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An Investigation of the 8 June 2007 Heavy-Rainfall Event in Central Taiwan

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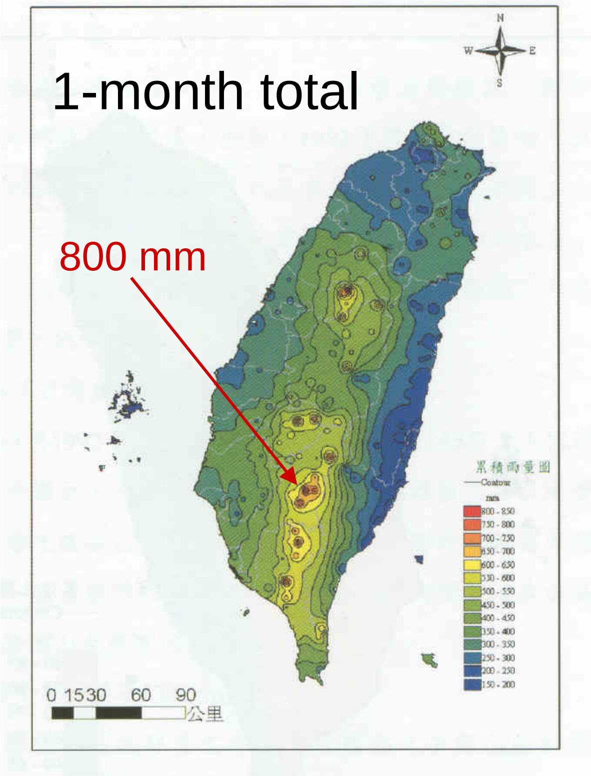
Presentation Outline:

- **Introduction**
- **Case Review and Motivation**
- **Synoptic Condition**
- **Model and Experiment Design**
- **Simulation Result**
- **Discussion and Conclusion**

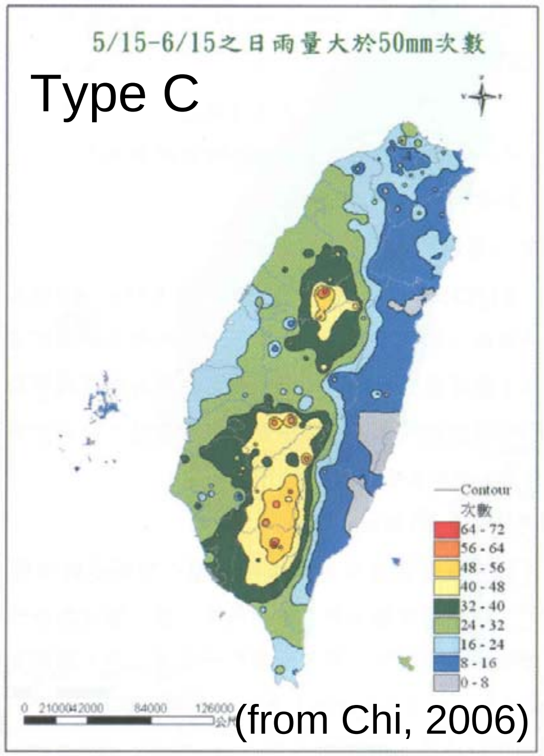
1. Introduction: (1)

- Heavy rainfall during the Mei-yu season in Taiwan occurs both over mountains and coastal regions

Mean total rainfall (mm)
ARMTS, 5/15-6/15, 1992-04

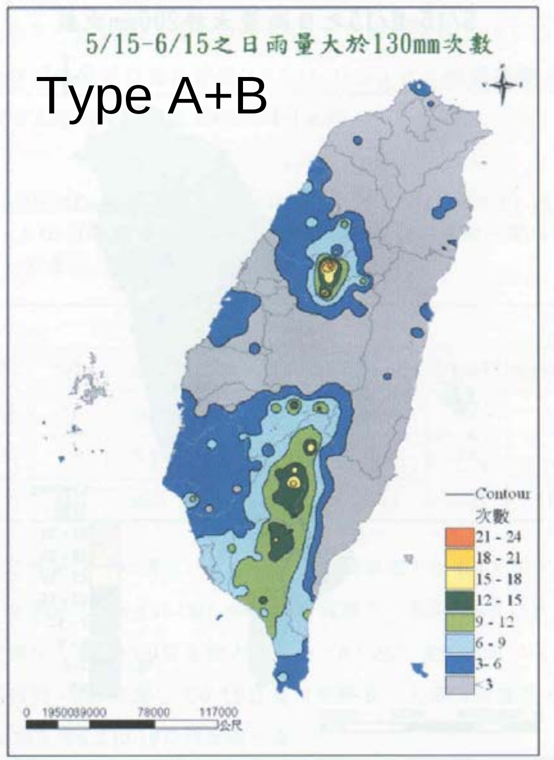


Total freq. of ≥ 50 mm/day
5/16-6/15, 1992-2004



(from Chi, 2006)

Total freq. of ≥ 130 mm/day
5/16-6/15, 1992-2004



1. Introduction: (2)

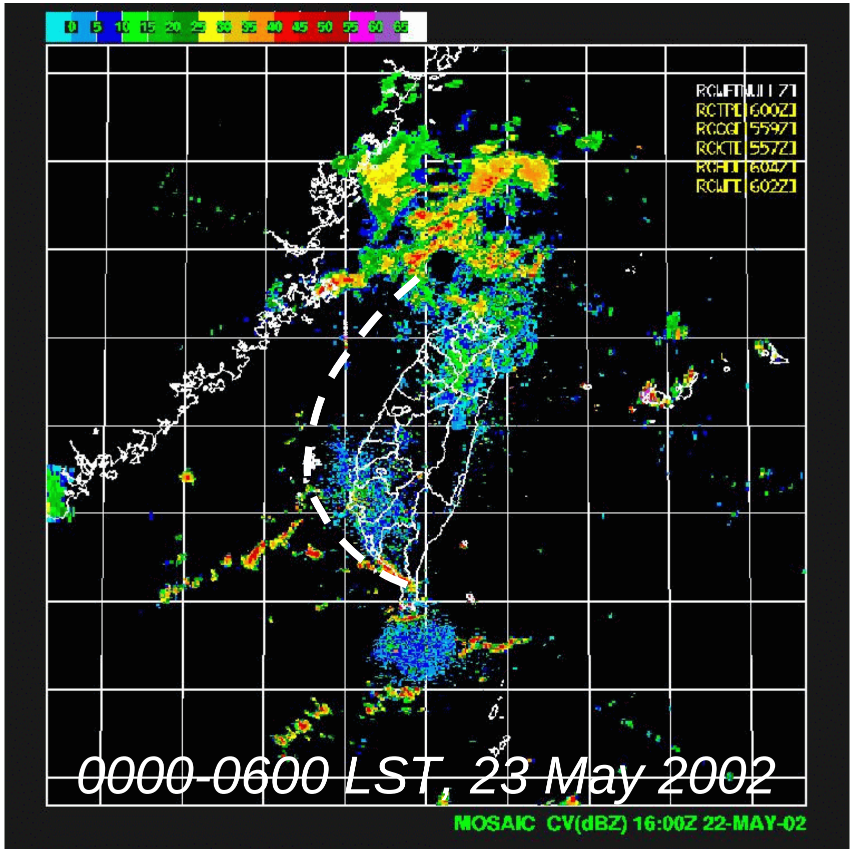
- To accurately forecast the initiation, development, and dissipation of mesoscale convective systems (MCSs) responsible for heavy rainfall at correct time and location around Taiwan is often difficult

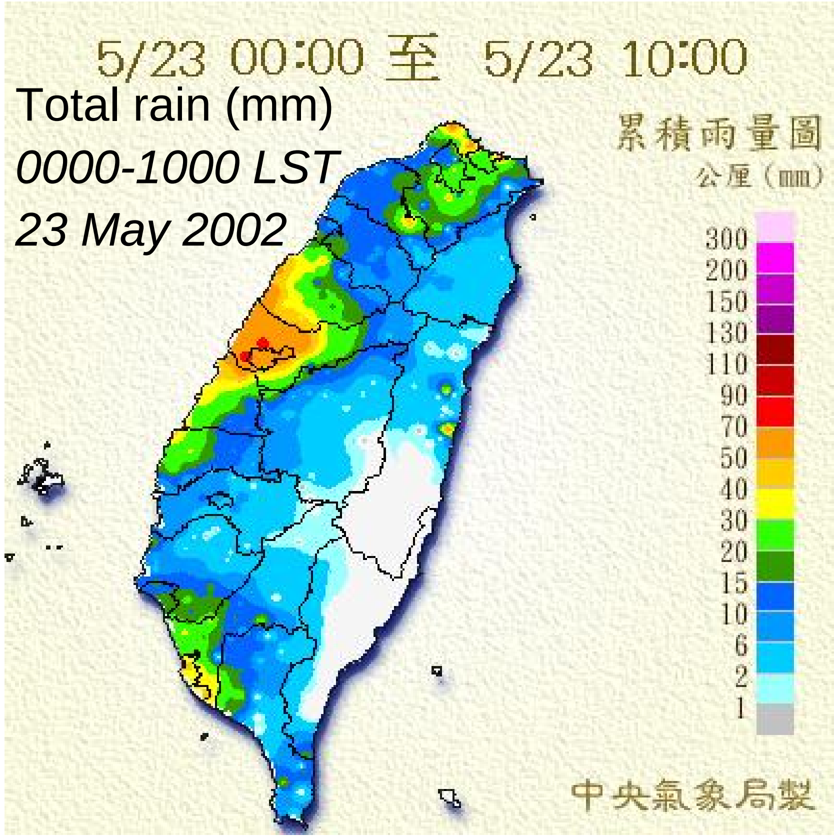
- Steep terrain and typically moist and unstable atmosphere

- MCSs and deep convection initiated by a variety of mechanisms: Frontal uplift, topographic uplift, dynamical forcing aloft, terrain blocking effect, solar heating during daytime (free convection), island circulation (land-sea and/or mountain-valley breezes), outflow boundary from previous/existing convection, … etc.

1. Introduction: (3)

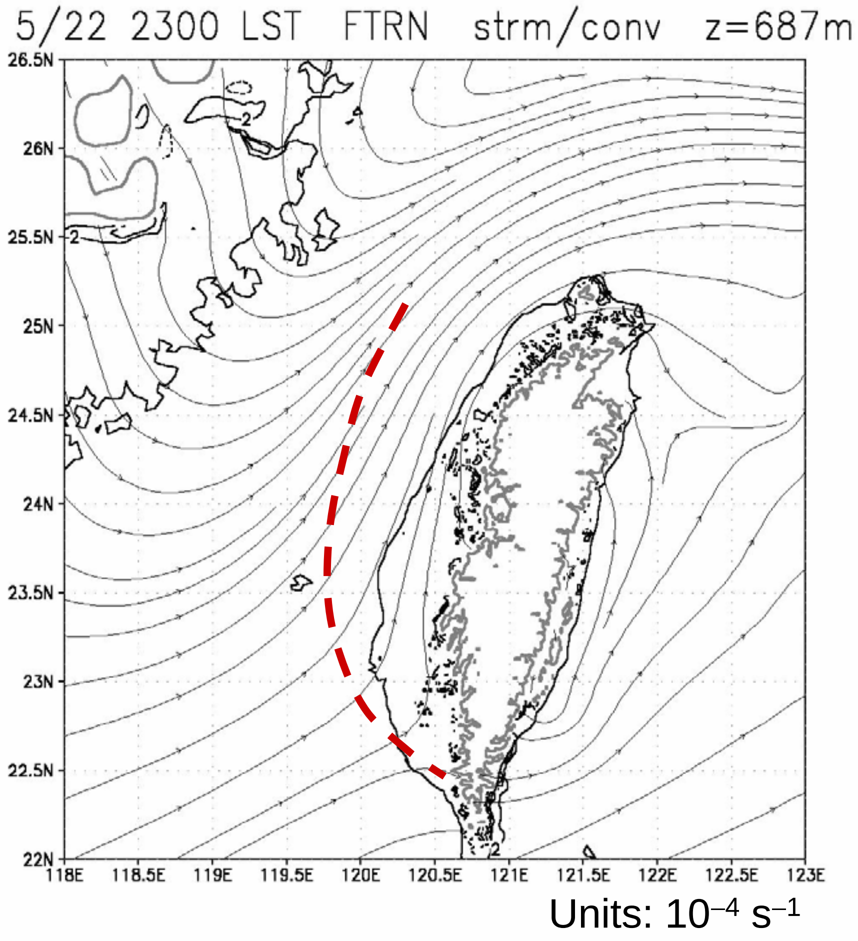
- An example of rainfall near the coast of central Taiwan, linked to terrain blocking of prevailing SW flow offshore

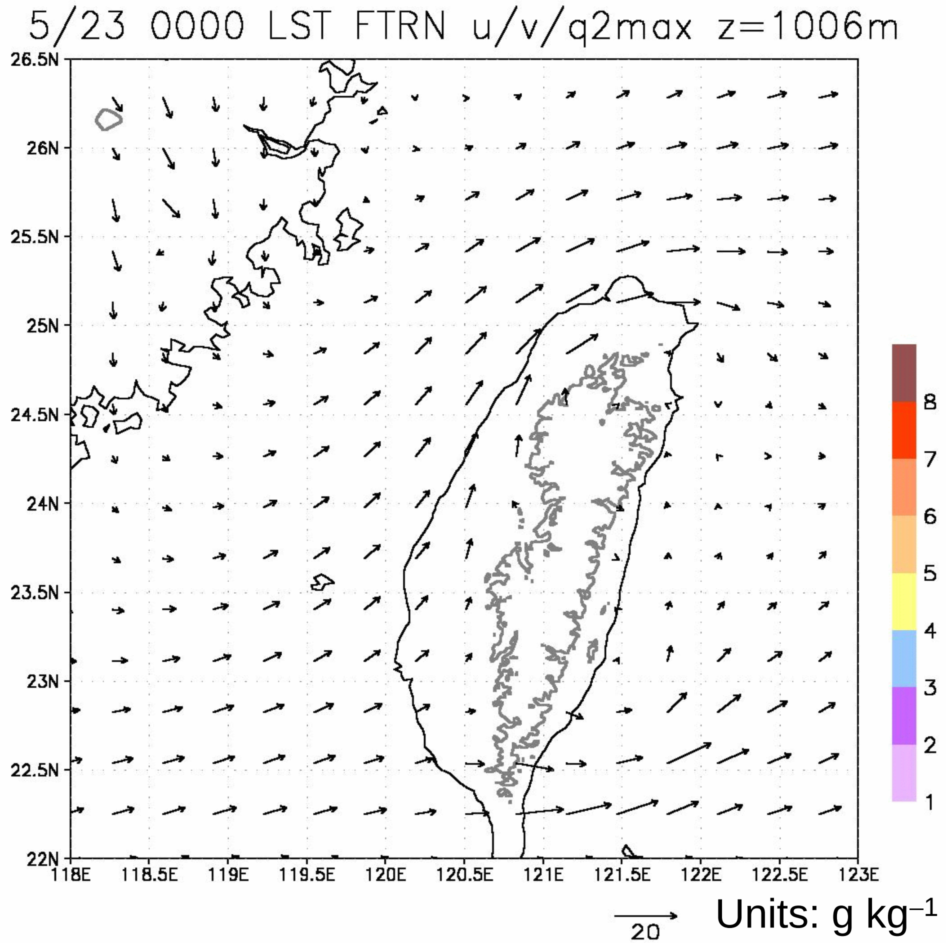




1. Introduction: (4)

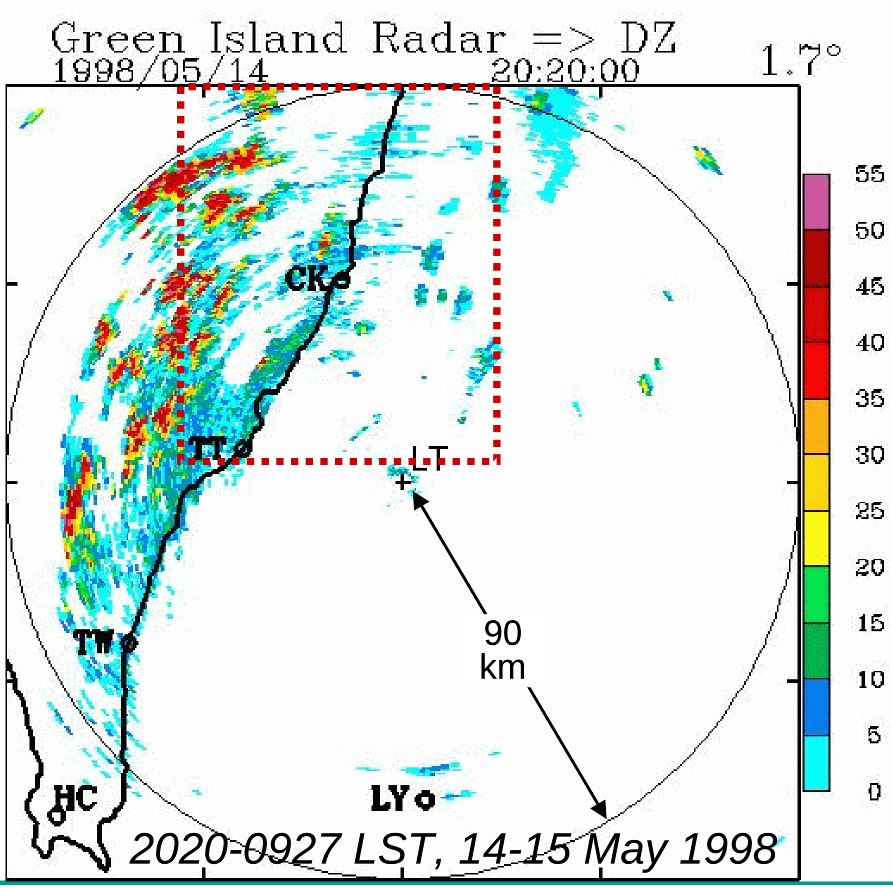
- CReSS model simulation (Wang et al., 2005, MWR)

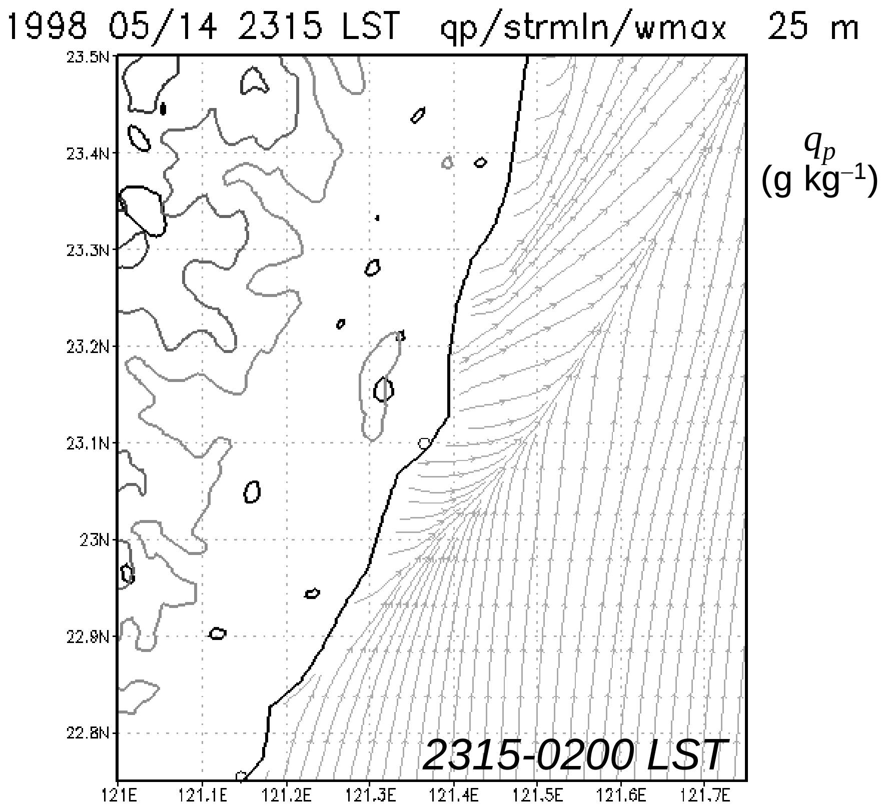




1. Introduction: (5)

- Another example of repeated convection initiation due to outflow boundary (Wang and Huang, 2009, GRL)

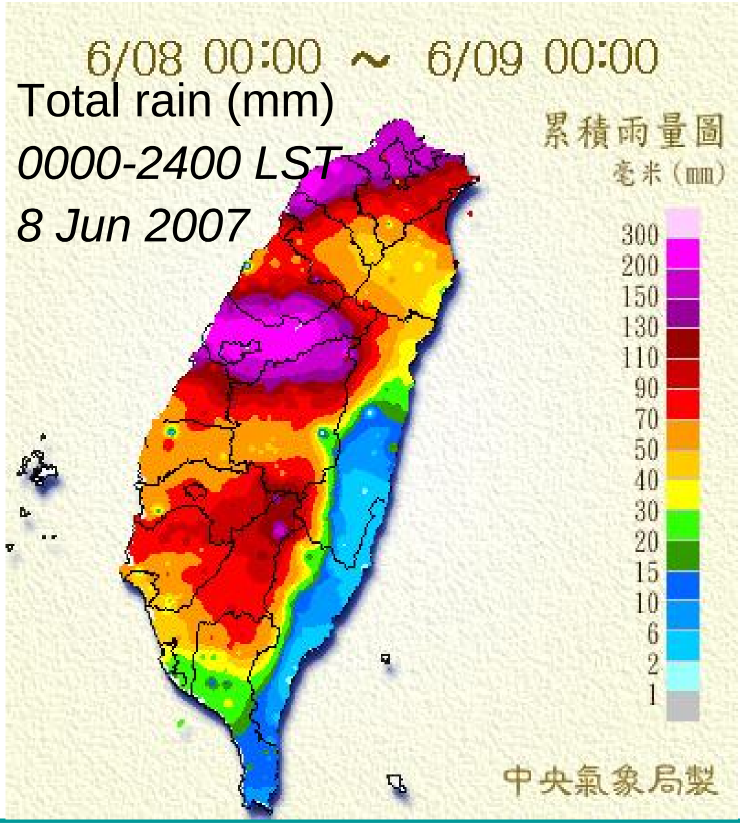


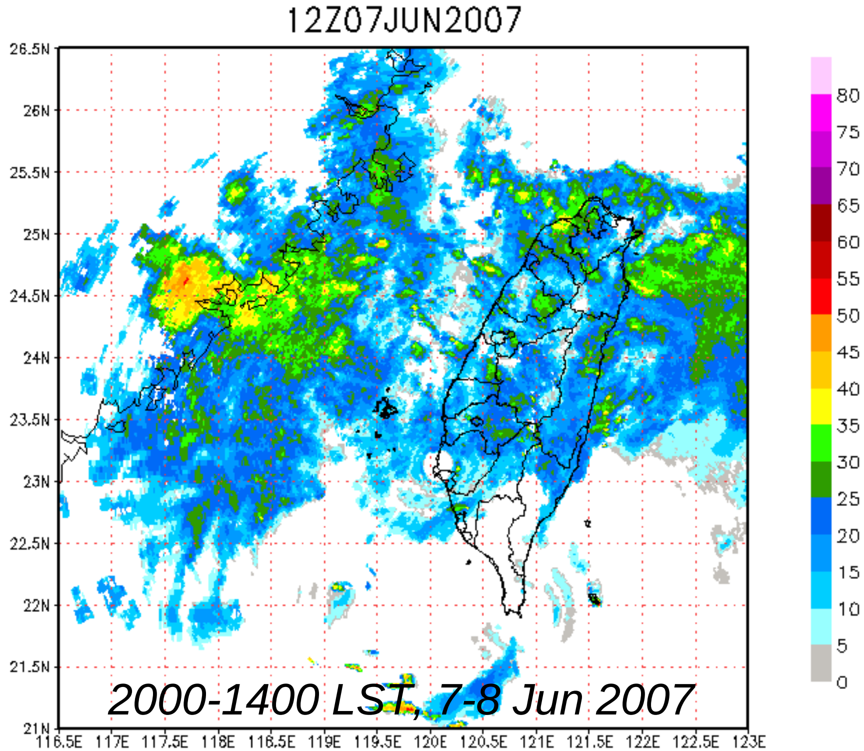


(Max +w plotted at 0.5, 2, 6, 10 m s^{-1})

2. Case Review and Motivation: (1)

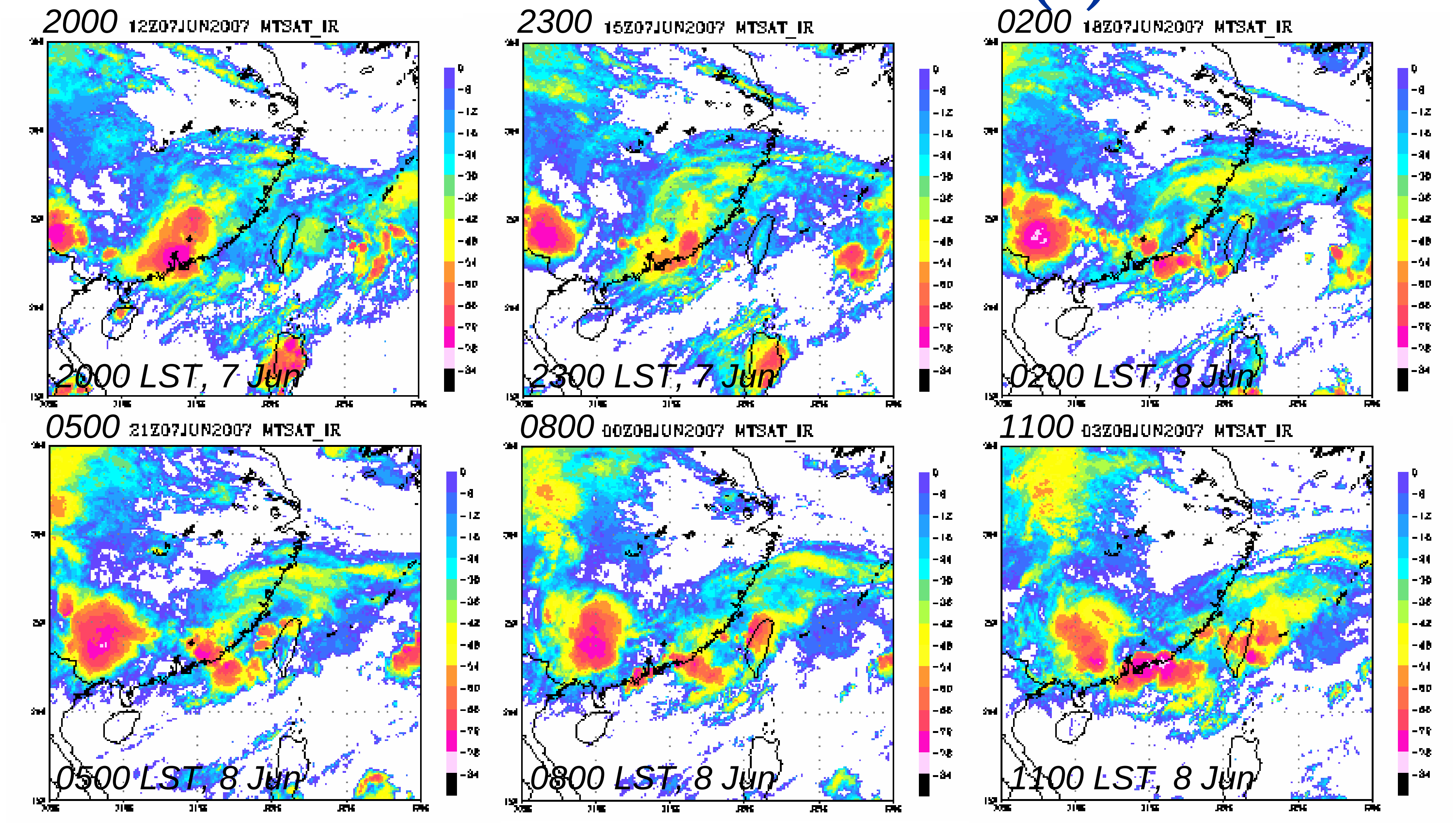
- Significant rainfall over northern, central, and southern Taiwan on 8 Jun 2007, but heaviest in central Taiwan, including the coastal region (daily total >250 mm)



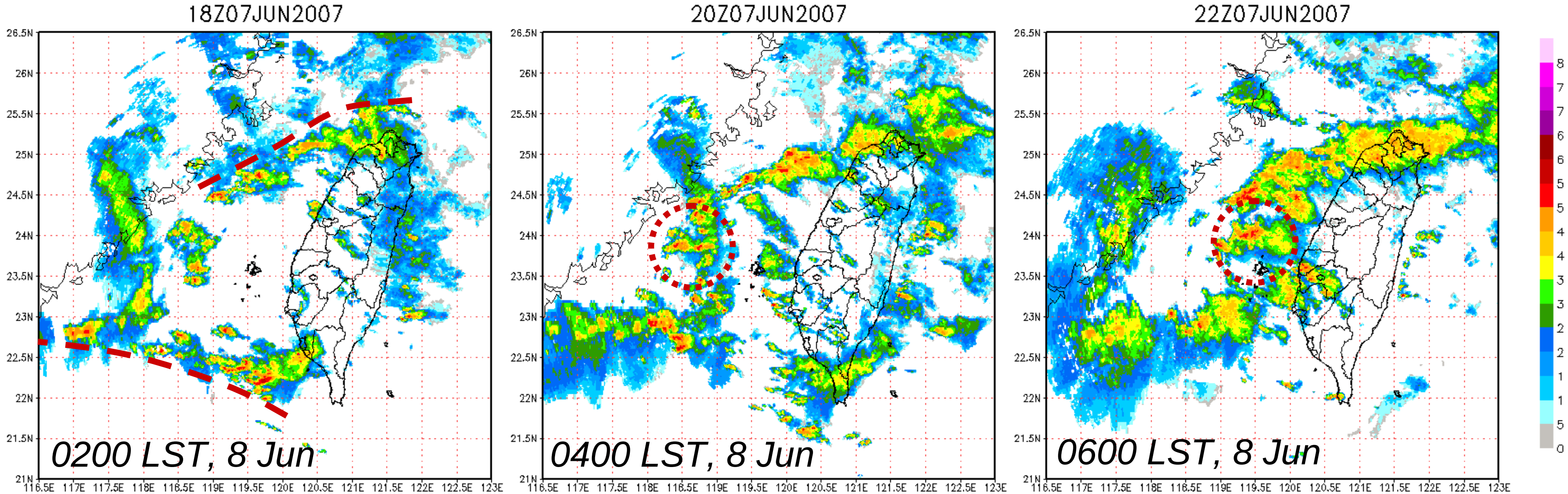


Radar Column Max Echo Composite (dBZ)

2. Case Review and Motivation: (2)



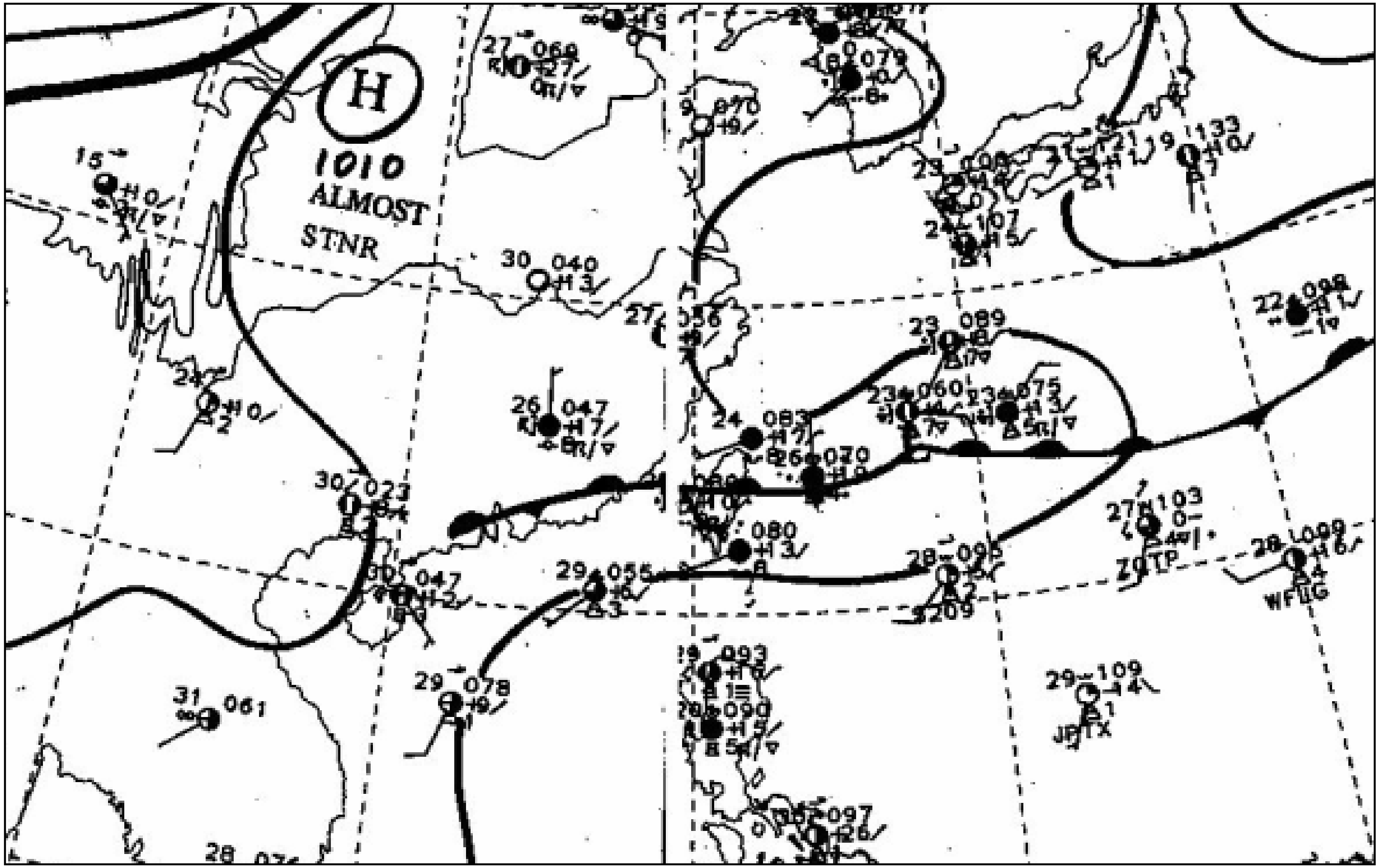
2. Case Review and Motivation: (3)



- Two pre-existing lines of convection: One over northern strait along the front (ENE-WSW) and the 2nd over southern strait (ESE-WNW) linking to MCSs moving offshore from China
- Why was convection initiated in between the two lines (over central Taiwan Strait), to eventually move over central Taiwan and cause heavy rainfall along the coast?

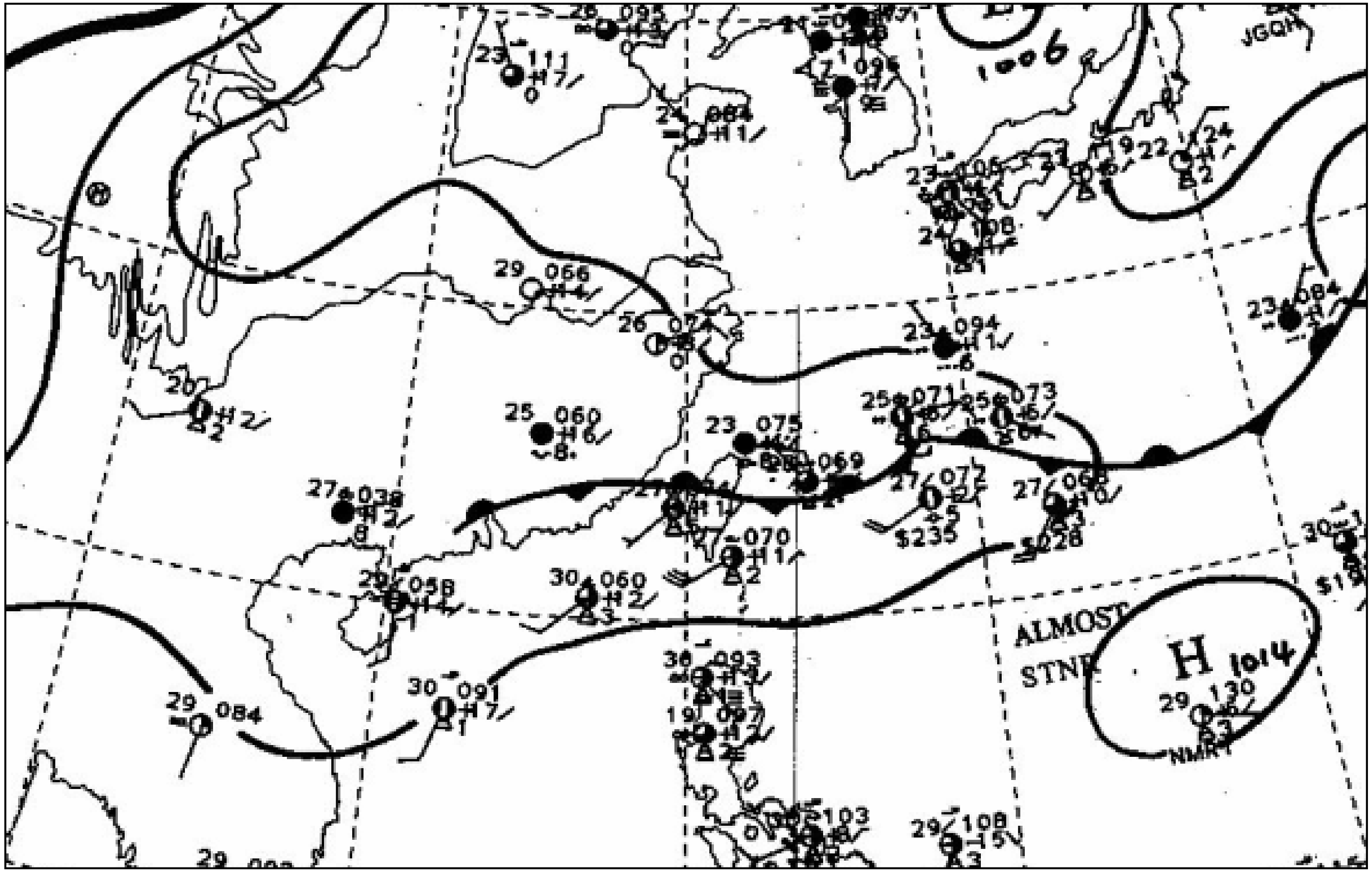
3. Synoptic Condition: (1)

CWB Surface map: *2000 LST* (*1200 UTC*), *7 Jun 2007*



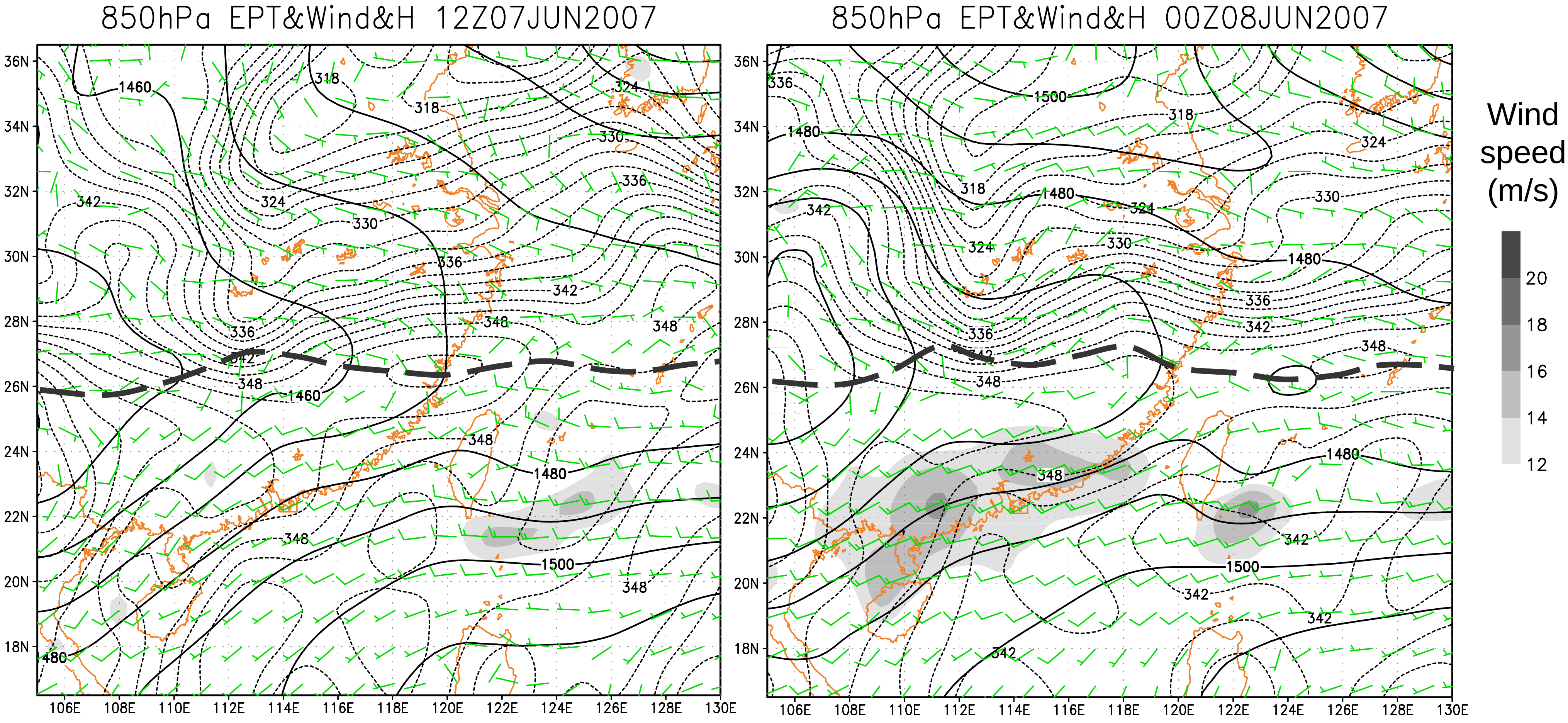
3. Synoptic Condition: (1)

CWB Surface map: *0800 LST* (*0000 UTC*), *8 Jun 2007*



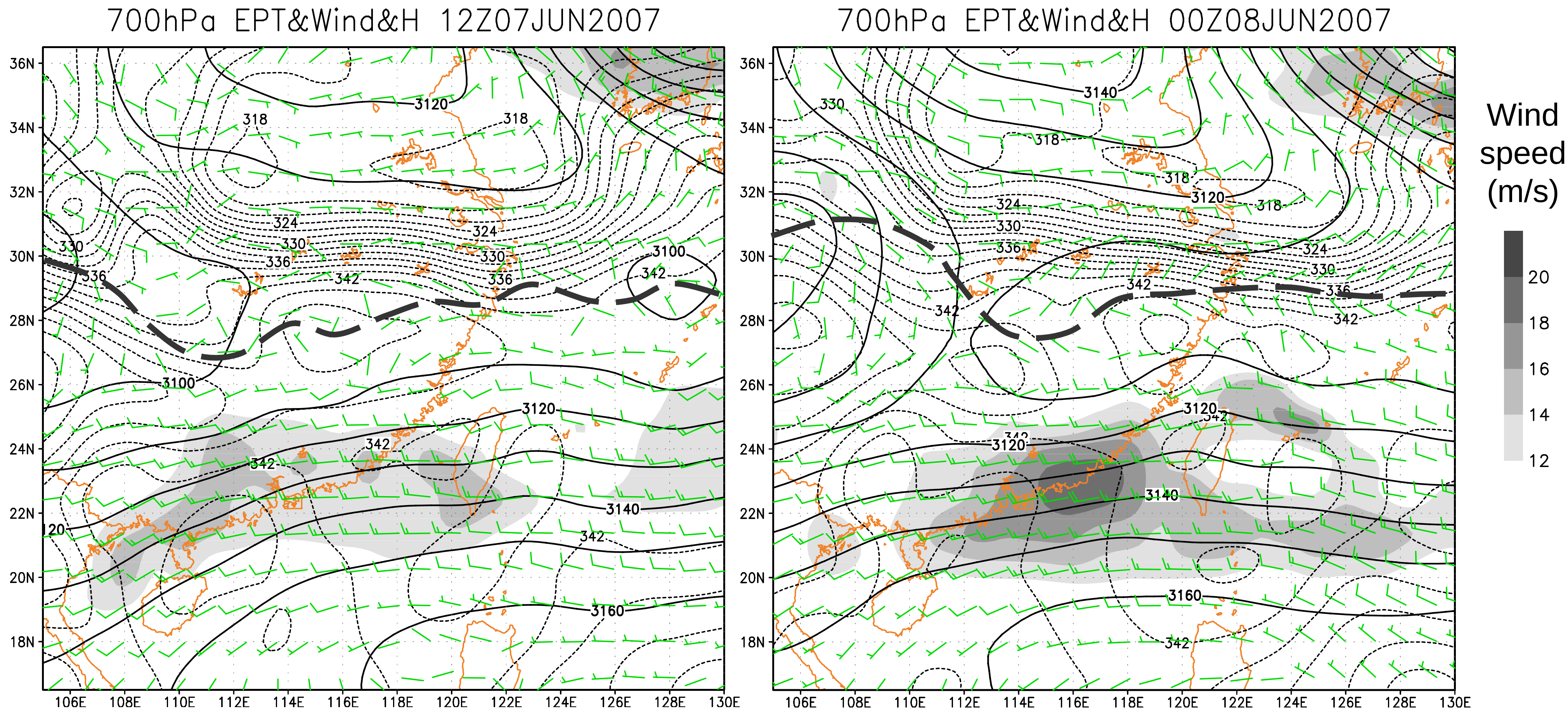
3. Synoptic Condition: (2)

2000 LST, 7 Jun 2007 (850 hPa, ECMWF) *0800 LST, 8 Jun 2007*



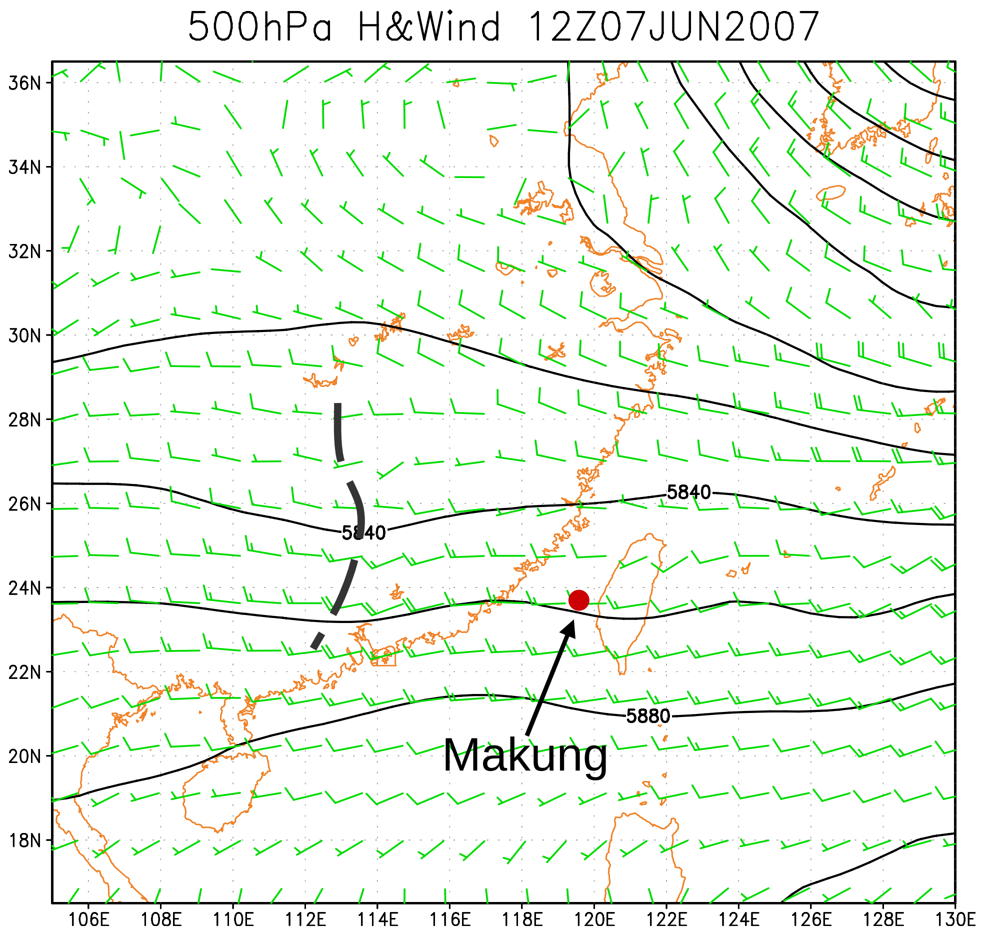
3. Synoptic Condition: (3)

2000 LST, 7 Jun 2007 (700 hPa, ECMWF) *0800 LST, 8 Jun 2007*

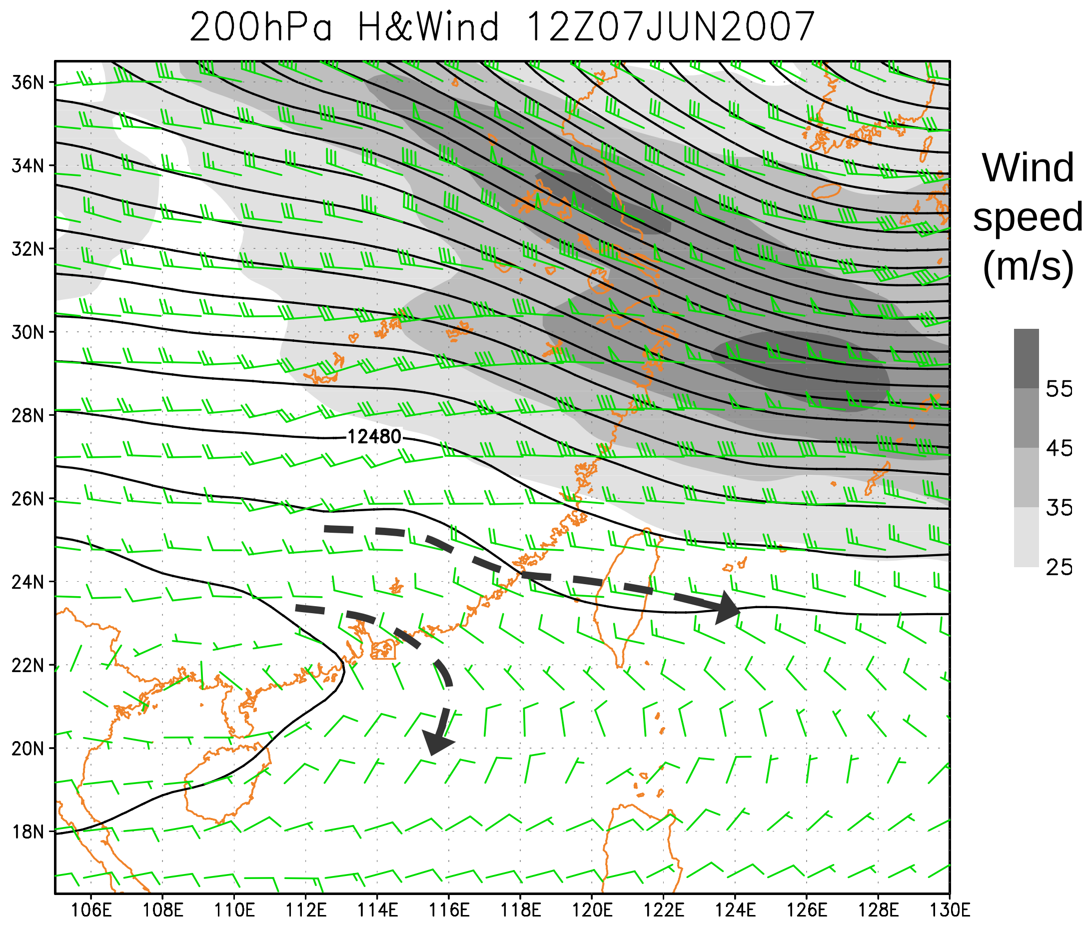


3. Synoptic Condition: (4)

500 hPa, *2000 LST, 7 Jun 2007*

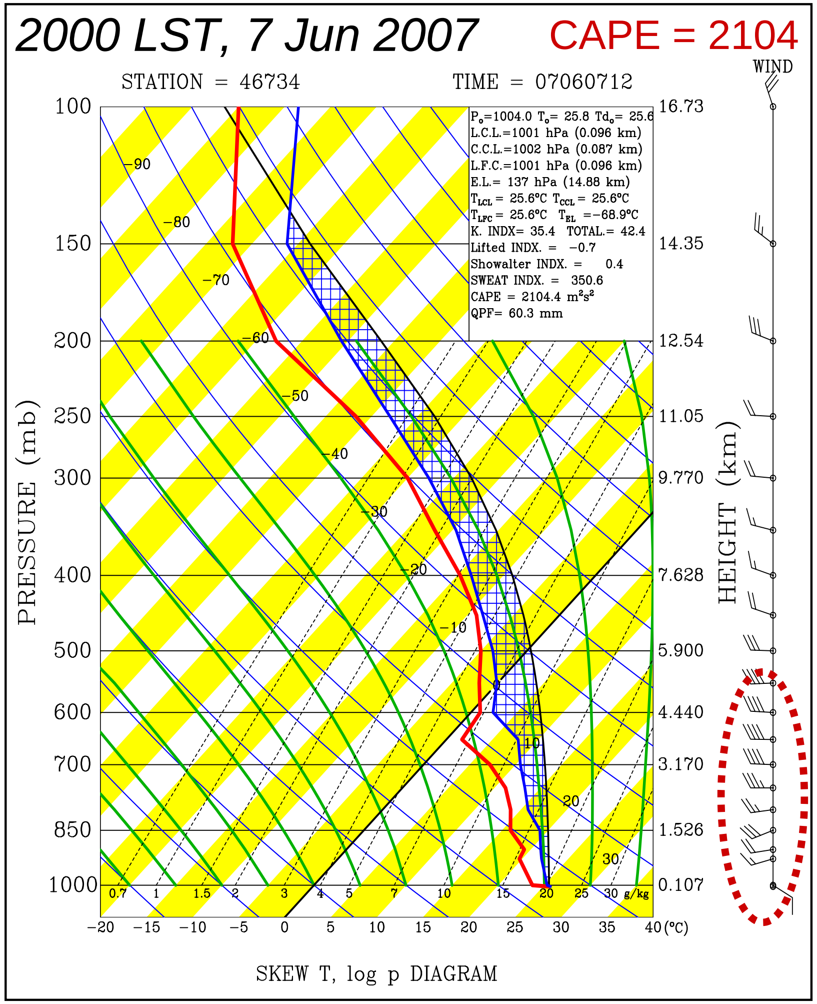


200 hPa, *2000 LST, 7 Jun 2007*

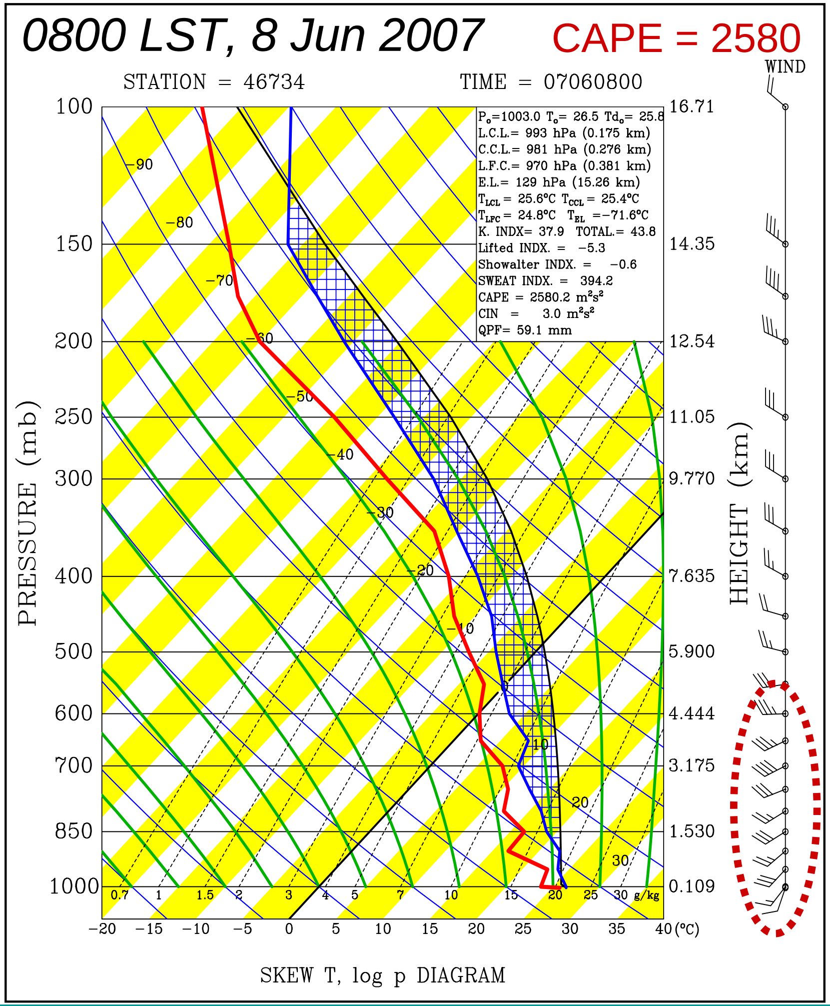


3. Synoptic Condition: (5)

Sounding at Makung (46734)



Sounding at Makung (46734)

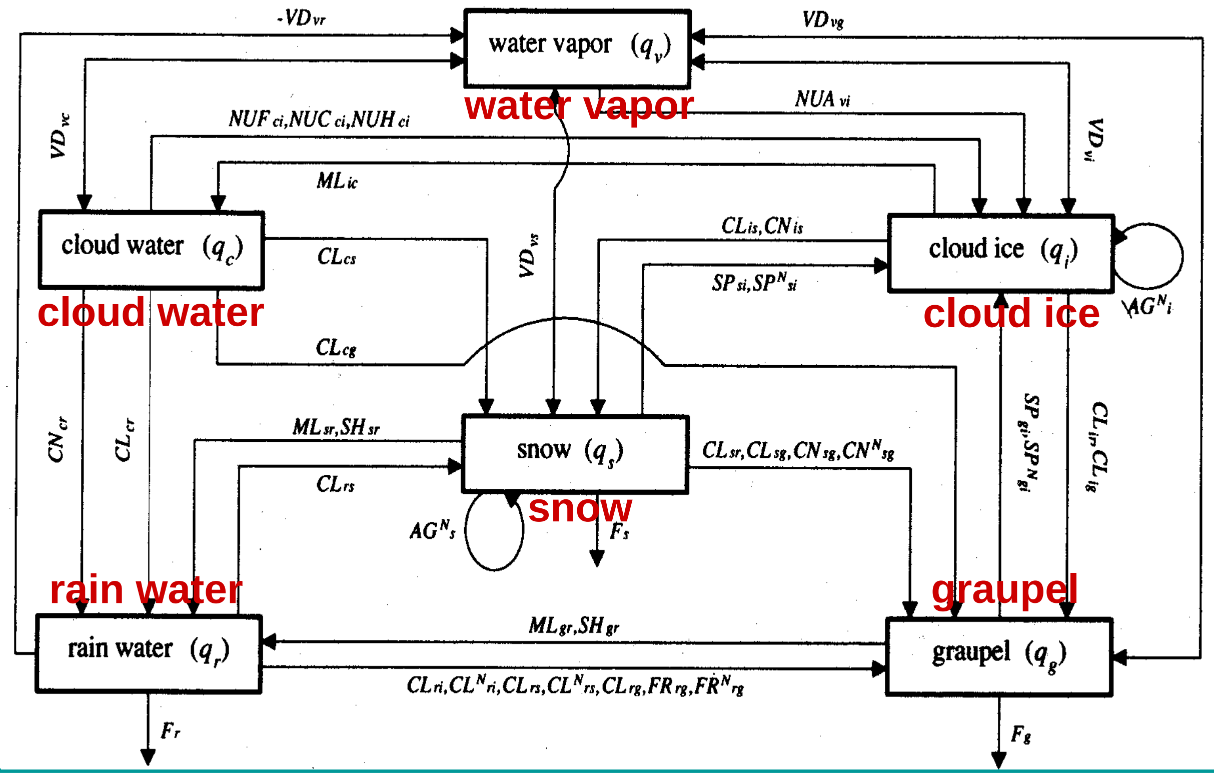


3. Synoptic Condition: (6)

- Synoptic-scale Mei-yu front running East-West and stationary over central Taiwan and central Taiwan Strait; front (shear-line) at 850 and 700 hPa farther north by about 300-400 km
- West-southwesterly Low-level jet (LLJ) of about 15 m s^{-1} at 850/700 hPa, providing strong vertical wind shear
- Short-wave trough approaching Taiwan at 500 hPa
- Diffluent northwesterly flow at 200 hPa over southern Taiwan Strait
- Central/southern Taiwan Strait ahead of the front, with high θ_e values, large convective available potential energy (CAPE, >2000 m^2 s^{-2}) and nearly no convective inhibition (CIN)
- Level of free convection (LFC) very close to surface, within 350 m (1001 and 970 hPa in Makung soundings)

4. Model and Experiment Design: (1)

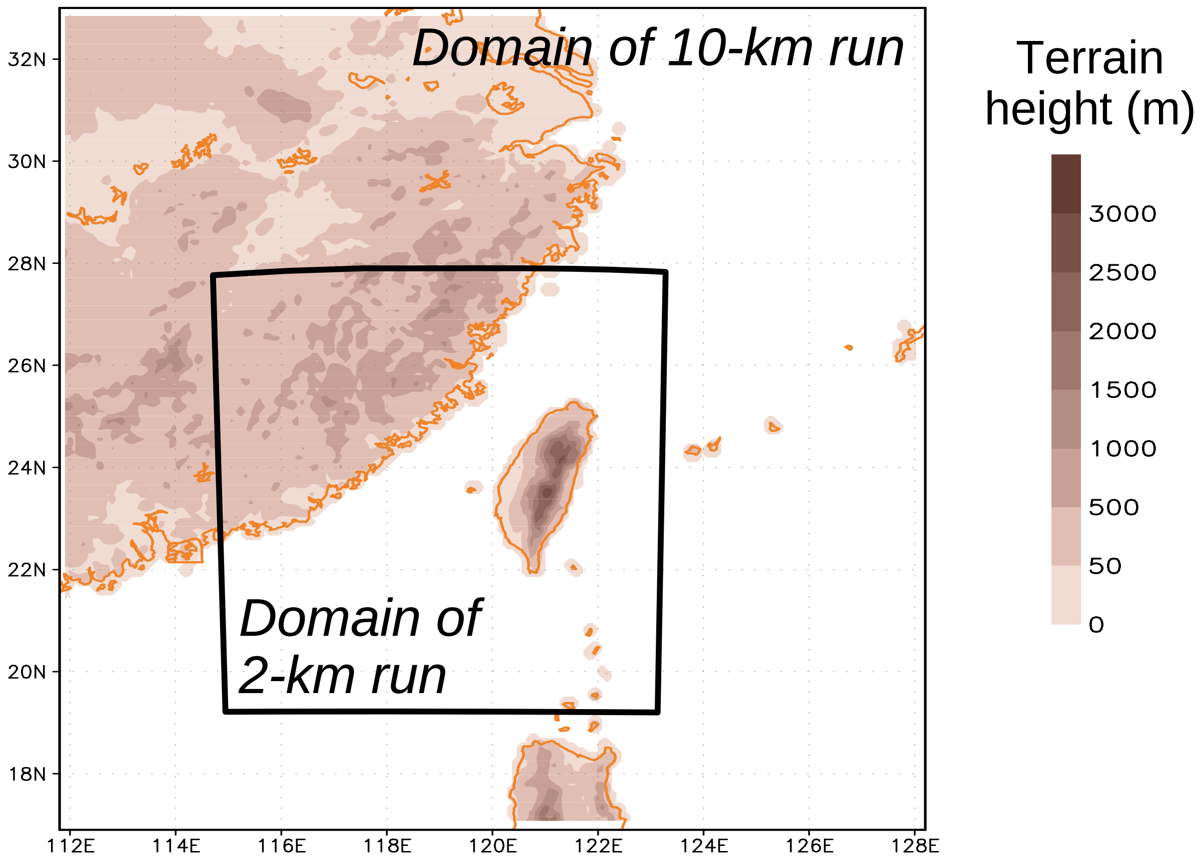
- Cloud-Resolving Storm Simulator (CReSS) of Nagoya Univ.
  - Non-hydrostatic, compressible, terrain following coordinate
  - Explicit cloud microphysics with no cumulus parameterization



- Nucleation: Deposition/sorption, condensation-freezing, homogeneous process, contact, secondary
- Deposition, evaporation, sublimation, melting, freezing
- Falling, collection, conversion, aggregation, water shedding

4. Model and Experiment Design: (2)

- Two experiments are performed at increasingly higher resolution: 10-km and 2-km runs



4. Model and Experiment Design: (3)

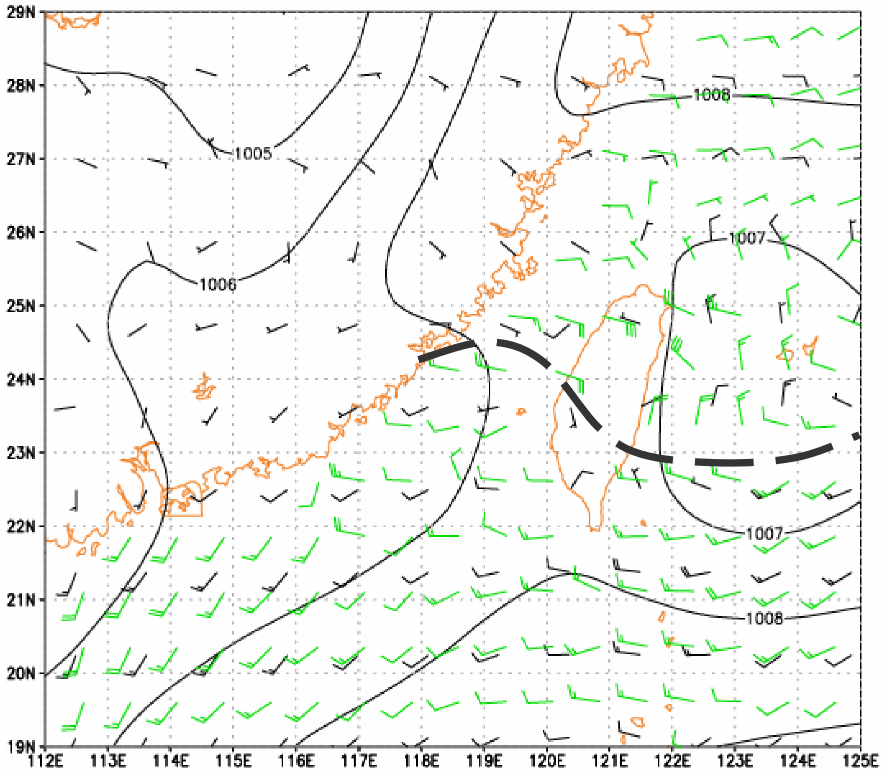
Experiment	One (10 km)	Two (2 km)
Projection	Lambert Conformal, center at 120°E, secant at 20°N and 50°N	
Grid spacing (km)	$10 \times 10 \times 0.6^*$	$2 \times 2 \times 0.35^*$
Dimension (x, y, z)	$180 \times 180 \times 40$	$540 \times 480 \times 60$
Minimum Δz	50 m	50 m (8 levels below 1 km)
Topography, SST	Real at (1/120)°, fixed at 28°C	
IC/LBCs	ECMWF 1.125°, 6 h	10-km run, 1 h
Initial time	2000 LST, 6 Jun	2000 LST, 6 Jun
Integration length and output frequency	72 h, 1 h	60 h, 10 min
Cloud microphysics	Bulk cold rain	
PBL parameterization	1.5-order closure with TKE prediction	
Surface processes	Energy/momentum fluxes, shortwave/longwave radiation	
Soil model	41 levels, every 5 cm to 2 m deep	

* The vertical grid spacing (Δz) of CReSS is stretched (smallest at the bottom), and the value given here is the averaged spacing.

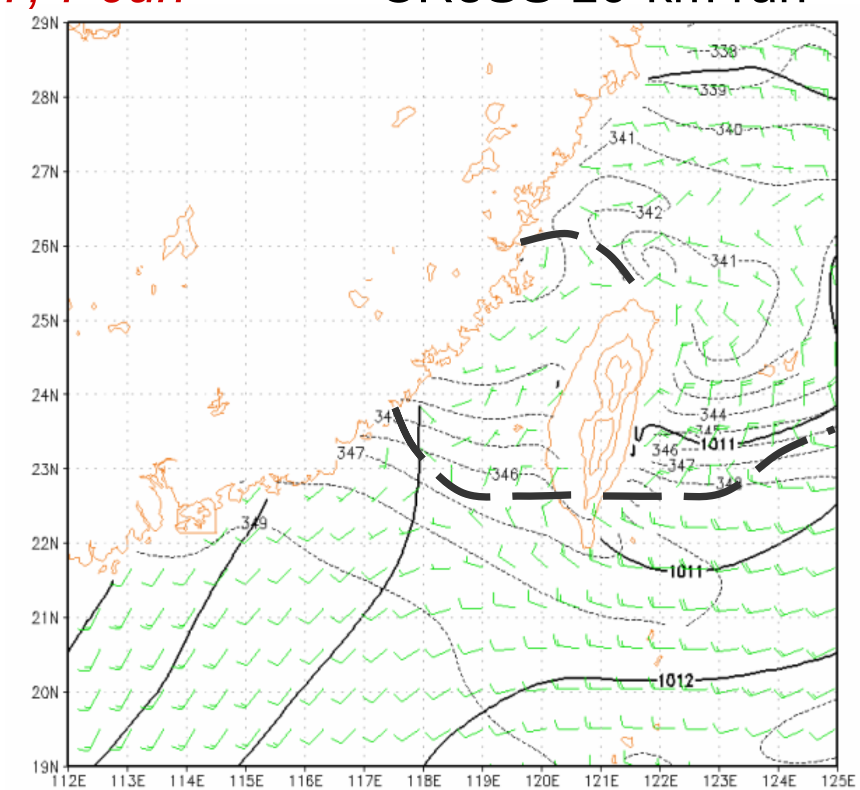
5. Simulation Result: (1)

- Surface frontal position: ECMWF + QuikSCAT vs 10-km run

ECMWF + QuikSCAT *2000 LST, 7 Jun* CReSS 10-km run



SLP (hPa) and Surface wind (kt)

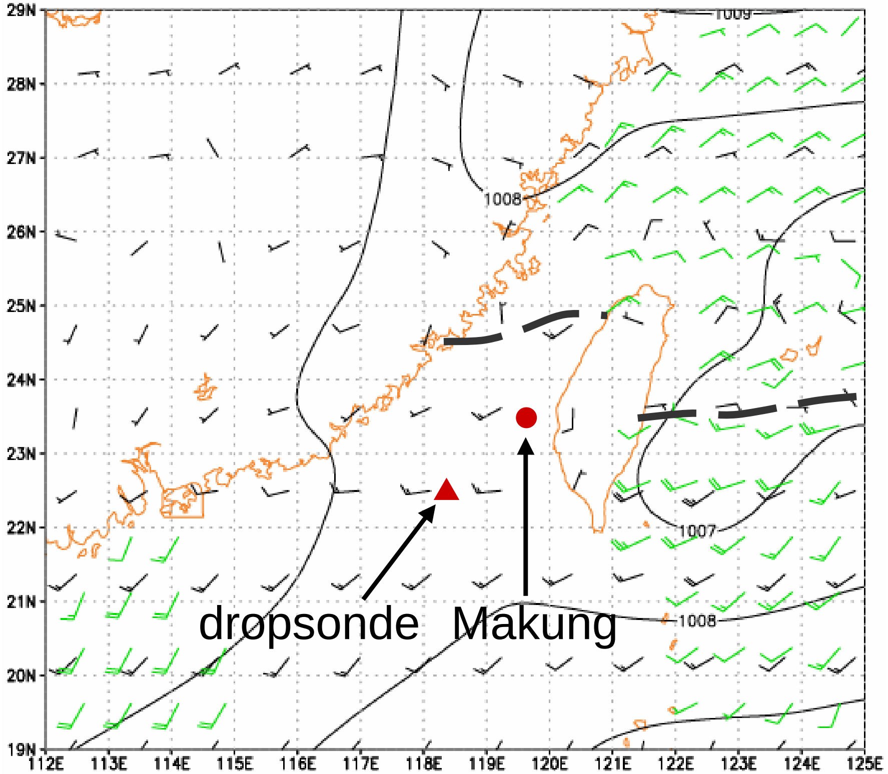


Surface p (hPa), wind (kt), and θ_e (K)

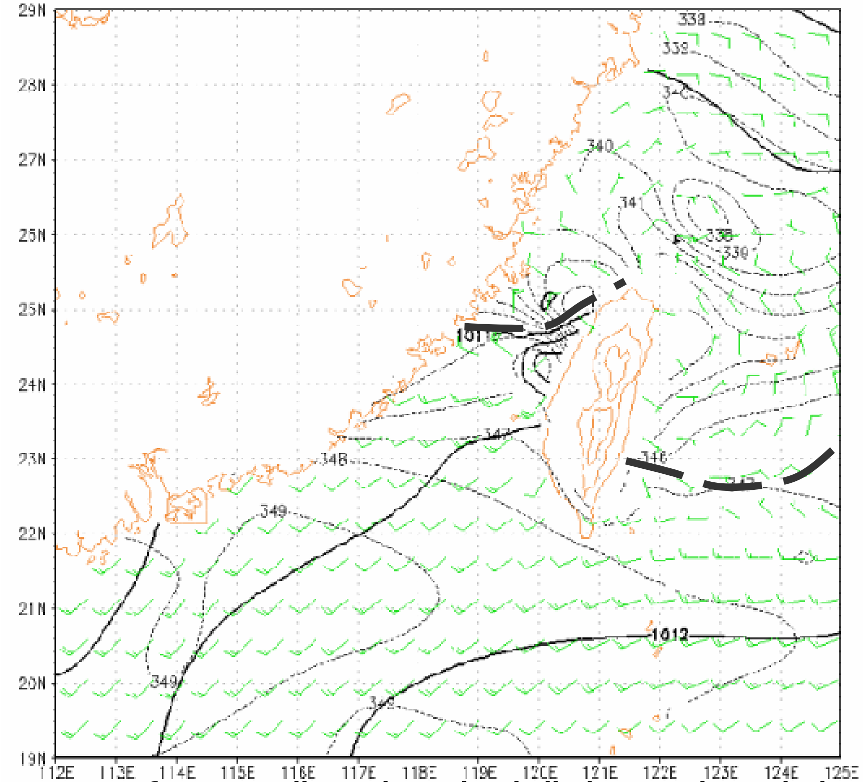
5. Simulation Result: (1)

- Surface frontal position: ECMWF + QuikSCAT vs 10-km run

ECMWF + QuikSCAT *0800 LST, 8 Jun* CReSS 10-km run



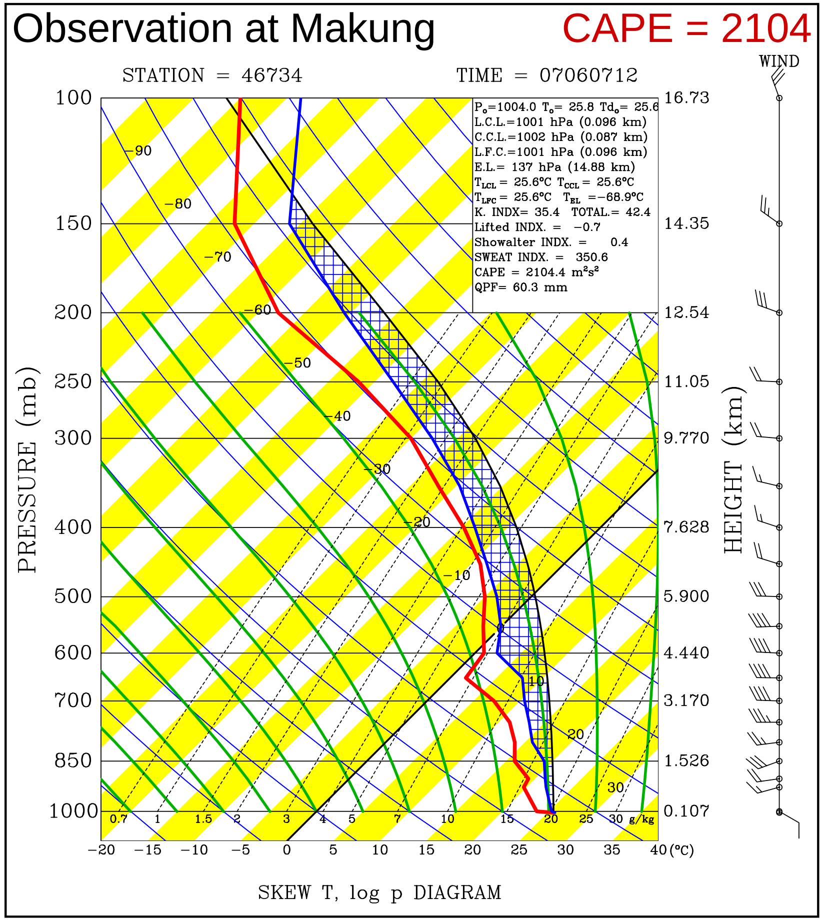
SLP (hPa) and Surface wind (kt)

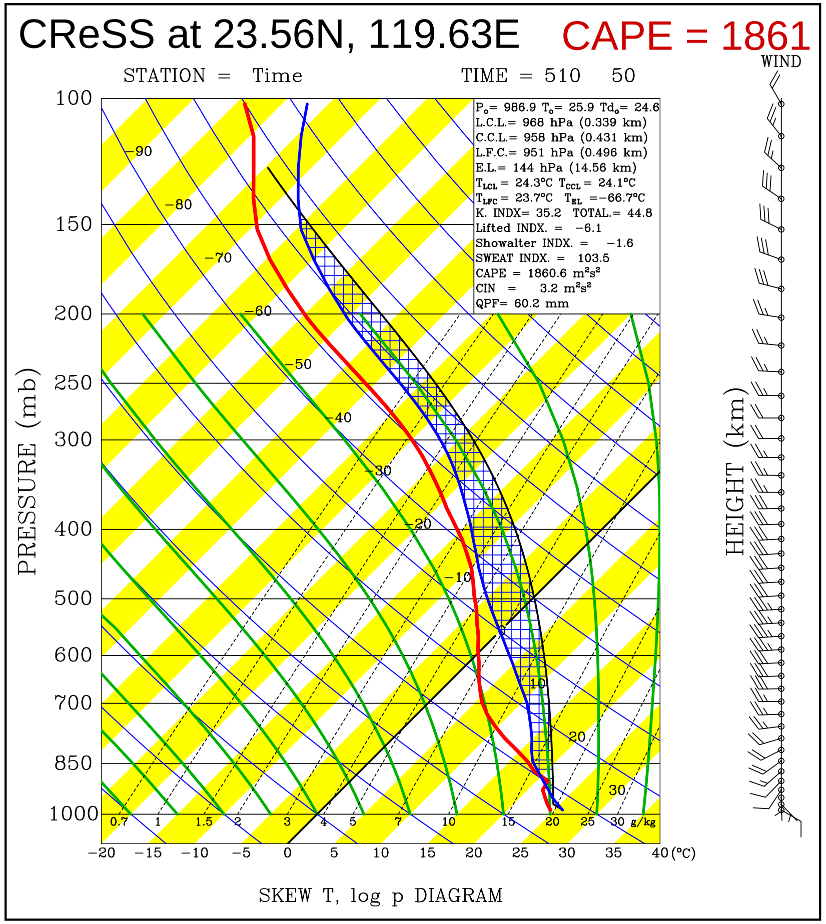


Surface p (hPa), wind (kt), and θ_e (K)

5. Simulation Result: (2)

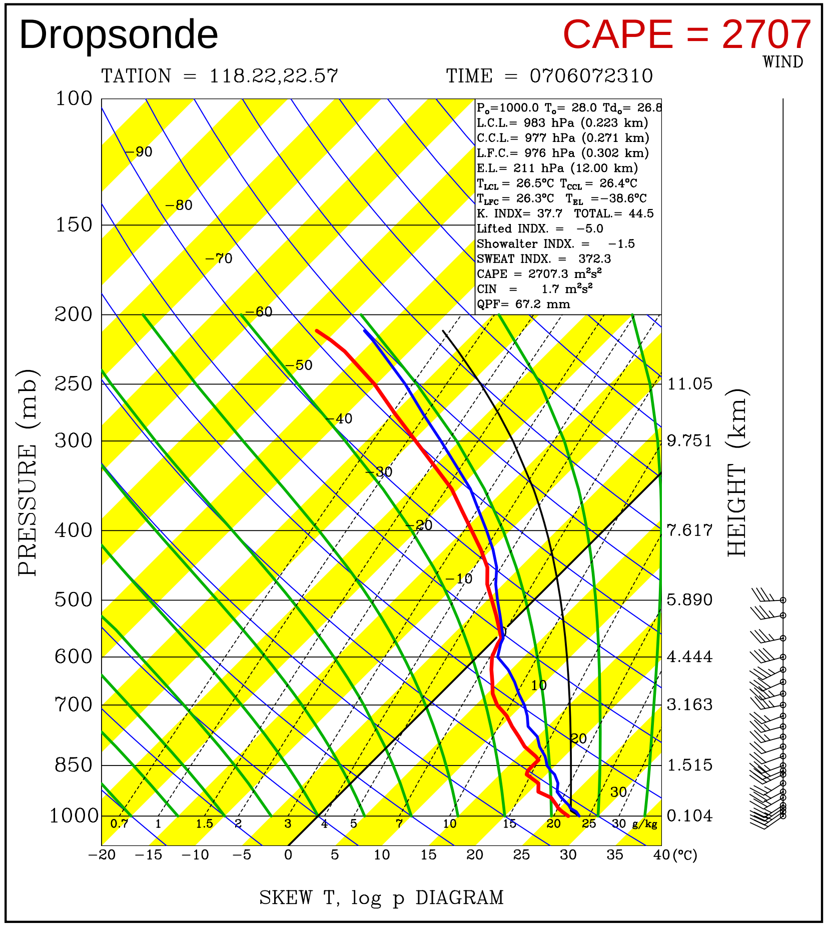
- Sounding comparison: at Makung (*2000 LST, 7 Jun 2007*)

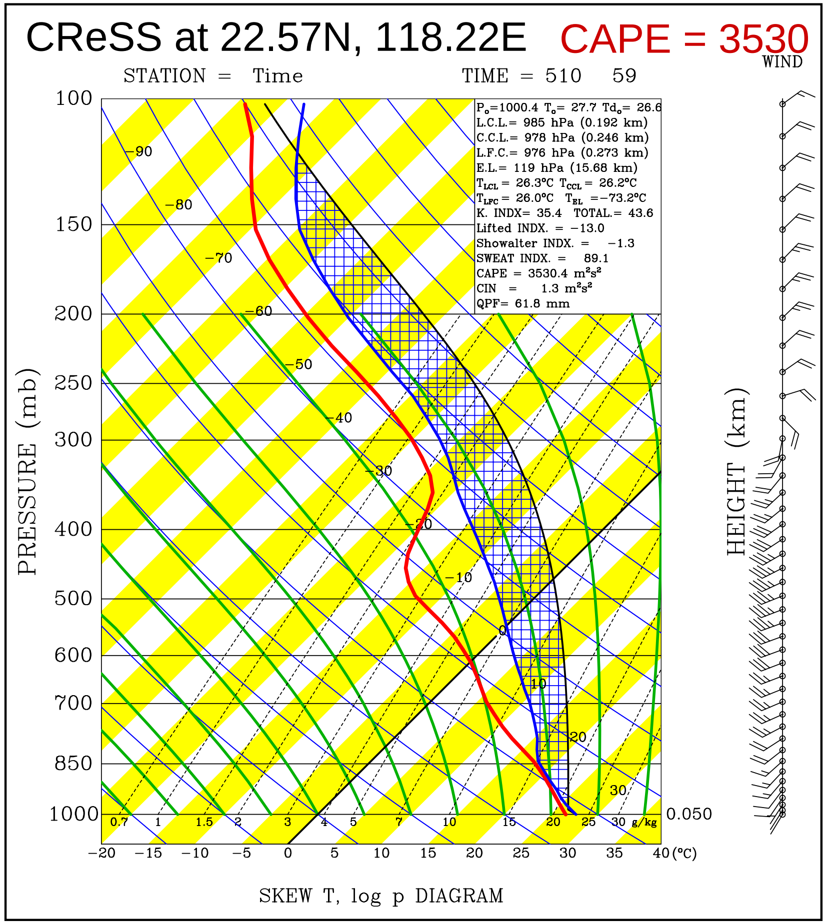




5. Simulation Result: (3)

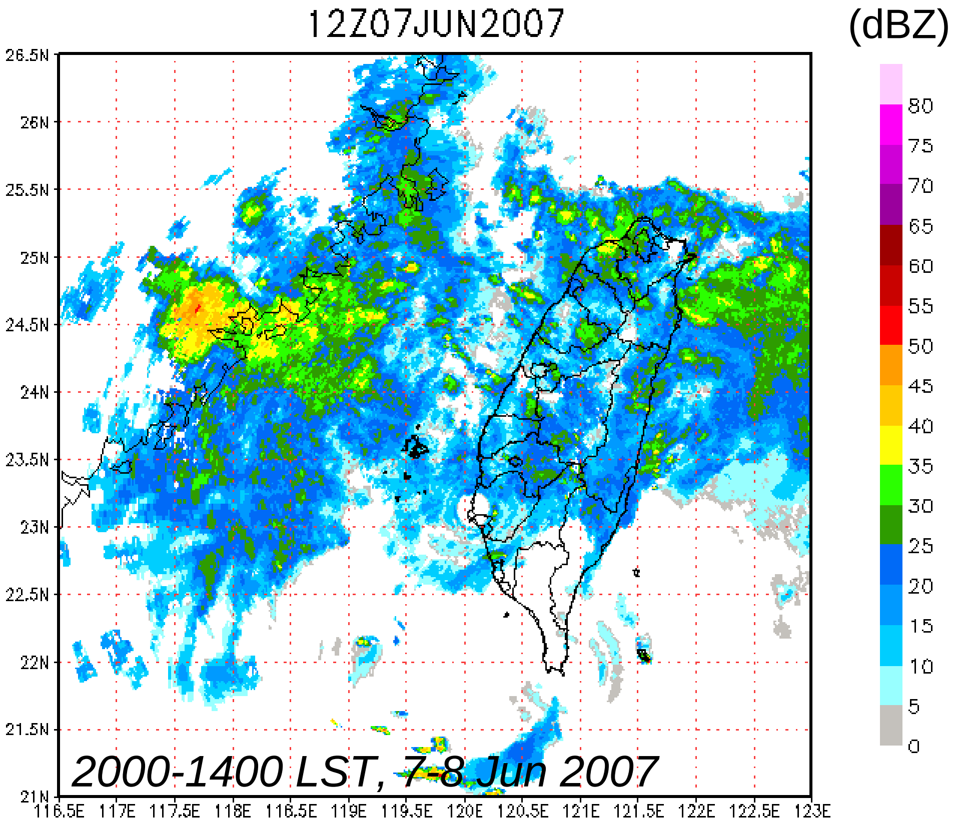
- Sounding comparison: with dropsonde (*2310 LST, 7 Jun 2007*)



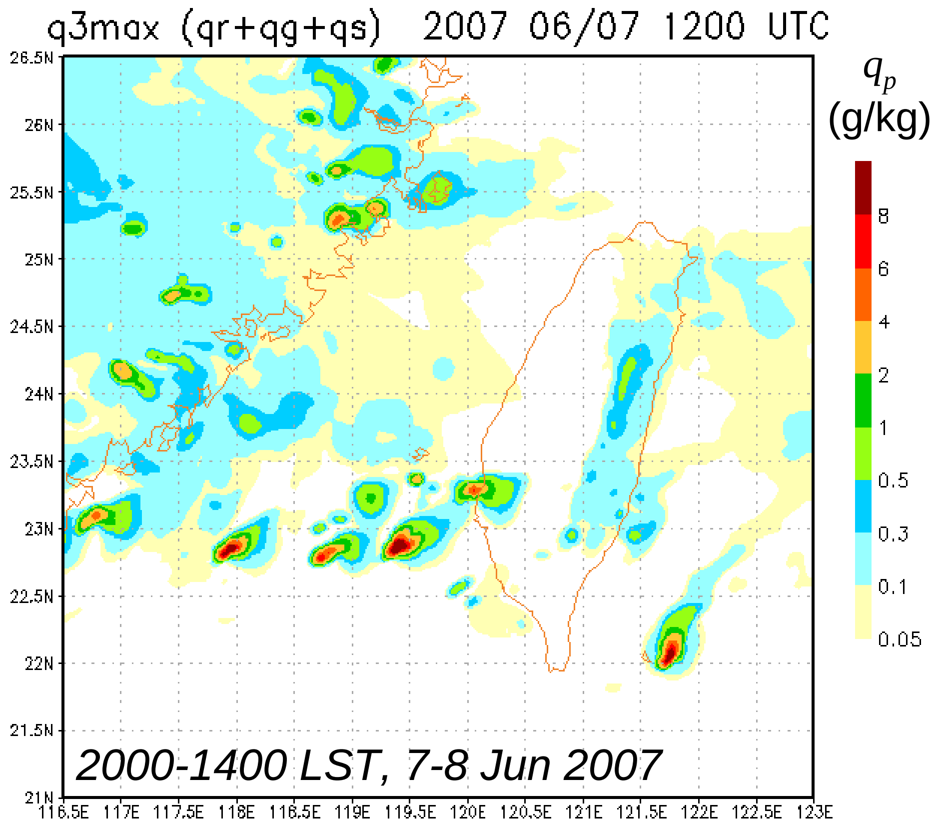


5. Simulation Result: (4)

- Convection distribution and evolution: Radar vs 2-km run

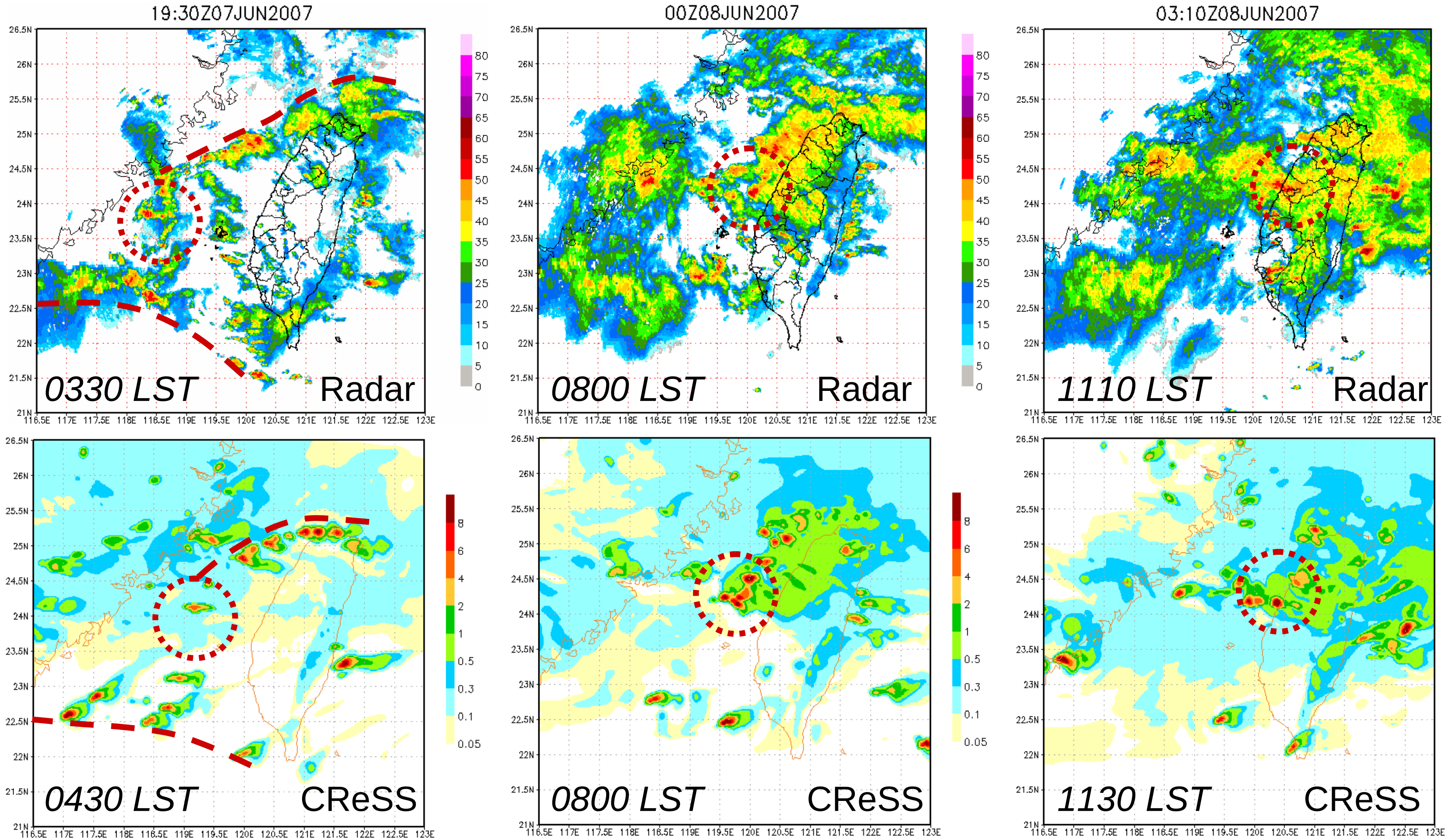


Radar Column Max Echo Composite (dBZ)



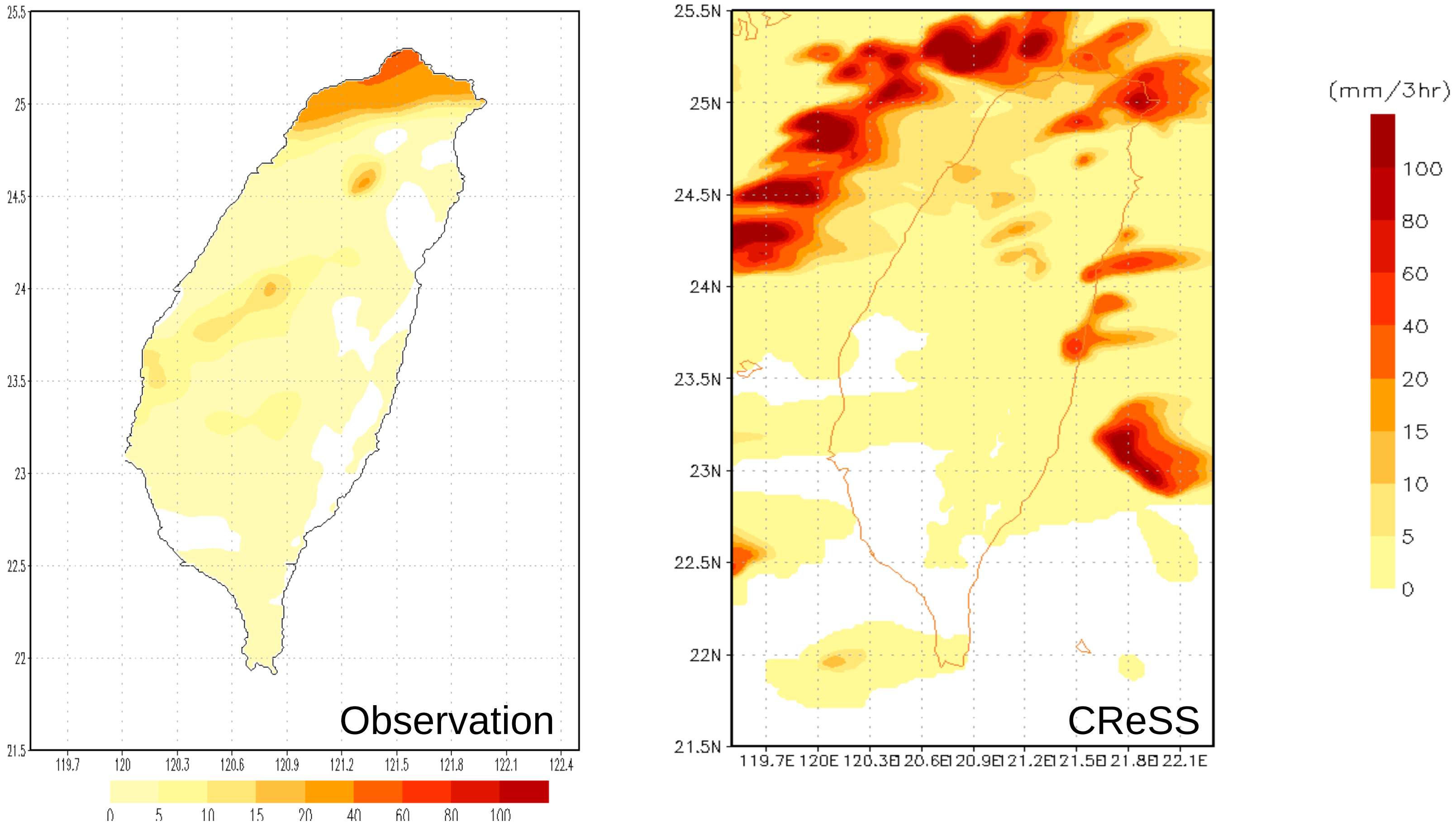
Max mixing ratio of precipitating hydrometeors

5. Simulation Result: (5)



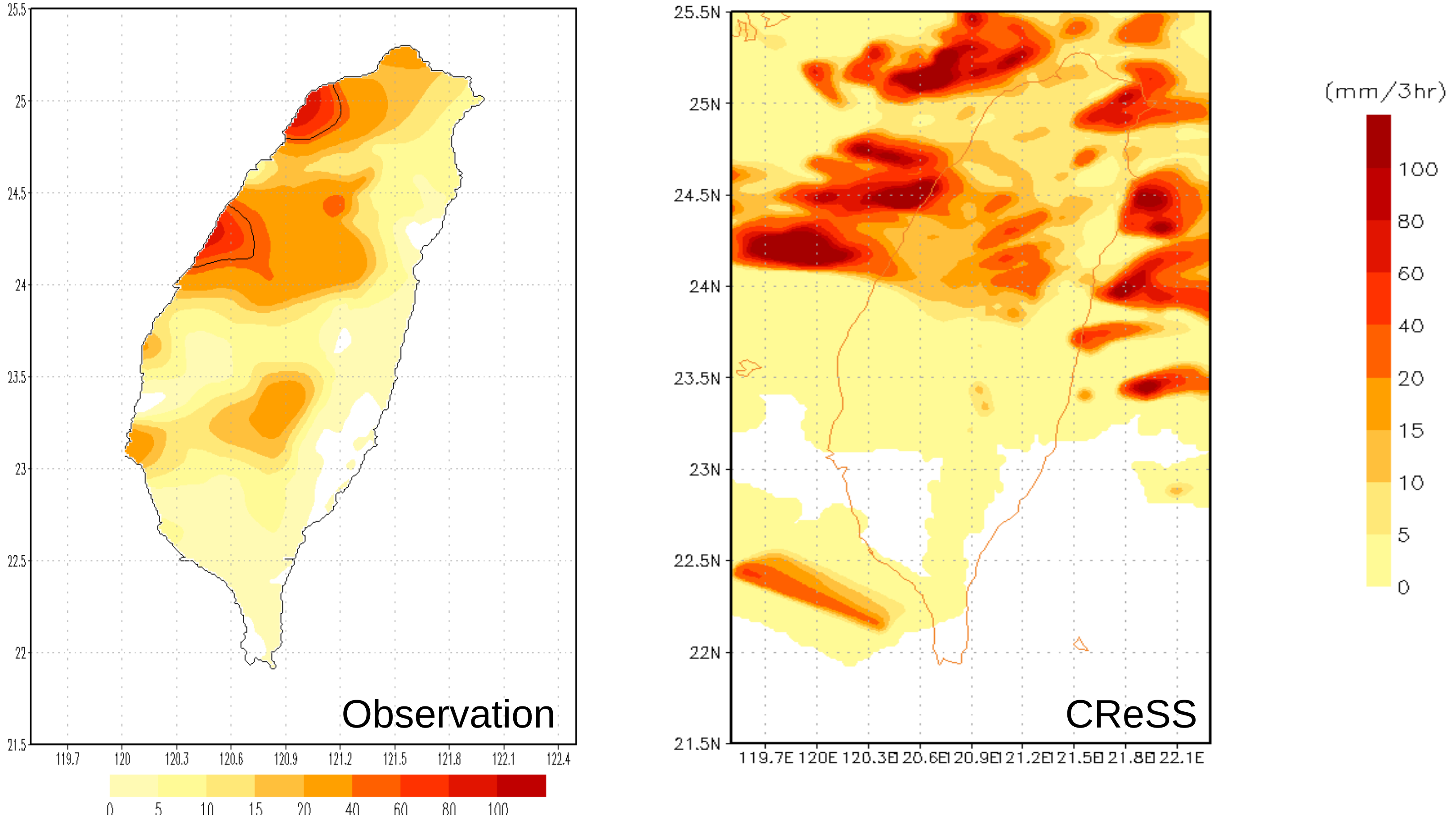
5. Simulation Result: (6)

- Rainfall accumulation every 3 h: *0500-0800 LST, 8 Jun*



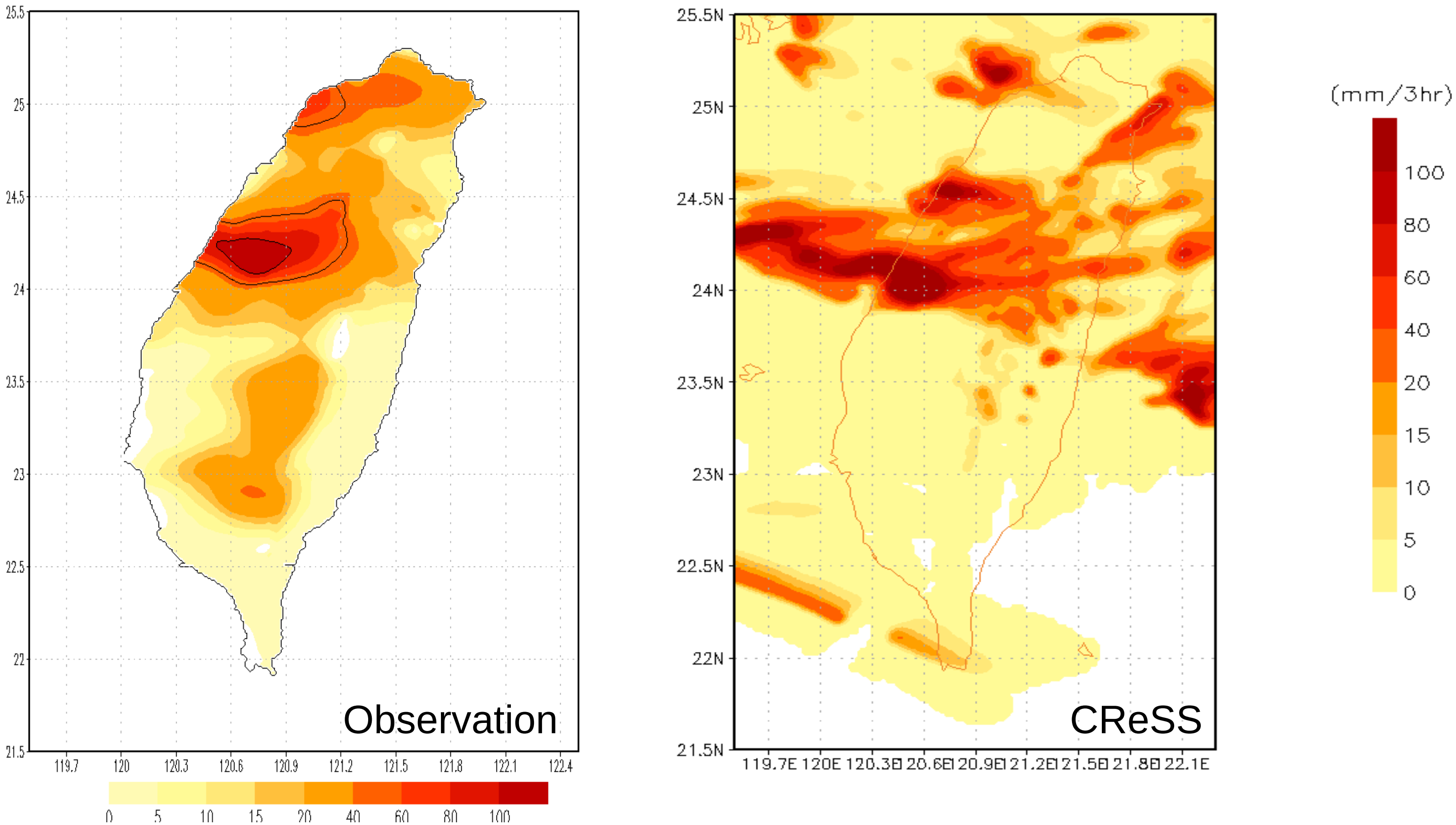
5. Simulation Result: (6)

- Rainfall accumulation every 3 h: *0800-1100 LST, 8 Jun*



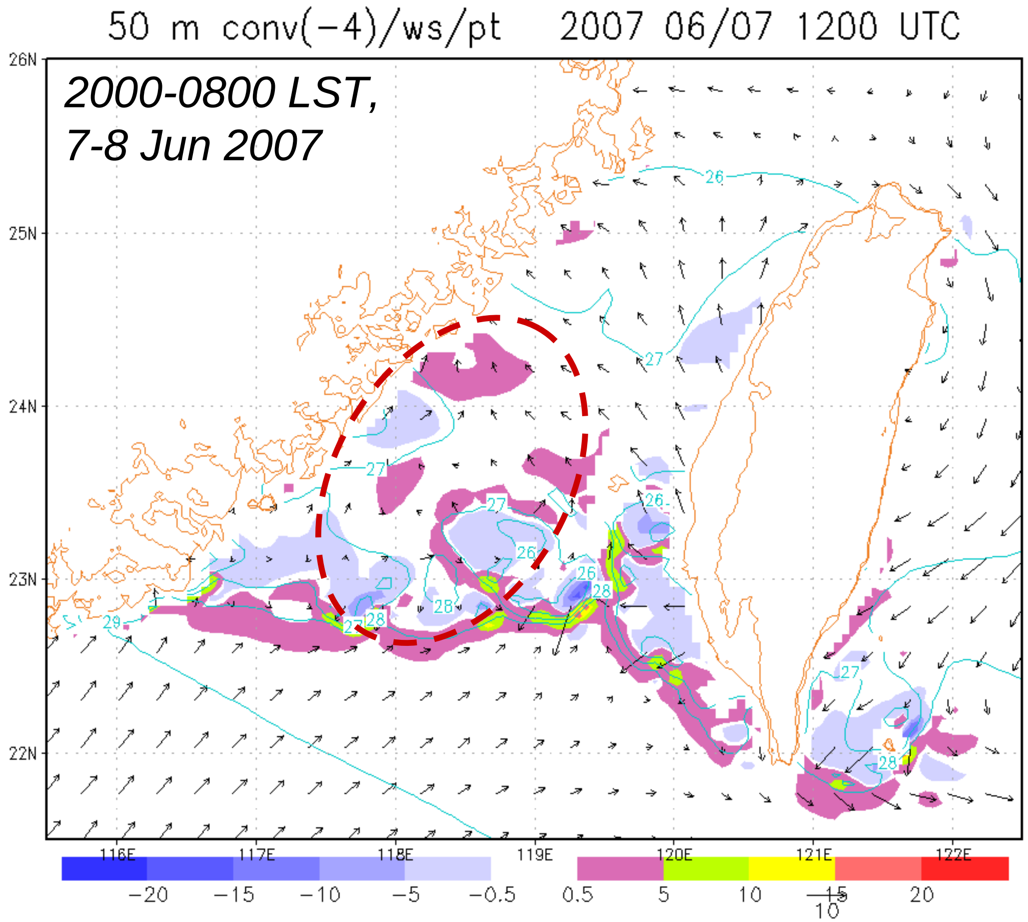
5. Simulation Result: (6)

- Rainfall accumulation every 3 h: *1100-1400 LST, 8 Jun*



5. Simulation Result: (7)

- Wind vector, θ, and convergence at 50 m: (every 30 min)

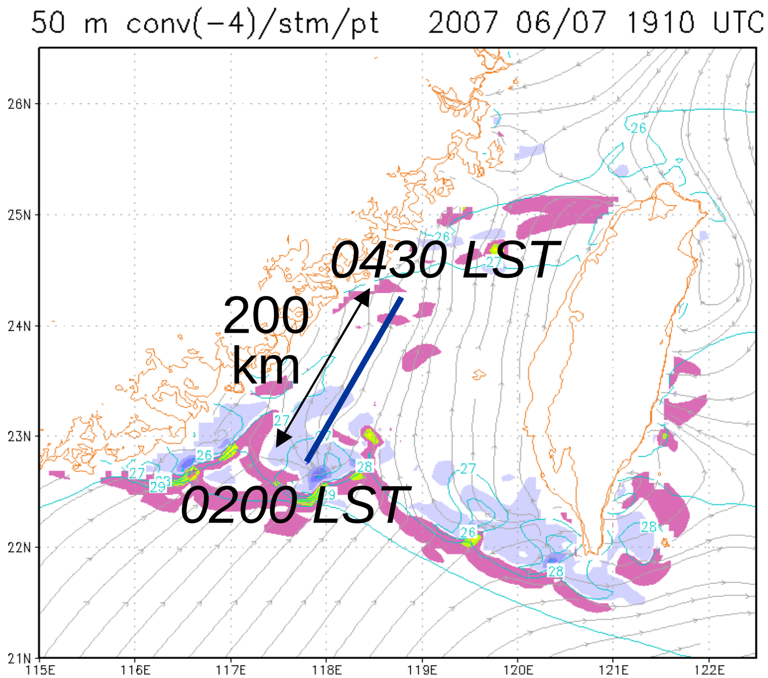


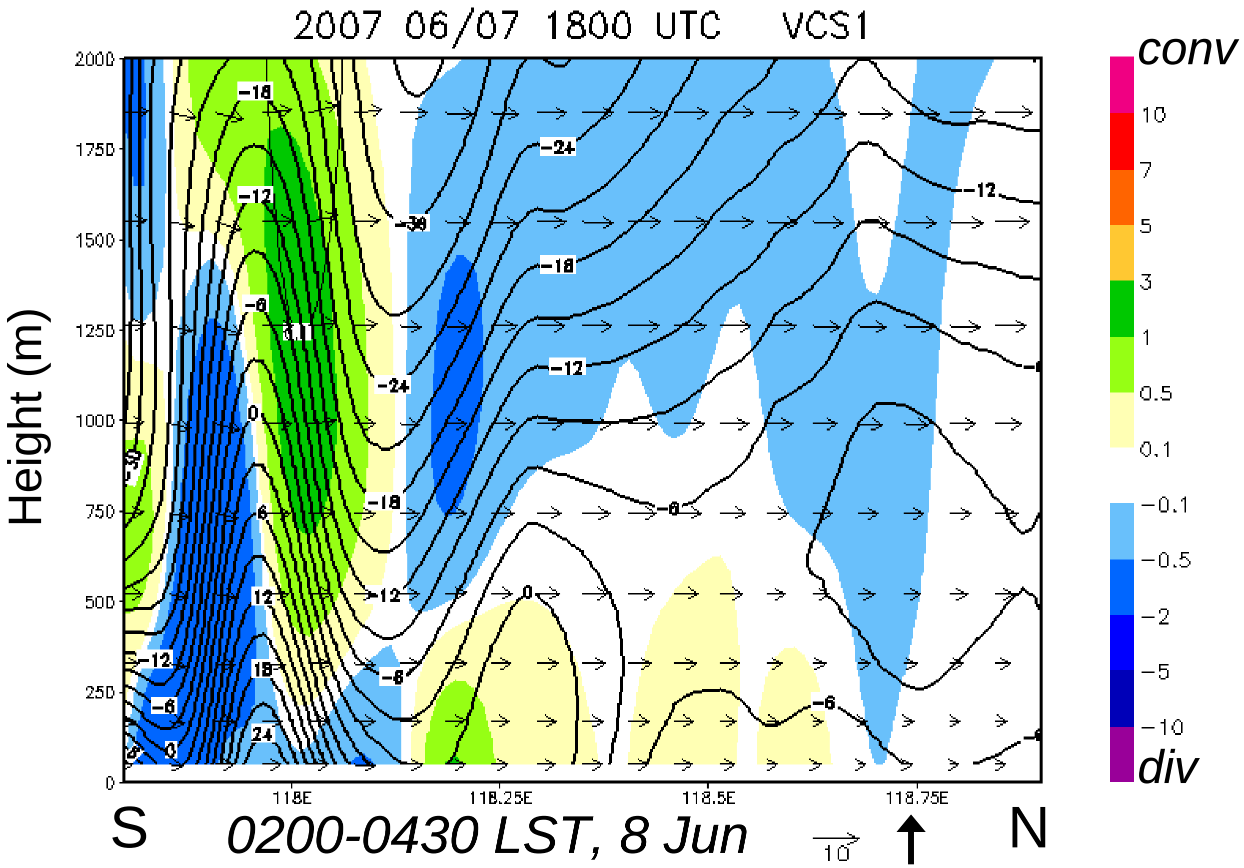
Conv. → positive
Div. → negative

Wind vector (m s^{-1})
Potential temp. (°C)
Convergence (10^{-4} s^{-1})

5. Simulation Result: (8)

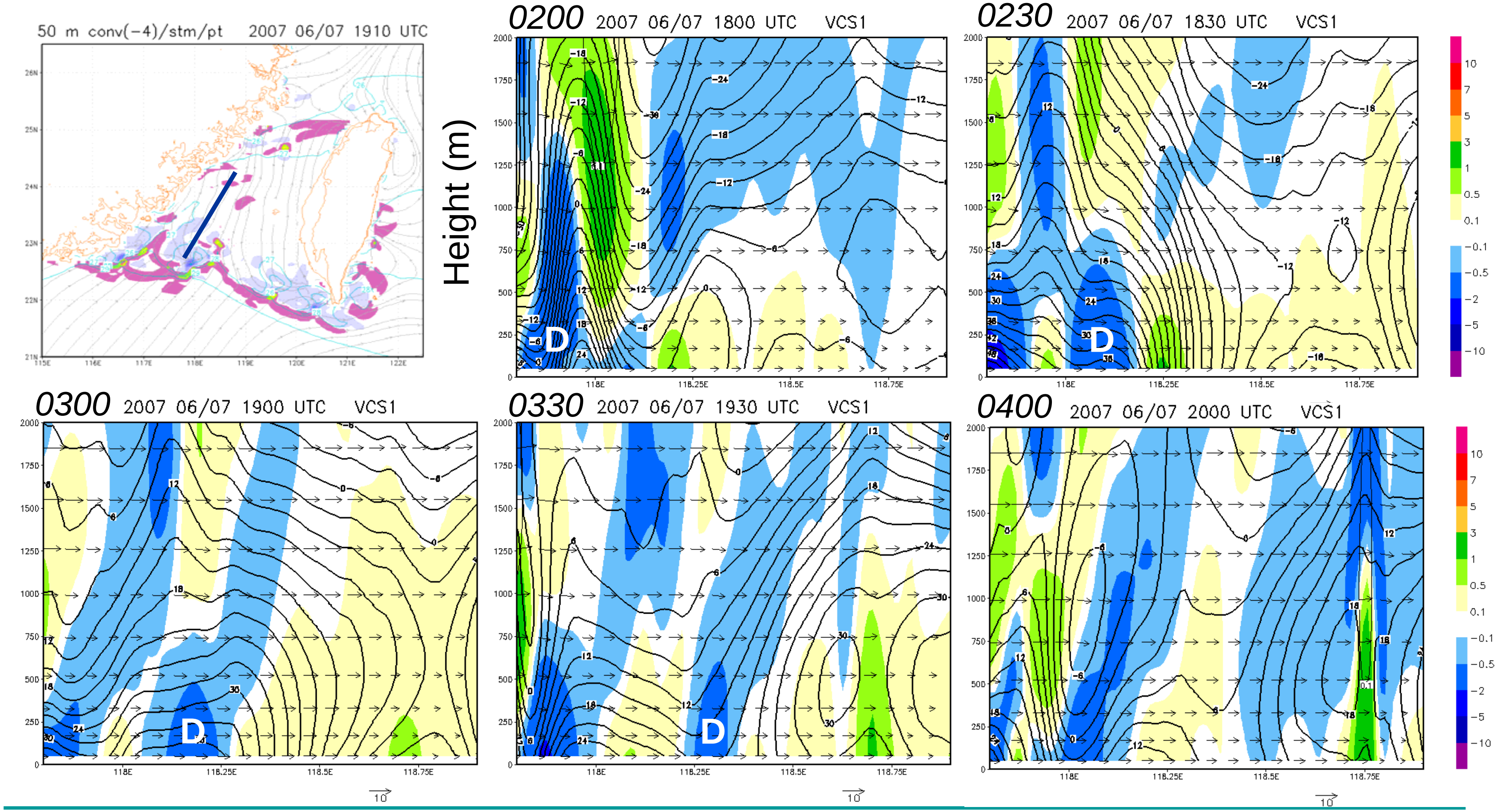
- Vertical cross-section: Northward propagation of cold air





Wind vector (m s^{-1}), conv/div (10^{-4} s^{-1}, color), pressure perturbation (Pa)
Mean = 0800 LST 7 Jun to 0800 LST 8 Jun, 2007

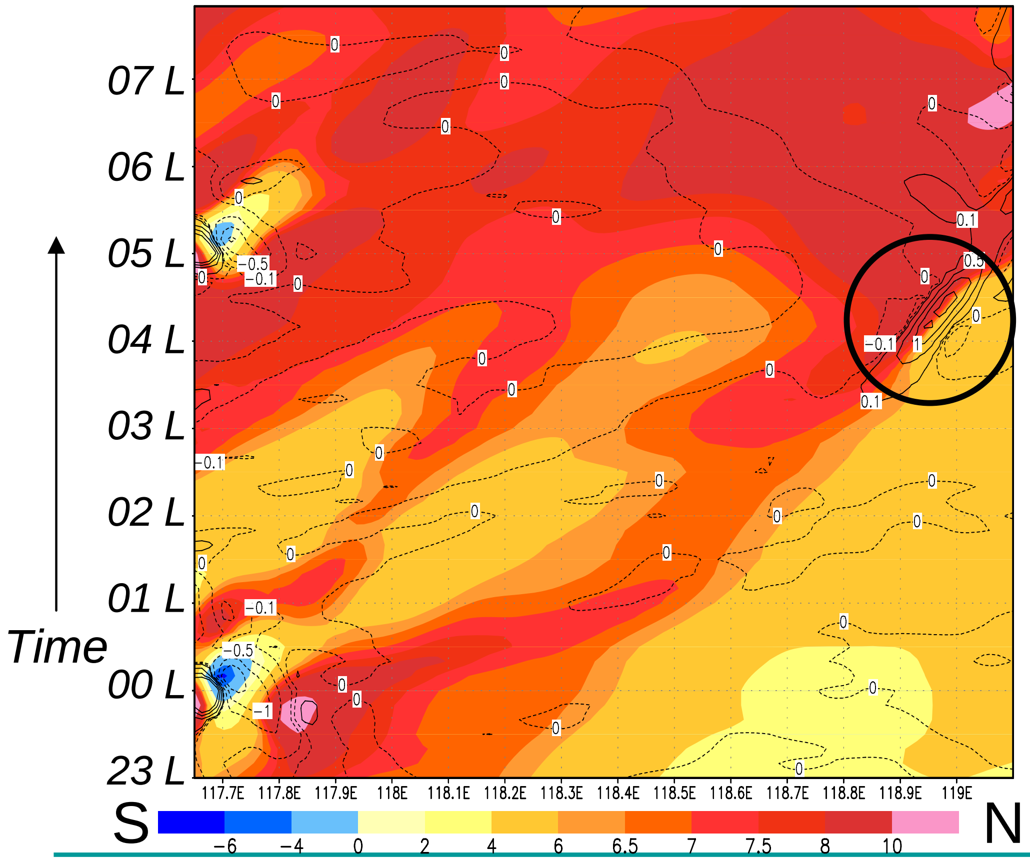
5. Simulation Result: (9)



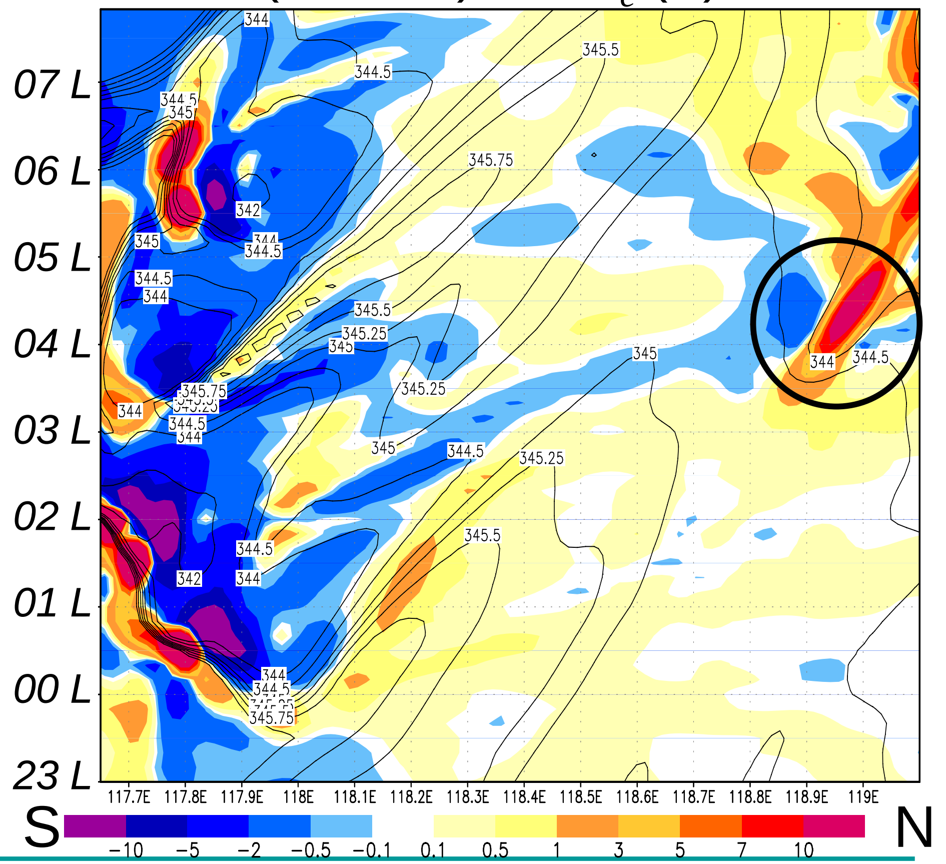
5. Simulation Result: (9)

- Vertical cross-section: Northward propagation of cold air

Wind speed and w (m s^{-1}) at 774 m



Conv/div (10^{-4} s^{-1}) and θ_e (K) at 170 m



6. Discussion and Conclusion: (1)

- Favorable synoptic conditions in the present case:
  - Presence of surface Mei-yu front
  - Conditional instability with large CAPE (2000 $m^2 s^{-2}$), negligible CIN, and low height of LFC (< 350 m)
  - LLJ at 850/700 hPa, providing vertical shear at low levels
  - Diffluent flow pattern in upper troposphere

- Initiation and evolution of convection well reproduced in the 2-km CReSS model simulation
  - Convection along Mei-yu front (ENE-WSW) over northern strait
  - Convection from southern China (ESE-WNW) in southern strait
  - Initiation and subsequent development of convection over central strait, responsible for heavy rainfall in central Taiwan

6. Discussion and Conclusion: (2)

- Outflow from previous/existing convection in southern strait
  - Cold air with $D > 0$ and $p' > 0$ propagated northward
  - Increase in southerly wind speed upstream from the area of initiation, with enhanced convergence ahead
  - Lead to initiation of convection over central Taiwan Strait, and eventually heavy rainfall over central Taiwan

$$\frac{1}{\rho}\nabla p \approx \frac{1}{1.2}\frac{30}{50\times10^3} \approx 0.5\times10^{-3}\ \mathrm{m\,s^{-2}}$$ $\Rightarrow$ Reaching 5 m s^{-1} in 3 h

$$C \approx u_0 + \left(\frac{\Delta\theta}{\theta_0} g\,h\right)^{0.5} \approx 0 + \left(\frac{1}{100}\cdot 10\cdot 500\right)^{0.5} \approx 7\ \mathrm{m\,s^{-1}}$$ $\Rightarrow$ Traveling 75 km in 3 h

- In other runs starting at 12 h earlier or later:
  - No convection over southern strait, and consequently no convection reproduced over central strait at the correct time
  - Convection indeed contributed by existing cells to the south

The End

Thank you for your attention!