence and upper-level divergence) over northern Taiwan as seen from S-Pol radar on 07 UTC 23 June.

Source:
Michael Bell

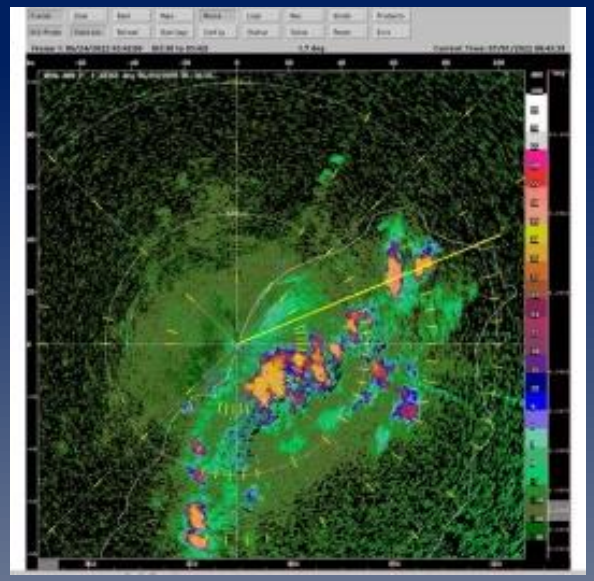


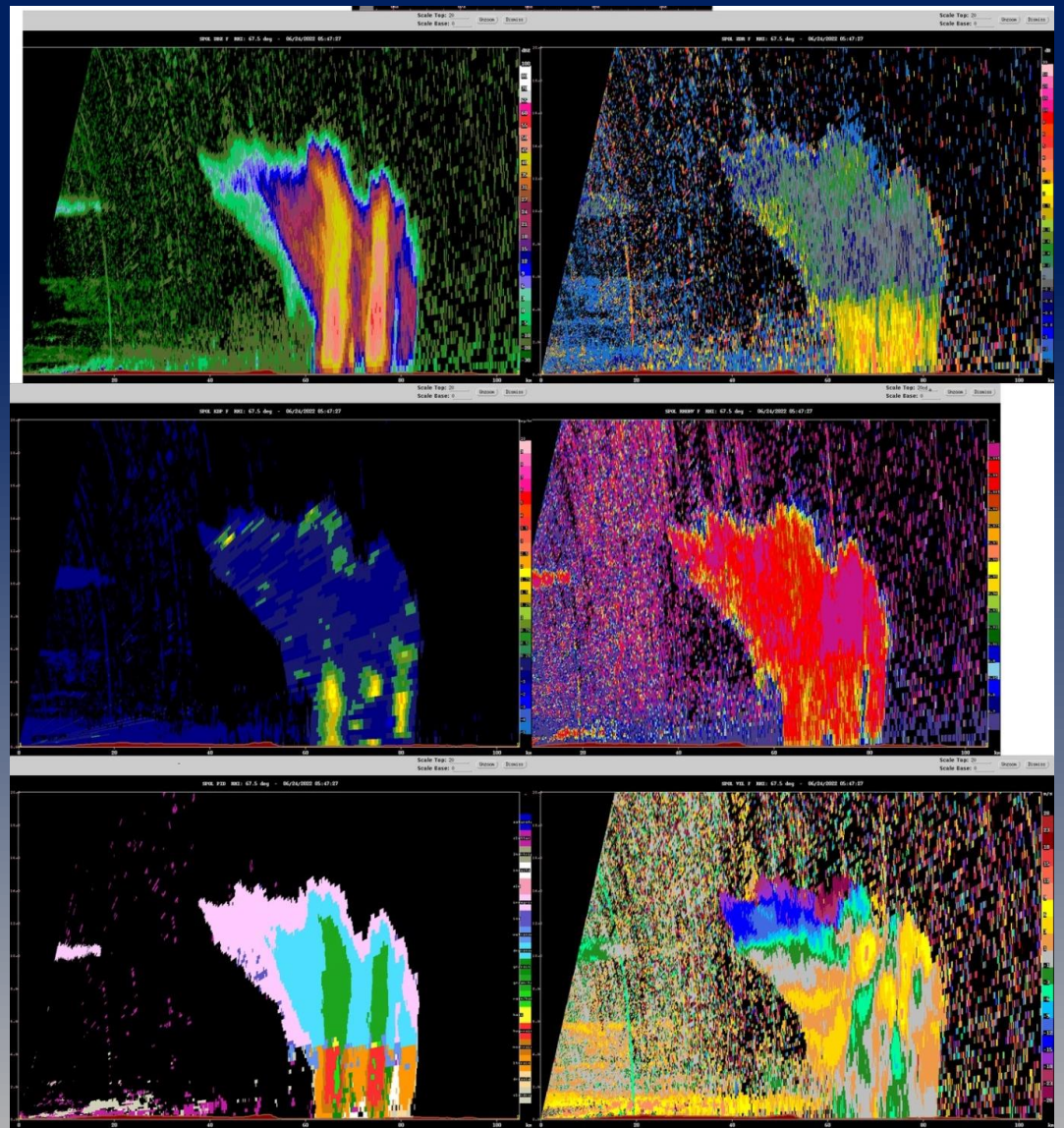
Vertical profiles of Z, W, Zdr, and Kdp
at the center of the storm



Radar reflectivity & circulation vector

Special Observation on June 24: Hailstone in central Taipei

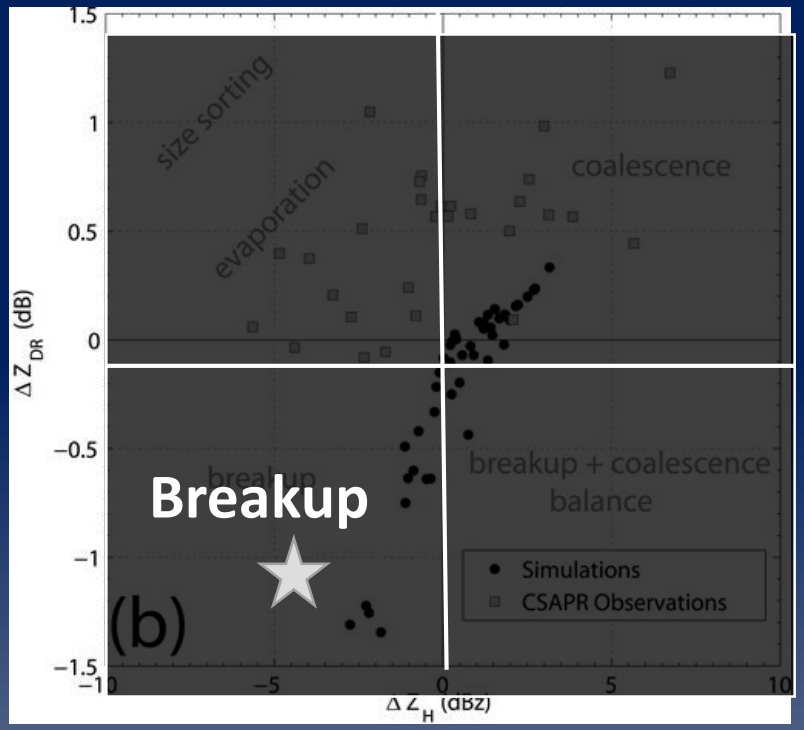


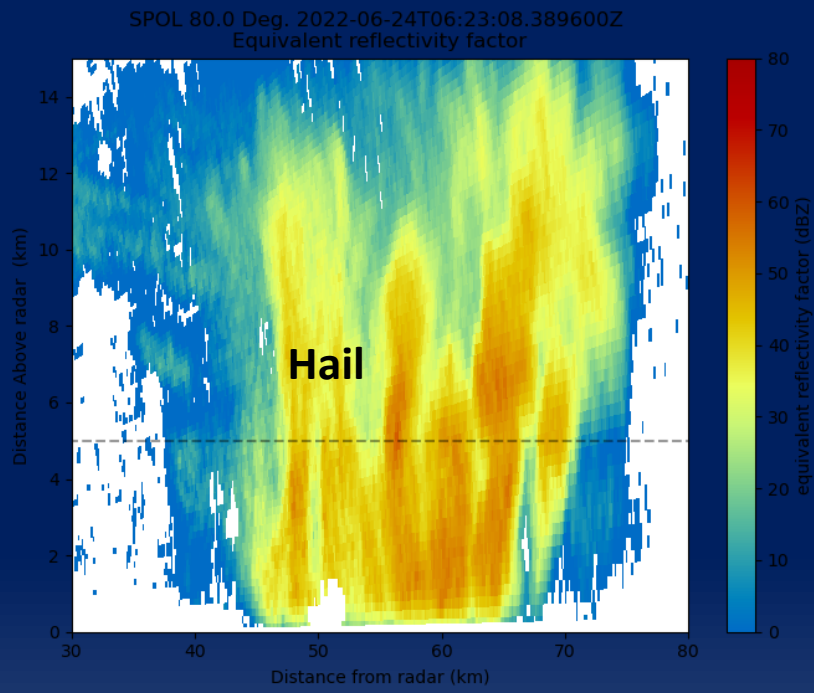


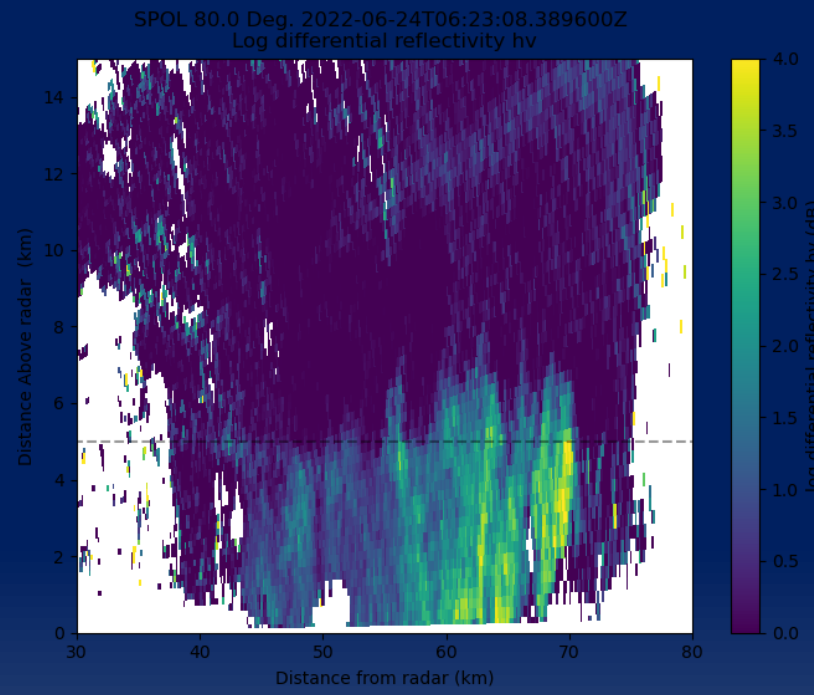
On 24 June, an intense downburst with hail particles in the center of Taipei (near CWB).

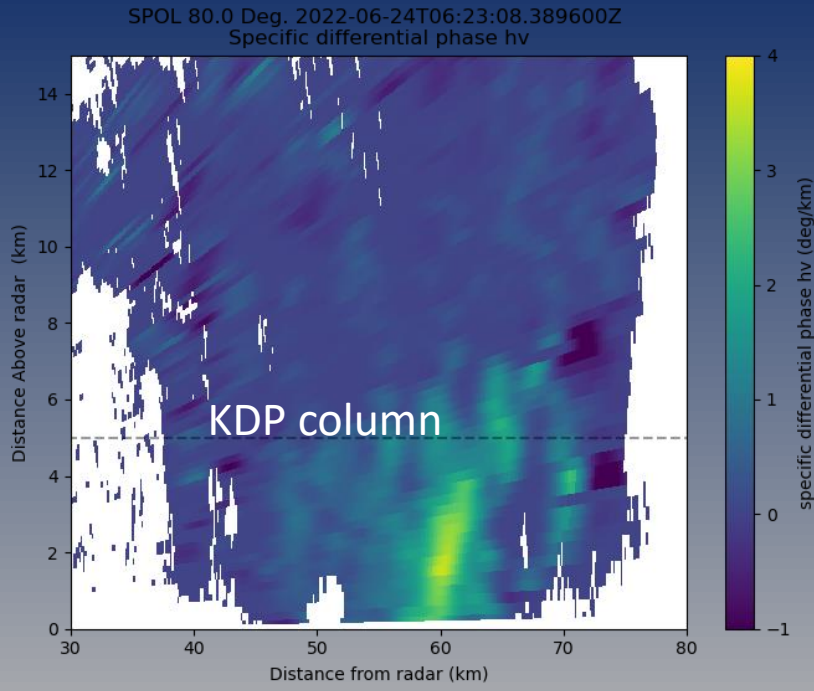
The RHI cross sections from SPOL radar showed intense convective storms with horizontal width less than 10 km.

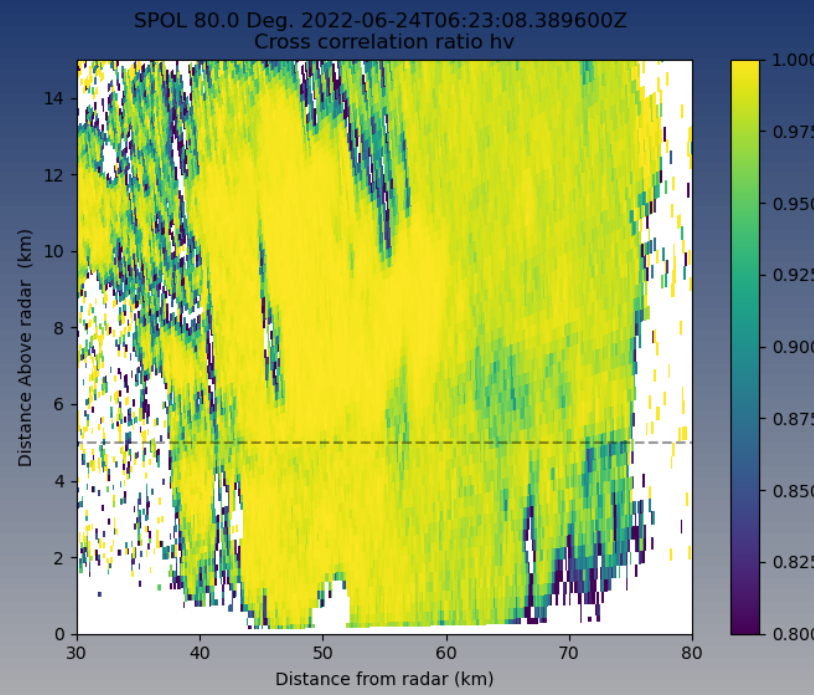
SOP3





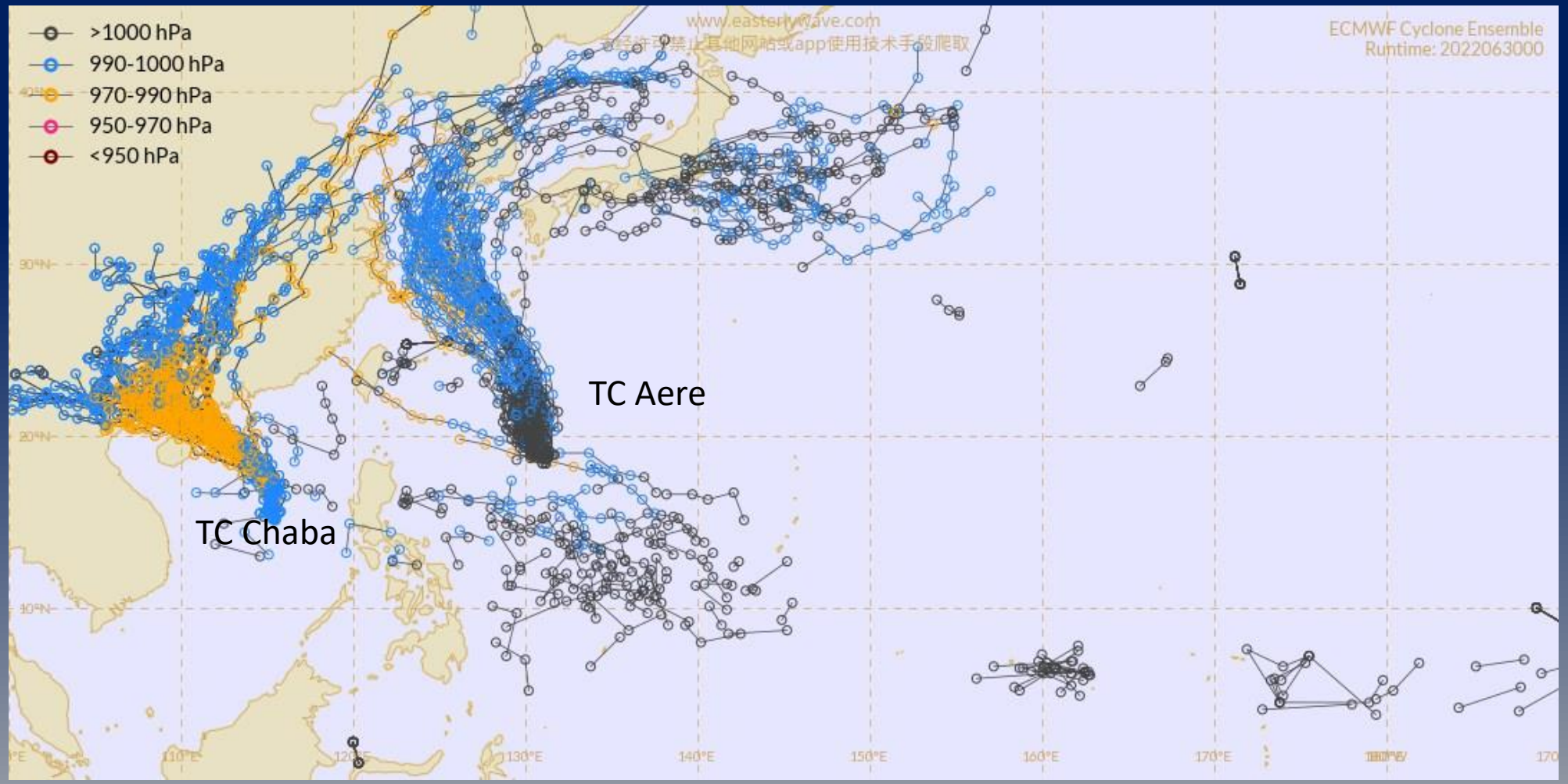




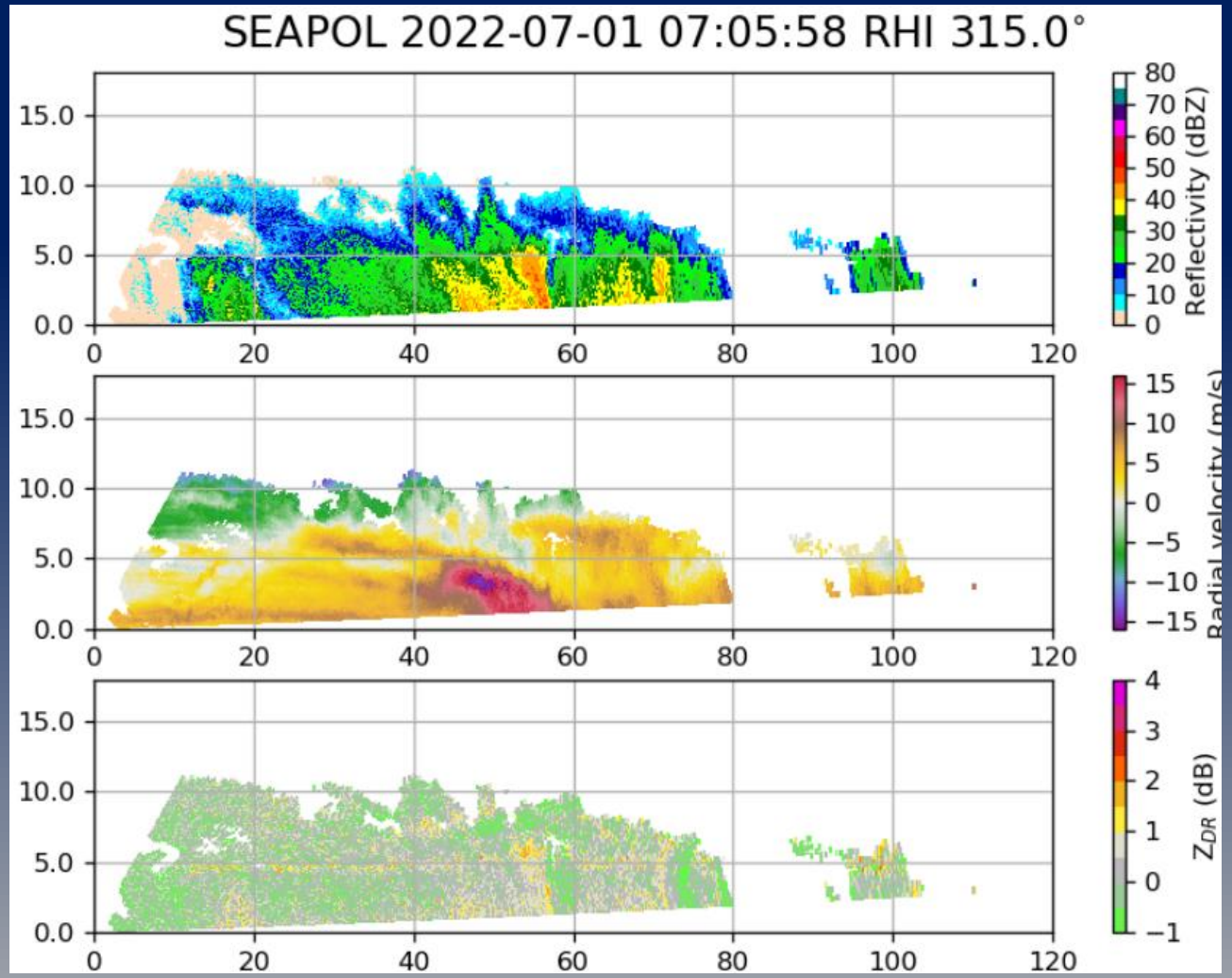


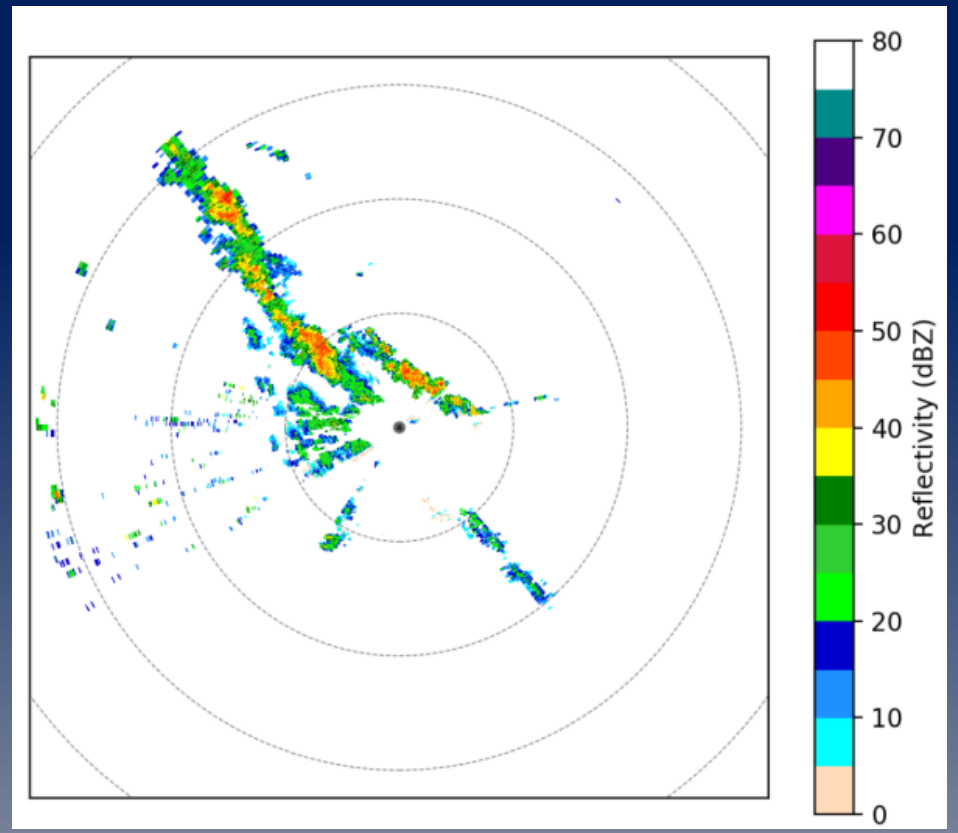
Source:
Chen-Hau Lan &
Pay-Liam Lin

IOP6: TCs Aere and Chaba near Taiwan



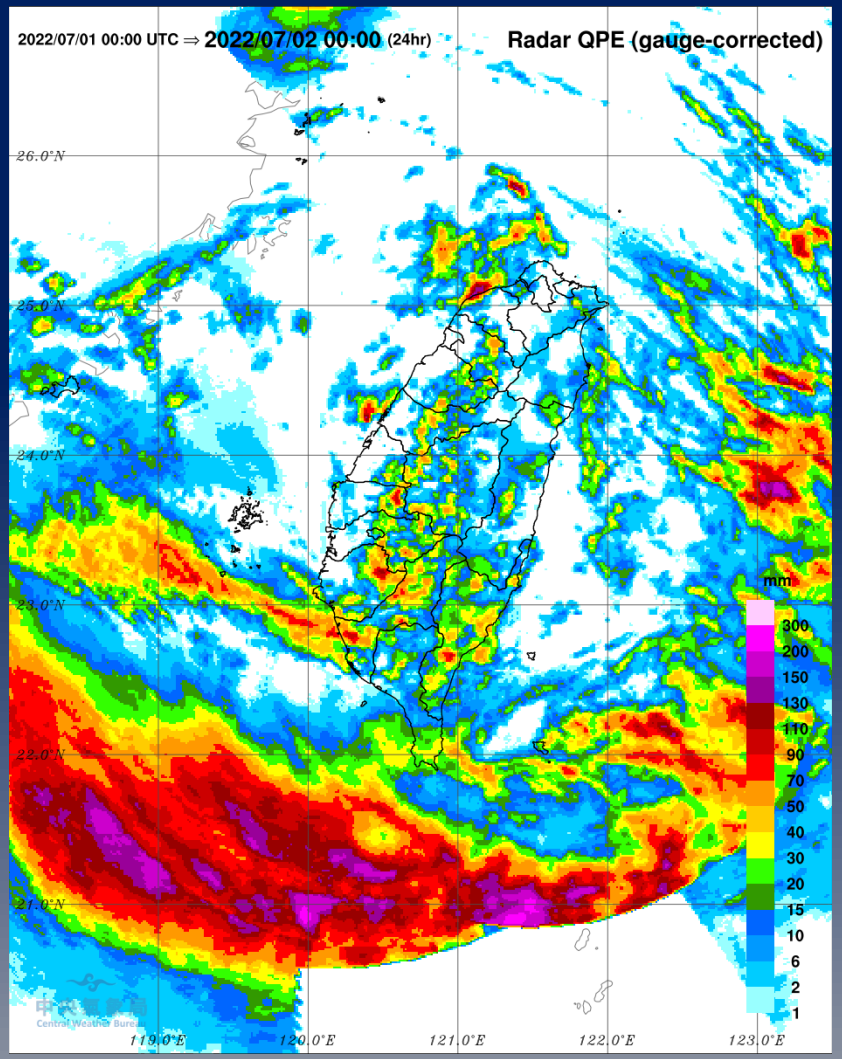
IOP6: TCs Aere and Chaba near Taiwan



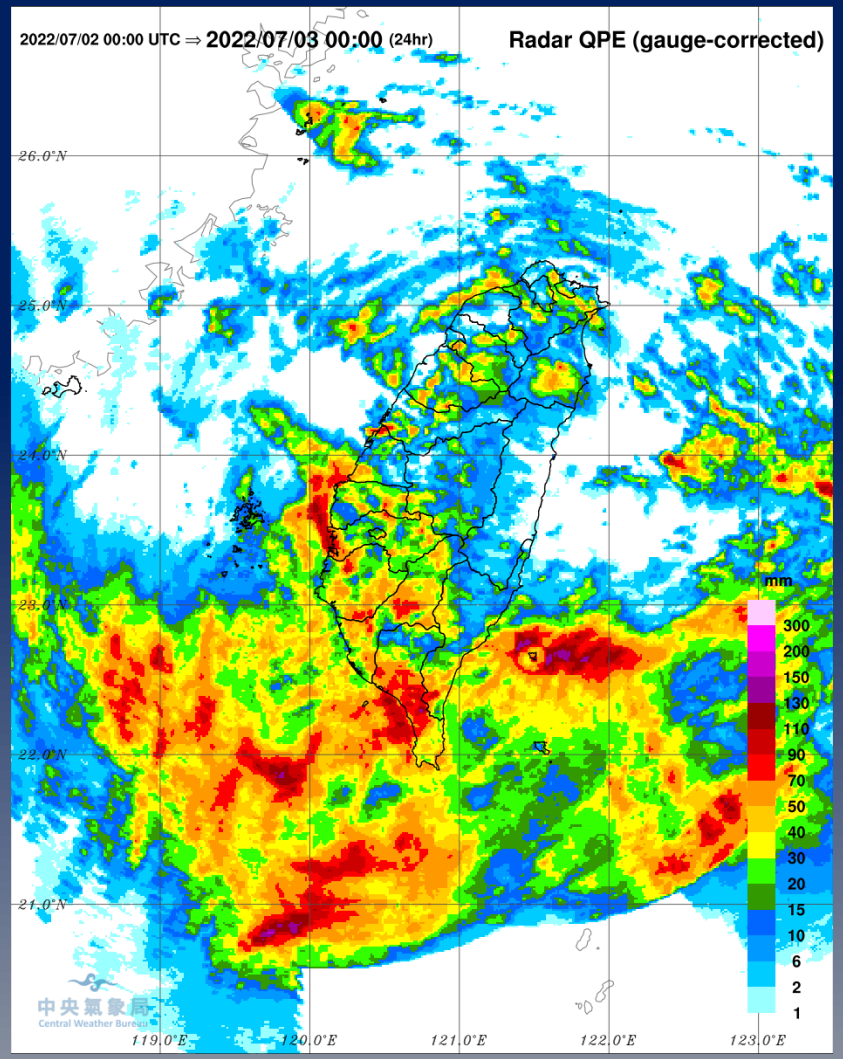


Squall-line feature near Yonaguni observed by SEA-POL radar on July 1st

IOP 6: TCs Aere and Chaba near Taiwan

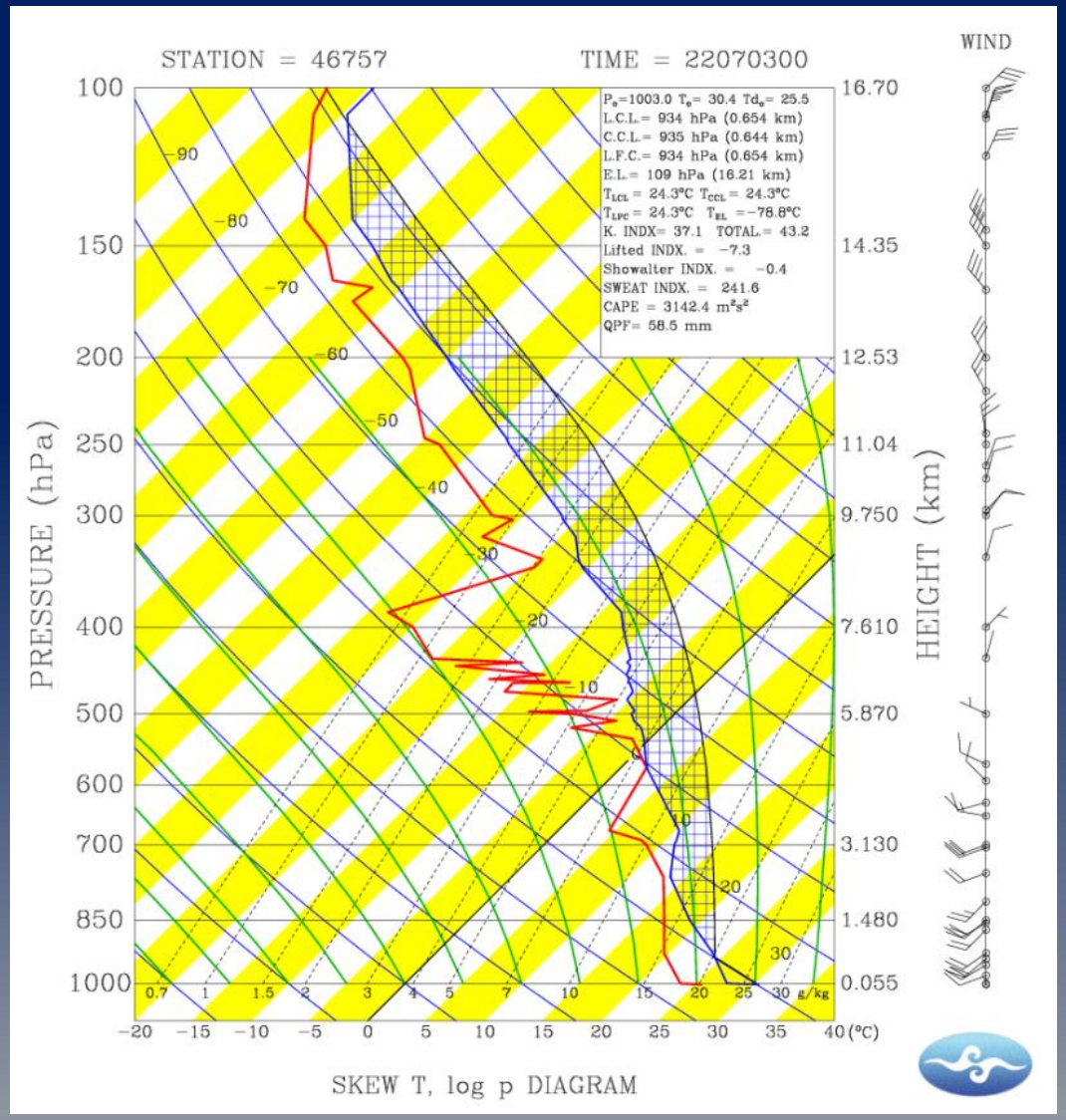


24-h Rainfalls associated with TC Aere on July 1st

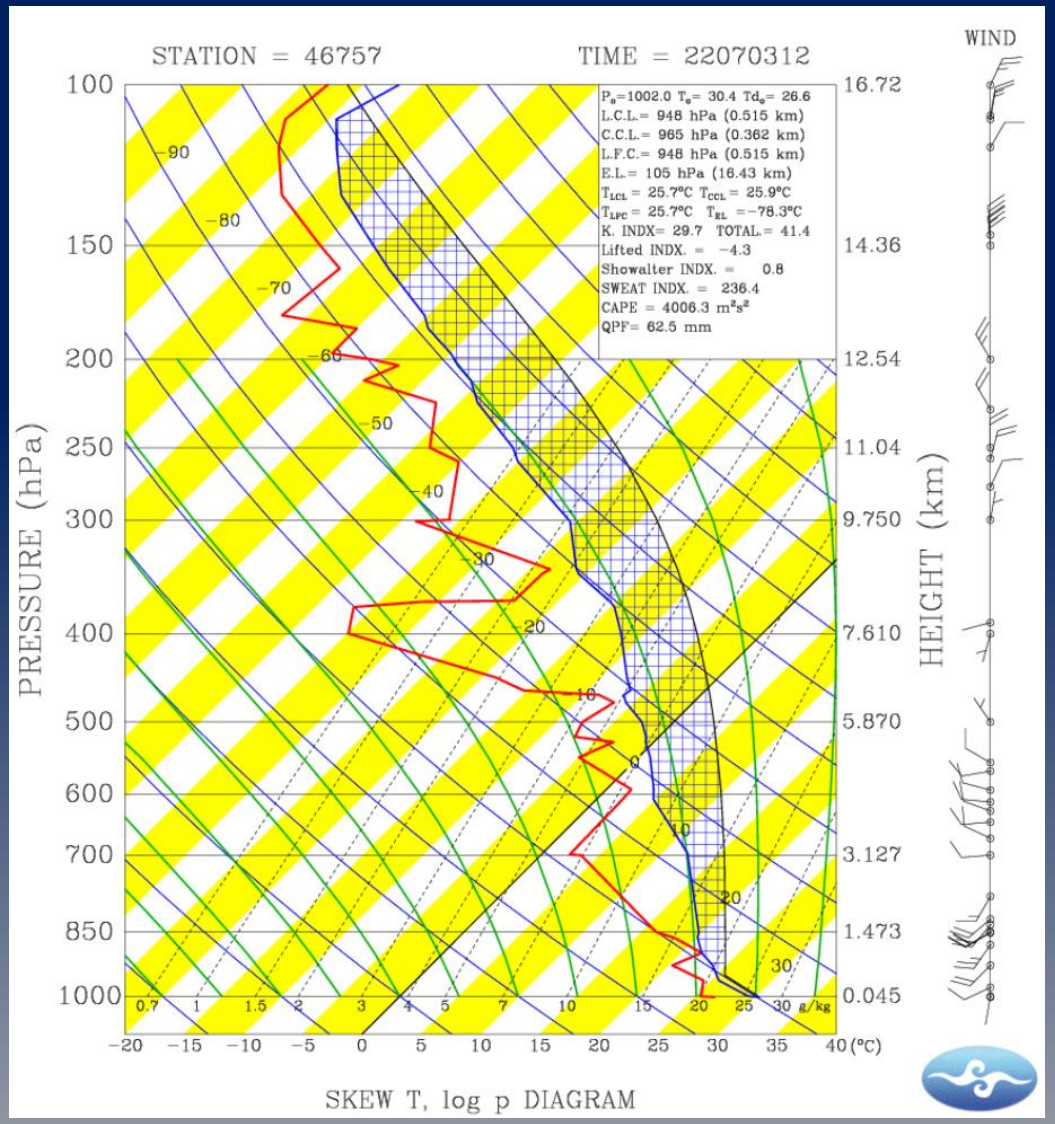


24-h Rainfalls associated with TC Aere on July 2nd

IOP 6: Unstable soundings at Hsinchu

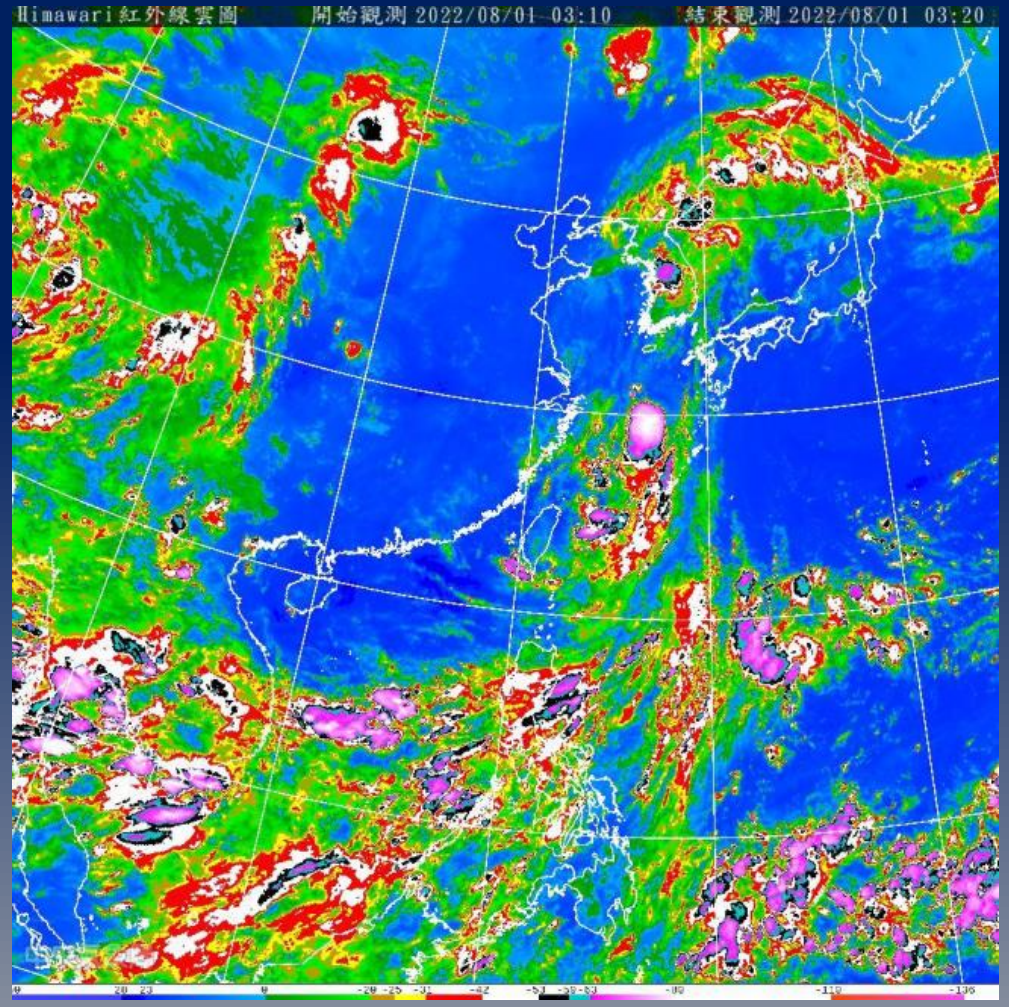


CAPE ~ 3100 J/kg at 00 Z on July 3rd

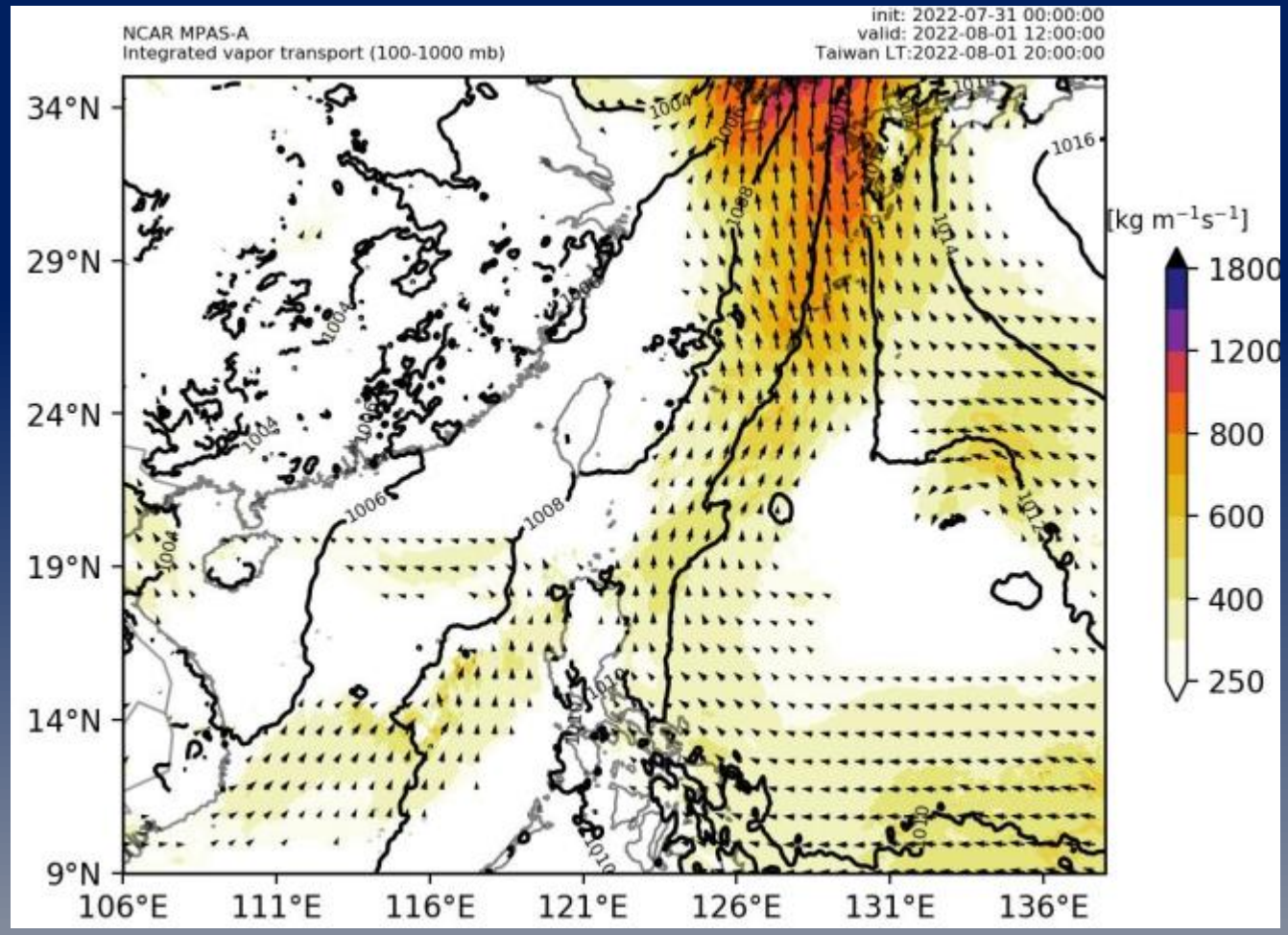


CAPE ~ 4000 J/kg at 12 Z on July 3rd, but only scattered showers observed near Hsinchu => Lack of forcing mechanisms

IOP 10: Moisture transport from low pressure during 1-3 August

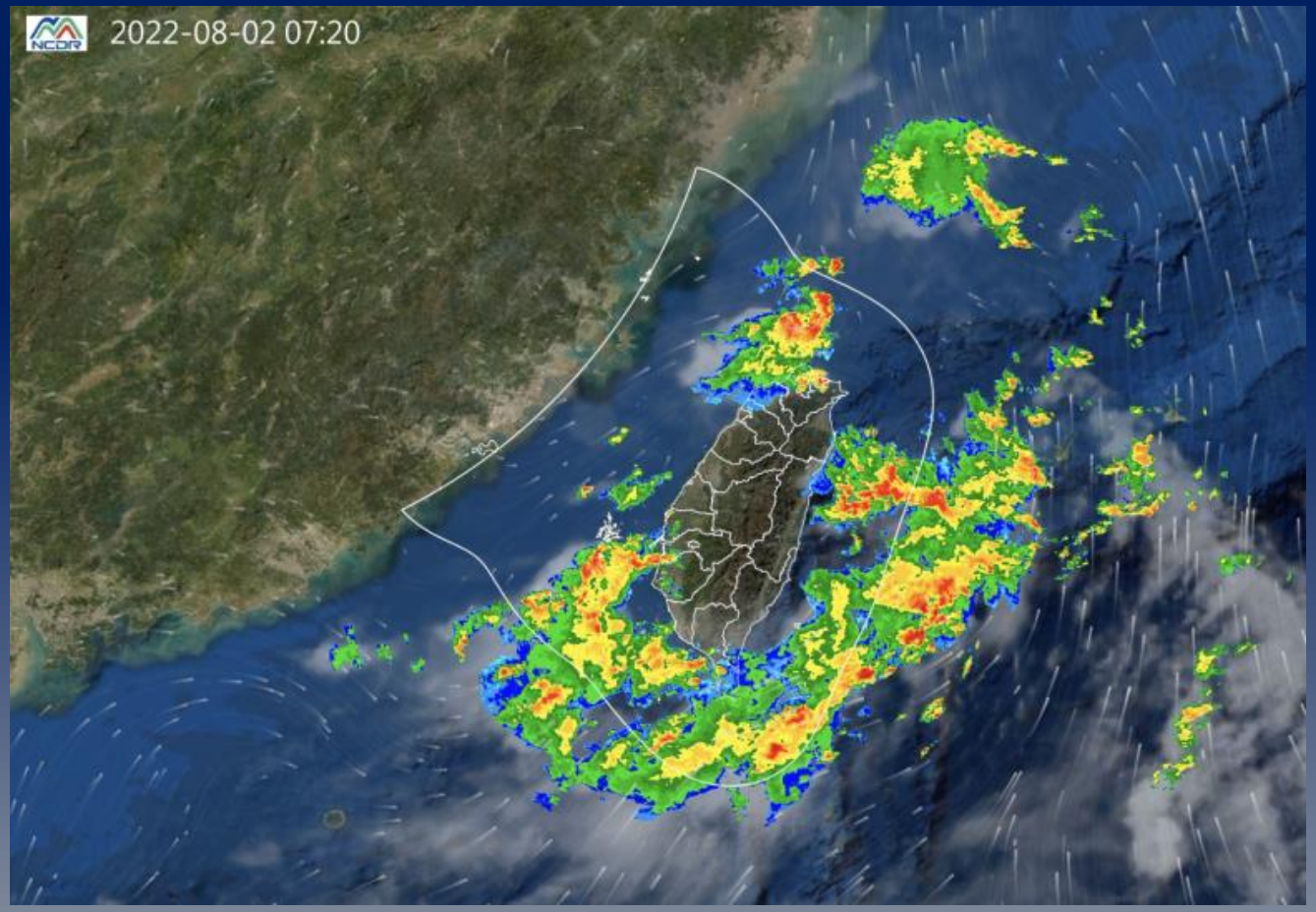


IR image on at 03 LST on August 1 =>
Low pressure to the northeast of Taiwan

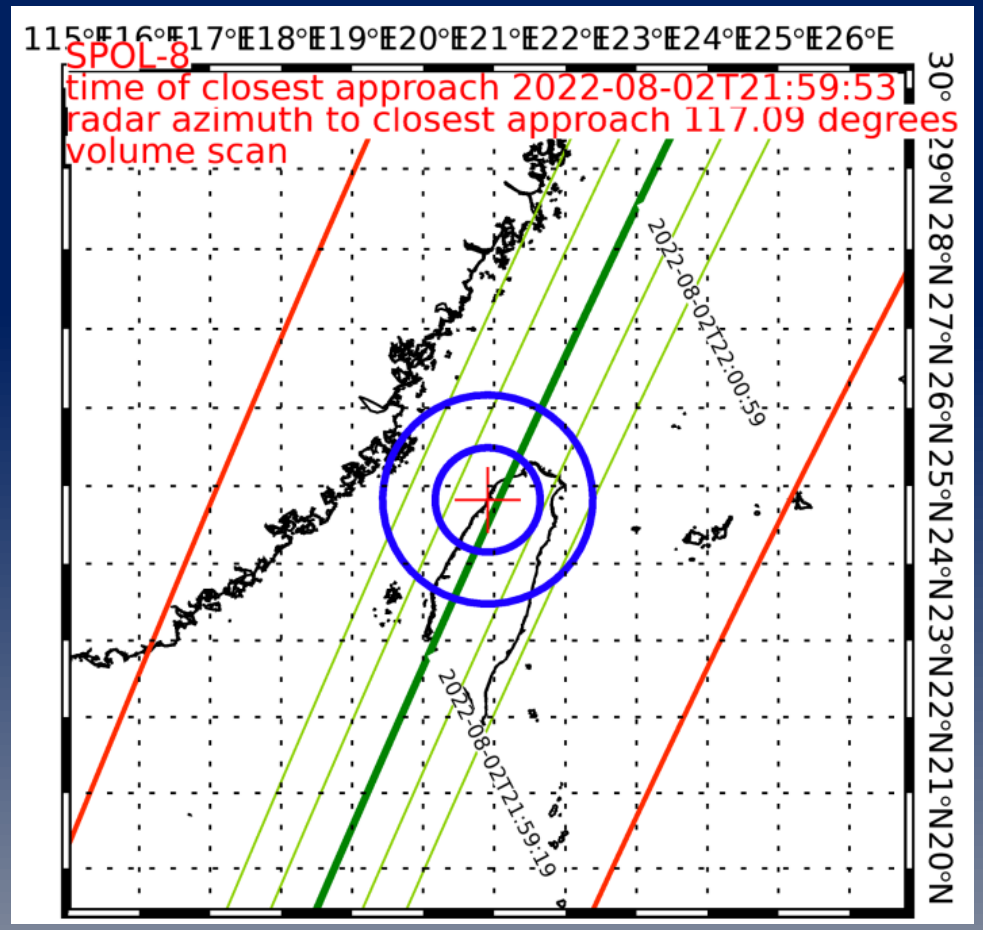


Integrated Vapor Transport at 12 UTC
on August 3

IOP 10: Moisture transport from low pressure during 1-3 August

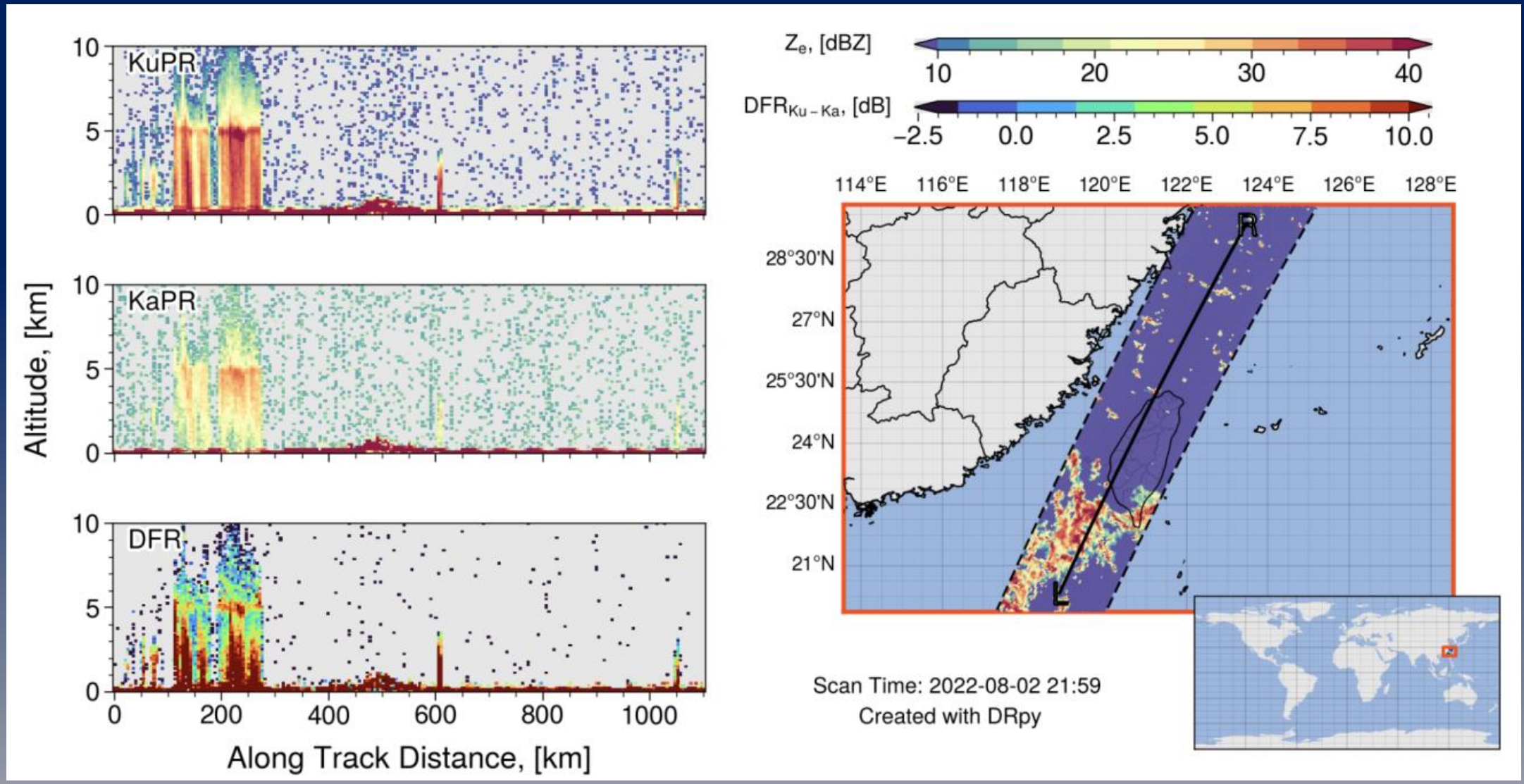


Radar composite on August 2



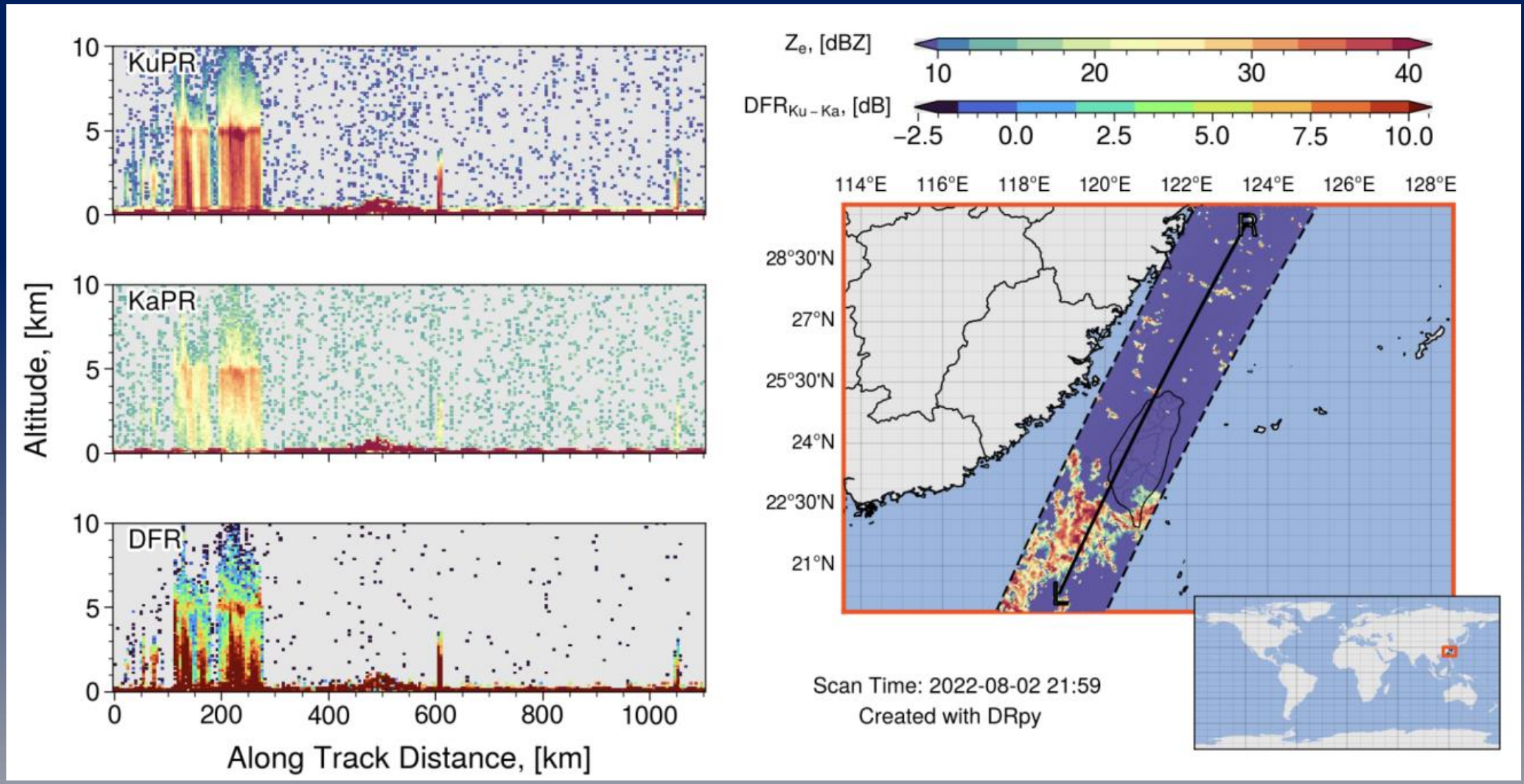
SPOL observations collcated with GPM satellite overpass

IOP 10: Moisture transport from low pressure during 1-3 August



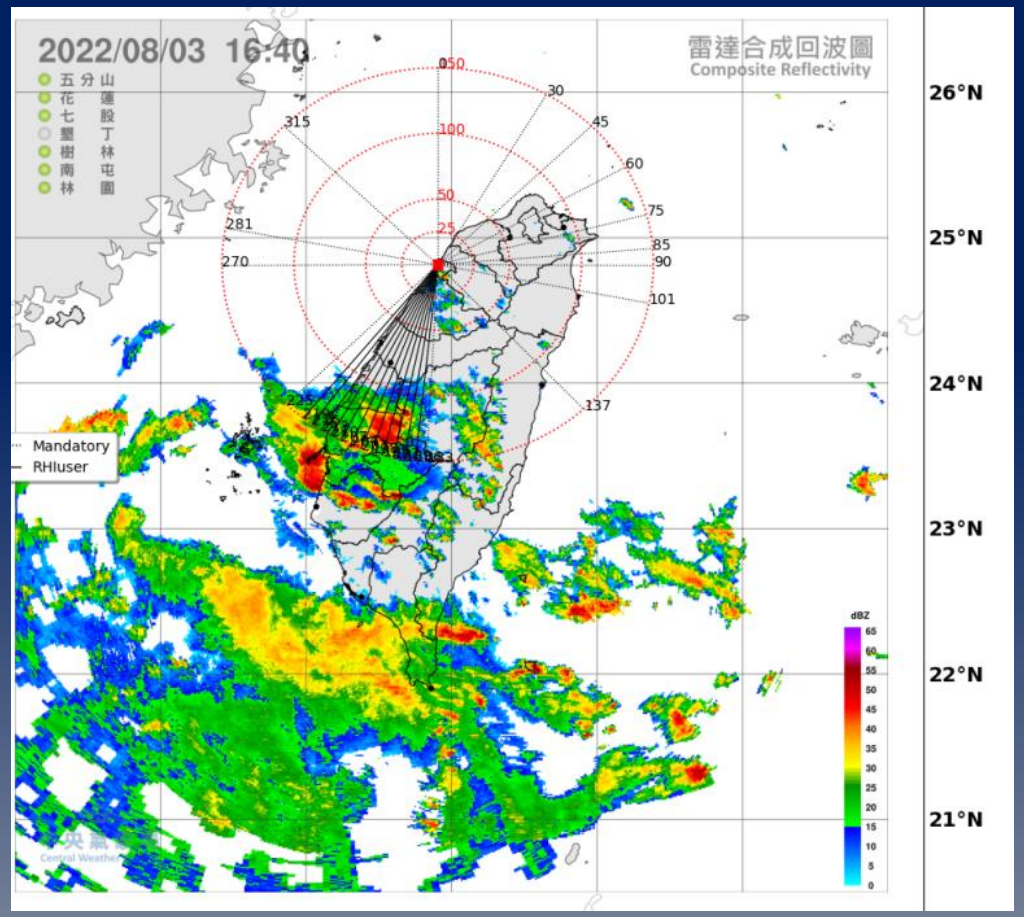
GPM overpass on August 2

IOP 10: Moisture transport from low pressure during 1-3 August

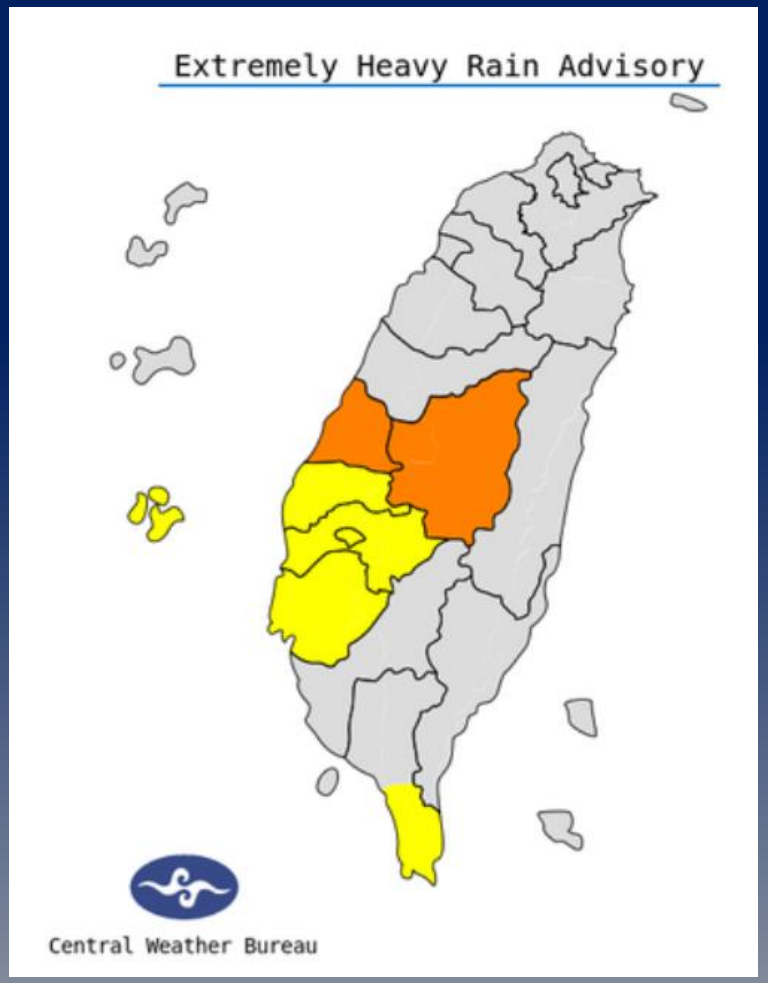


GPM overpass on August 2

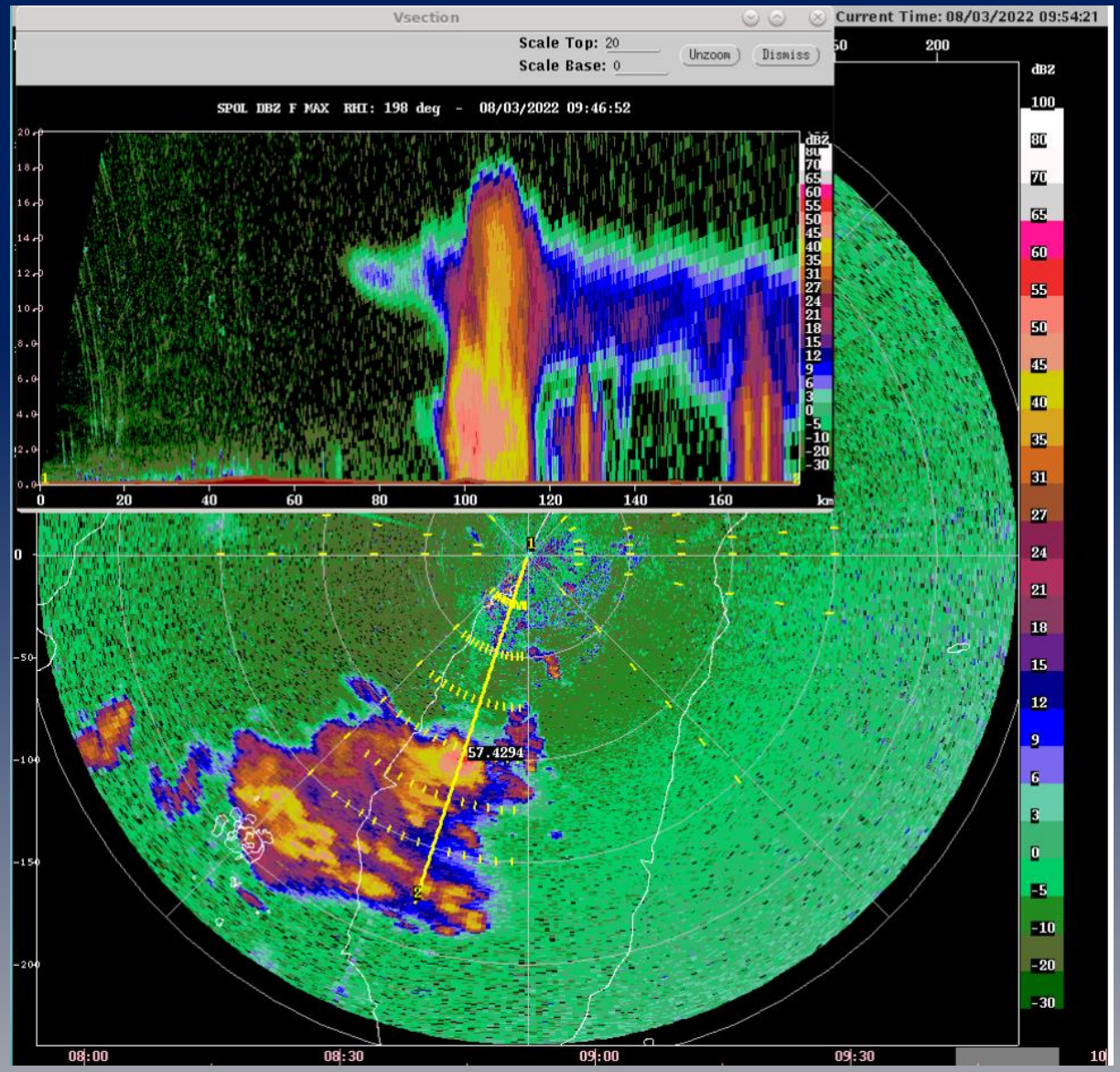
IOP 10: Moisture transport from low pressure during 1-3 August



S-Pol intense RHI scans on the thunderstorms on August 3 over central Taiwan

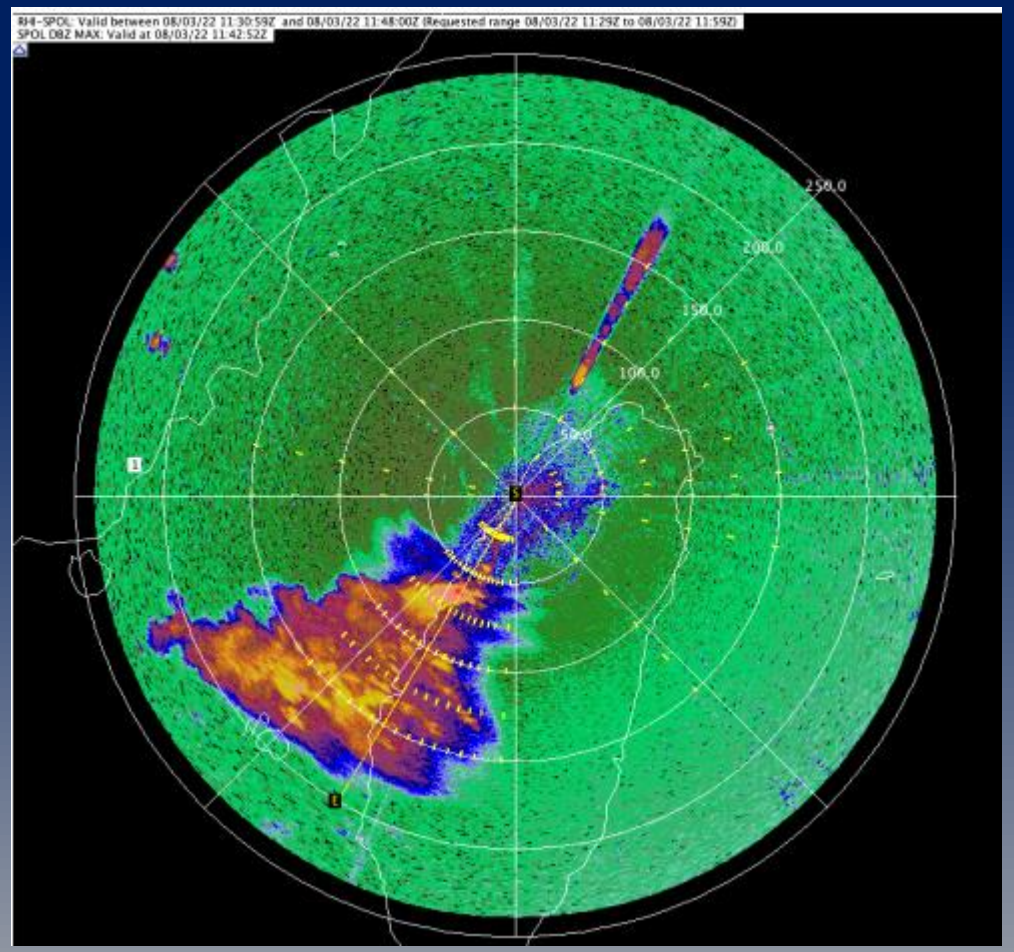


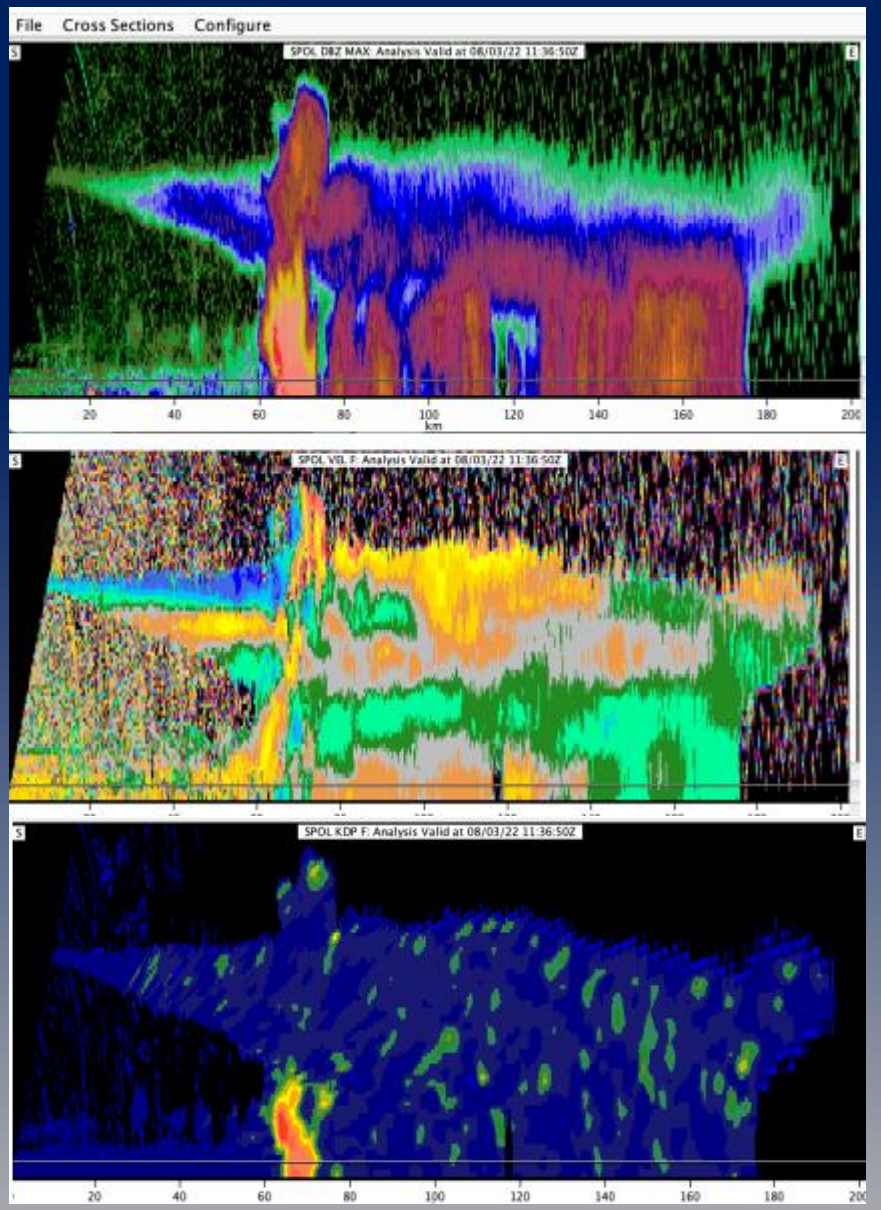
IOP 10: Moisture transport from low pressure during 1-3 August



S-Pol RHI scan on the thunderstorms on August 3

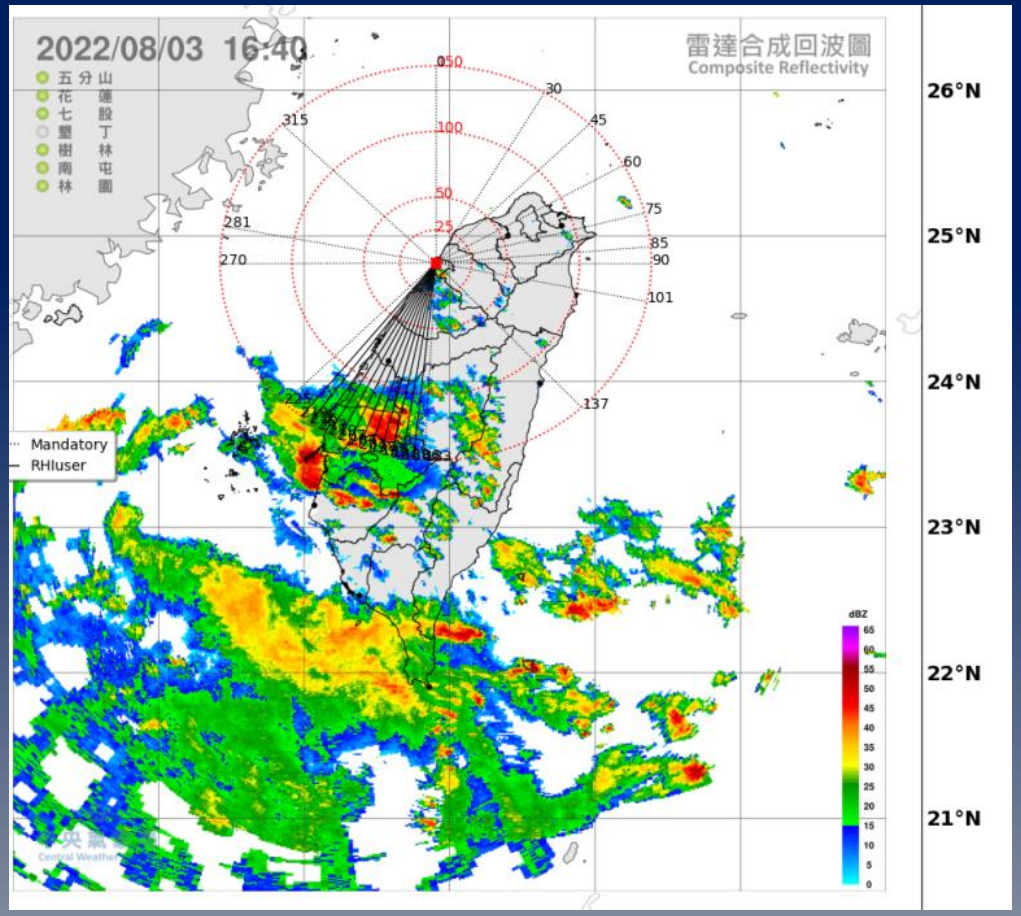
IOP 10: Moisture transport from low pressure during 1-3 August



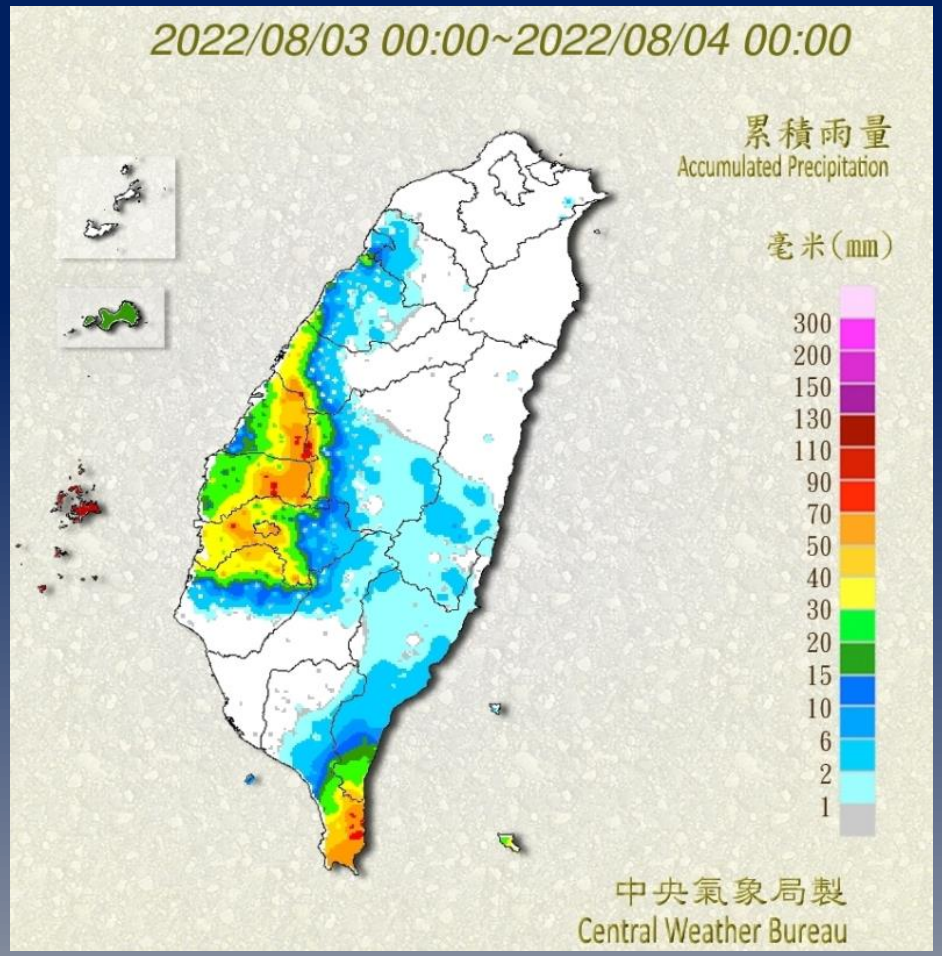


S-Pol intense RHI scans of Z, VR, and KDP on the thunderstorms on August 3

IOP 10: Moisture transport from low pressure during 1-3 August

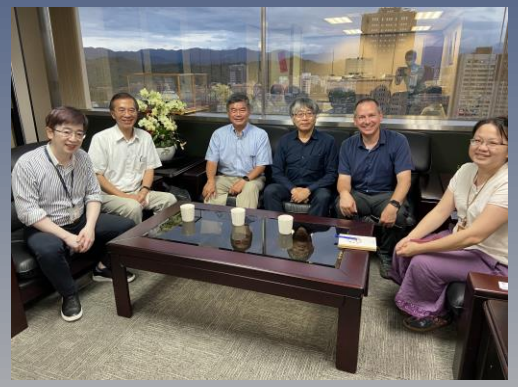


Radar Composite at
1640 LST on August 3



24-h rainfall on August 3


重光
美霖
雍嵐
佩迪




TION

Conclusions

- TAHOPE/PRECIP/T-PARCII 2022 field experiment were conducted successfully despite 2-year delay and ongoing COVID-19 pandemic
  - 1st deployment of NCAR MicroPulse DIAL (MPD) on Taiwan
  - 1st land-based deployment of CSU SEA-POL on Yonaguni, Japan
  - 1st international field campaign on Mei-Yu fronts, MCSs, thunderstorms, and typhoons
- Boundary-layer lifting in moisture-rich environment surrounding Taiwan is a critical factor
  - Strength and position of frontal forcing are essential
  - Diurnal heating over complex terrain on Taiwan – very predictable in some cases, but unpredictable in other cases
- Over 200,000 radar RHIs are composited into comprehensive profiles of polarimetric radar information, and the TAHOPE/PRECIP/T-PARCII data are now open to every one to use.
- TAHOPE data/science workshop at NTU on 29-30 November 2023.

Thank you !!!

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