Mechanisms of **Orographically Enhanced Precipitation** Associated with **Typhoon** Meari (2011) over Mt. Da-Tun

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Introduction

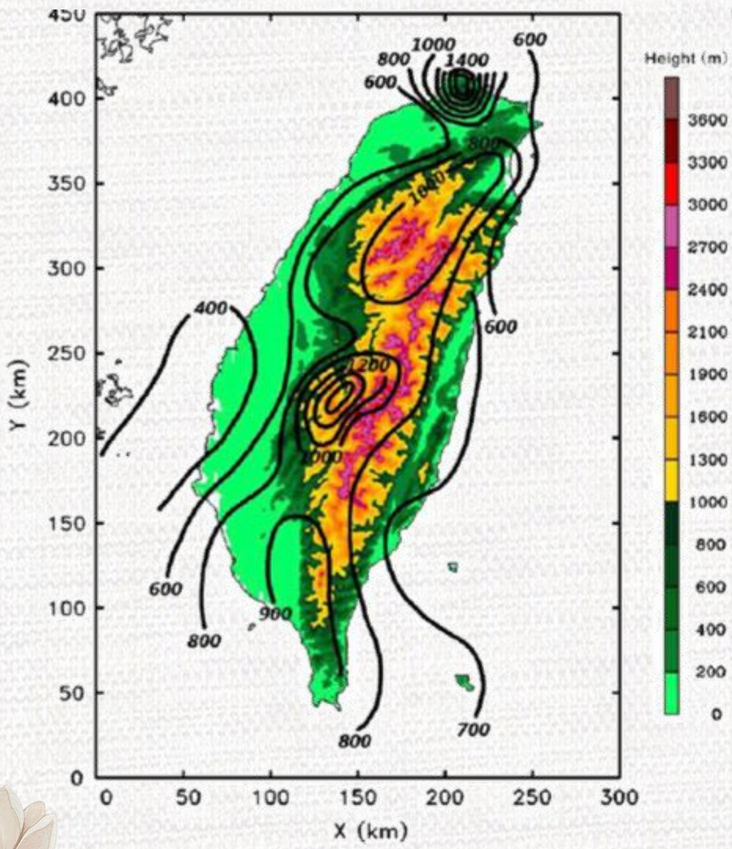


Fig. The horizontal distribution of the maximum rainfall accumulation (contours; mm) from rain gauges associated with typhoons influencing Taiwan from 1897 to 1996. (Yu and Cheng 2014)

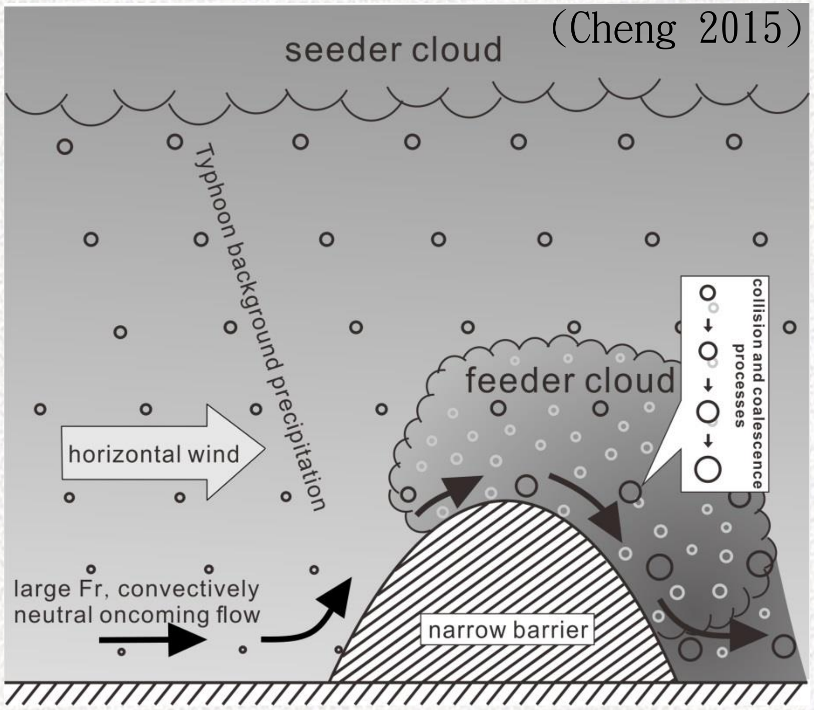
- Typhoon-induced heaviest rainfall in Taiwan has been concentrated over the mountainous region. (Wu et al. 2002; Lee et al. 2008; Yang et al. 2008)
- Hot spots: Mt. Da-Tun
  Snow Mountain Range
  Central Mountain Range
- A local rainfall max over Mt.Da-Tun

Introduction

- Previous studies demonstrated a crucial role of **orographic lifting** in contributing to precipitation enhancement over windward side of the mountains.
  (Lin et al. 2002; Wu et al. 2002; Yu and Cheng 2008; Huang et al. 2014)

- Precipitation enhancement in the typhoon environment was also related to the seeder–feeder mechanism.
  (Smith et al. 2009b; Yu and Cheng 2013; Yu and Cheng 2014)

- **Seeder–feeder mechanism** :
  - First proposed by Bergeron in 1965
  - Microphysical interaction between typhoon background precipitation/ rainbands and the precipitation produced by orographic lifting.



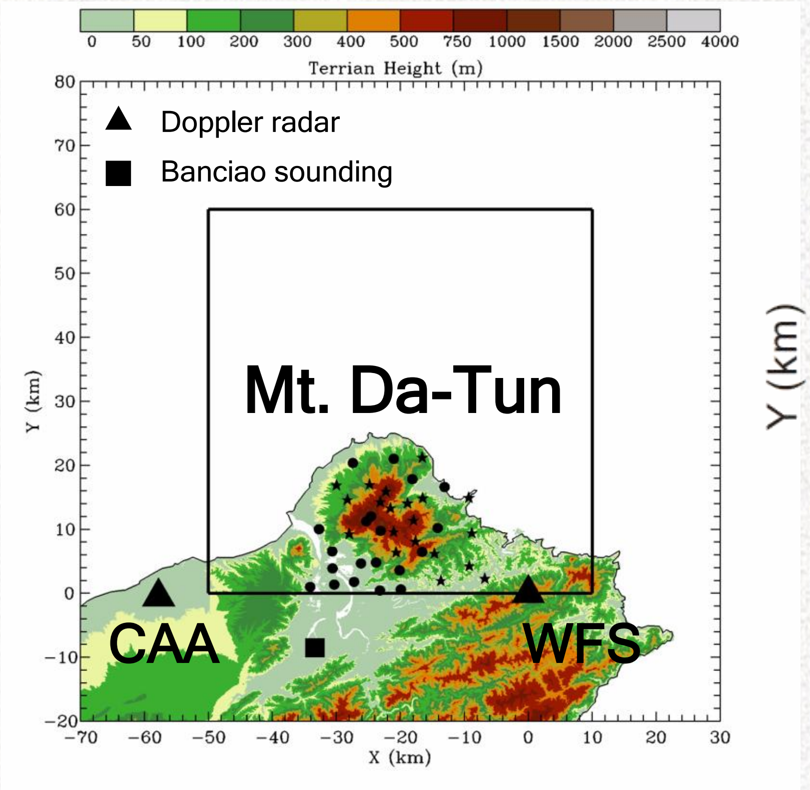
(Cheng 2015)

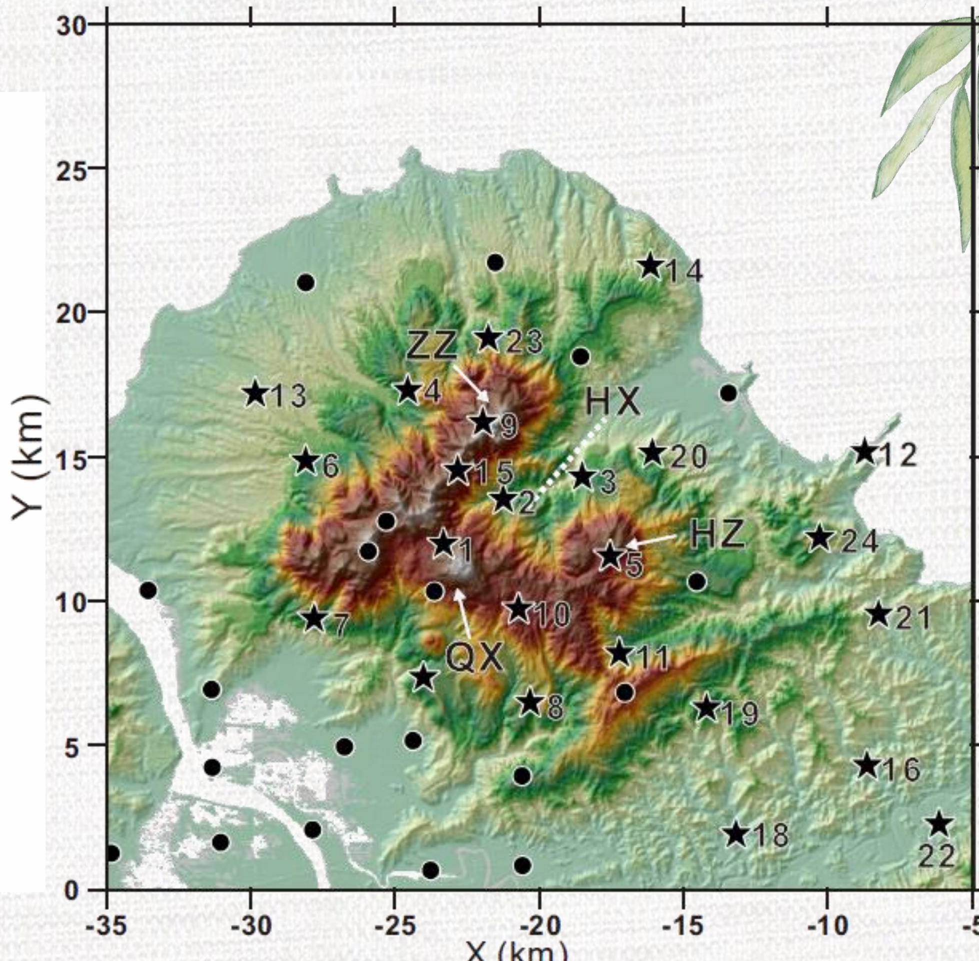
Motivation

- In the typhoon environment, upslope lifting is inadequate to explain the distribution and intensity of precipitation over mountains, limited studies had quantified the orographic enhancement.

- Using observational data, this study attempts to explore the possible physical mechanisms of rainfall enhancement and to quantify it.

Data & Methods





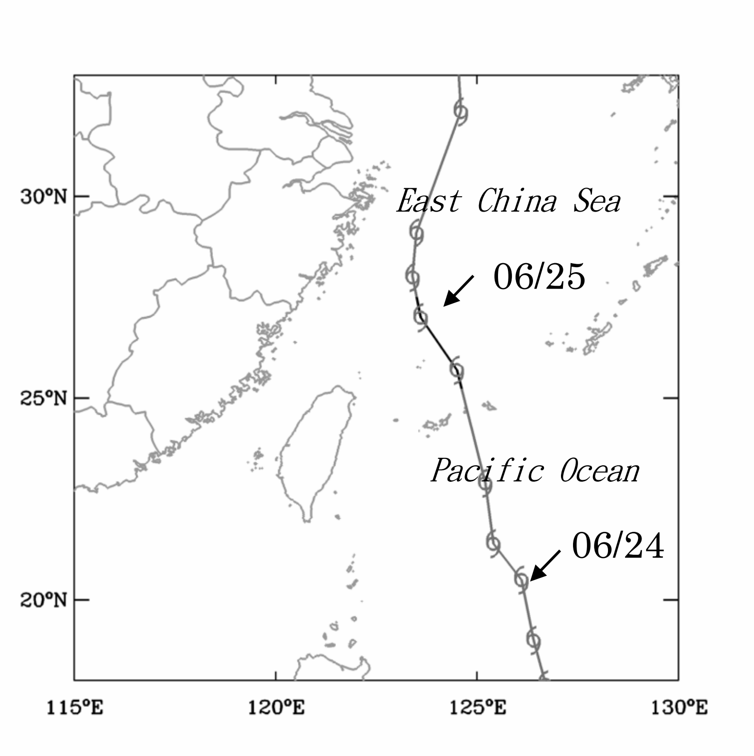
QX=Qi_Xing Mountain
HZ=Huang_Zui Mountain
ZZ=Zu_Zhi Mountain
HX=Huang_Xi Valley

1. Xiao_You_Keng
2. Lu_Jiao_Keng
3. Jie_Bei
4. San_Zhi
5. Huang_Zui_Shan
6. Xin_hua
7. Da_Tun
8. Ping_Deng
9. Zhu_Zi_Shan
10. Zhu_Gao_Shan
11. Xi_Di
12. Ye_Liu
13. Zhong_Tai
14. Jin_Shan
15. Song_Shan
16. Ma_Ling
17. Ding_Nei
18. Bei_Gang
19. Meng_Hu
20. Peng_Lai
21. Long_Sheng
22. Zhang_Xing
23. Jian_Shan_Hu
24. Fei_Cui

● CWB rain gauge

★ DTRGN

Case study-Overview



Typhoon Meari (2011):

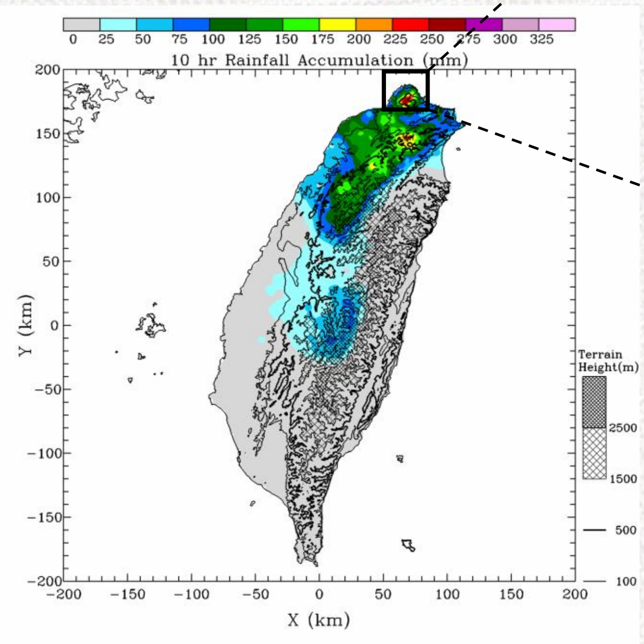
① Moving northwesterly passing by northeast sea area of Taiwan

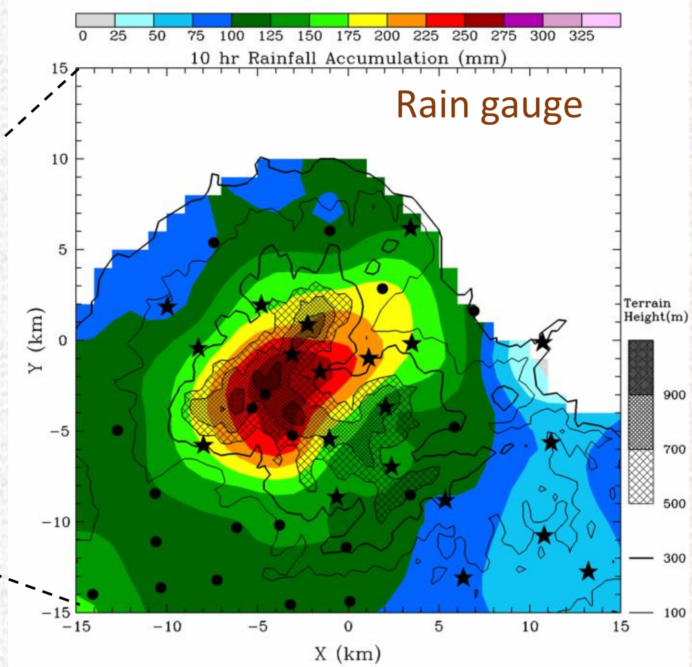
② Outer circulations of the typhoon persistently passed over northern area

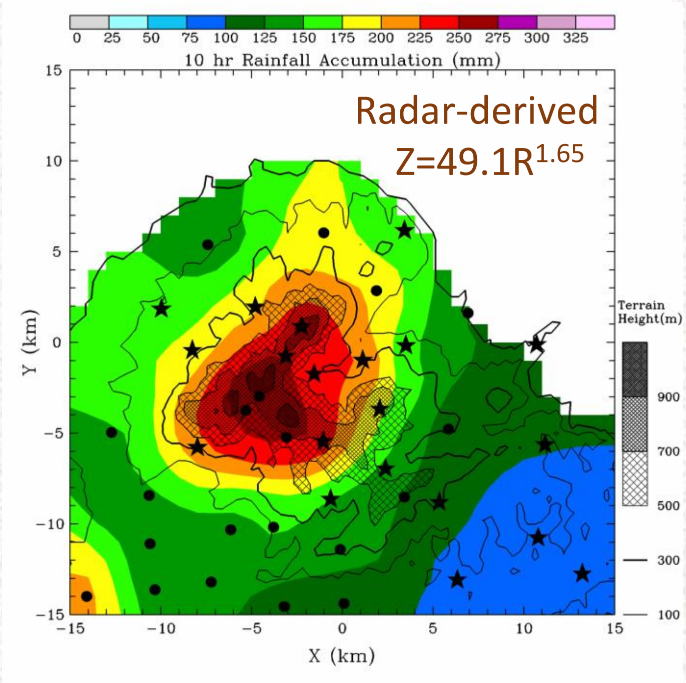
③ Studying period:
6/24 17UTC- 6/25 03UTC

Case study-Overview

10 hr rainfall accumulation





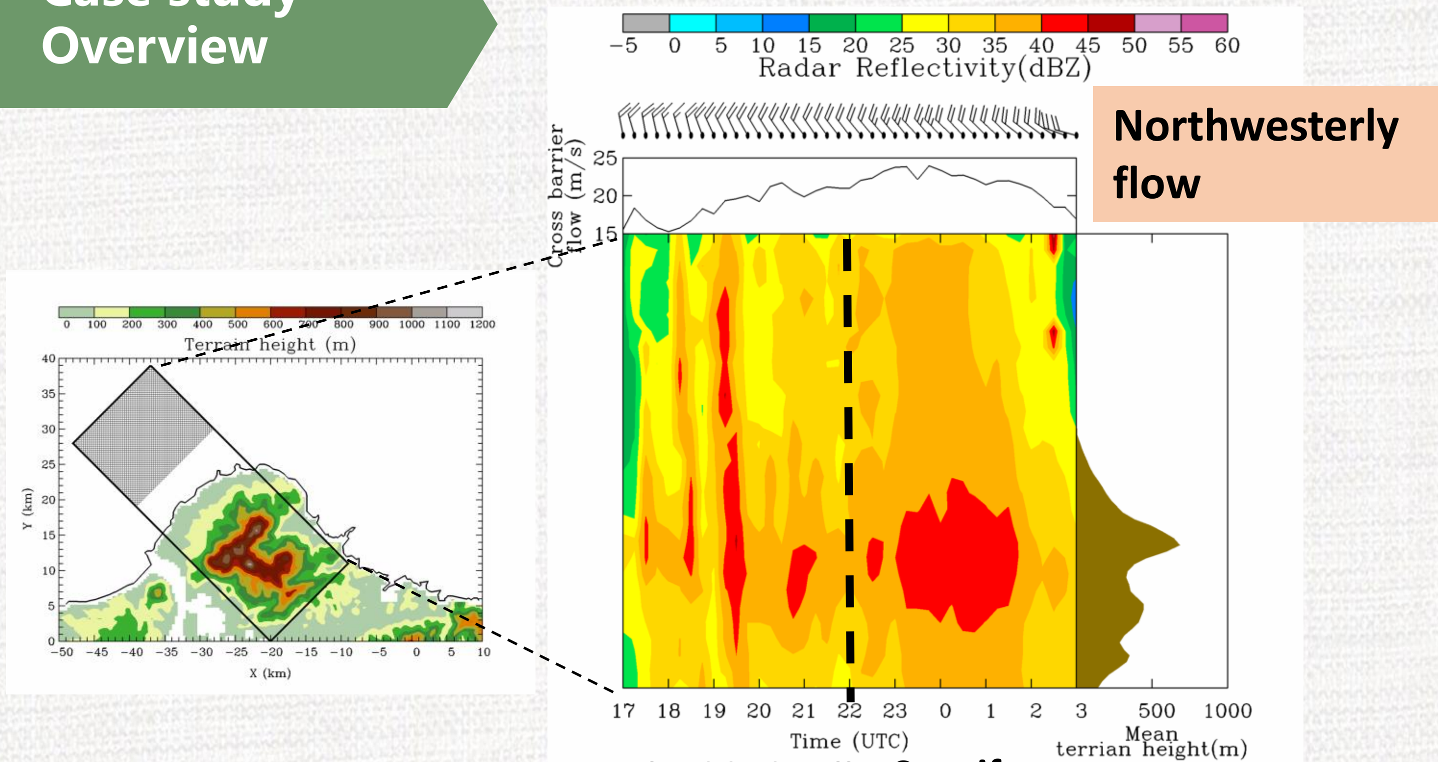


R= 0.81

RMSE = 5.3 mm/hr

Case study-Overview

Hovmöller Diagram



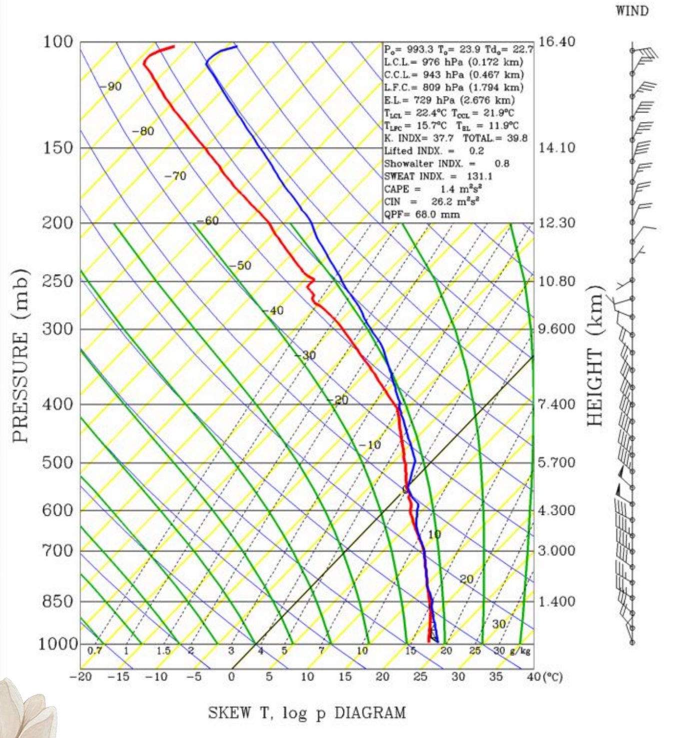
Embedded-cell stage **Stratiform stage**

- Embedded-cell stage: convective cells passed by
  Stratiform stage: background precipitation is more stratiform
- Radar reflectivity max @ near and downstream of the crest
- Stronger enhanced rainfall over mountain while cross barrier flow getting stronger

Case study – Upstream conditions

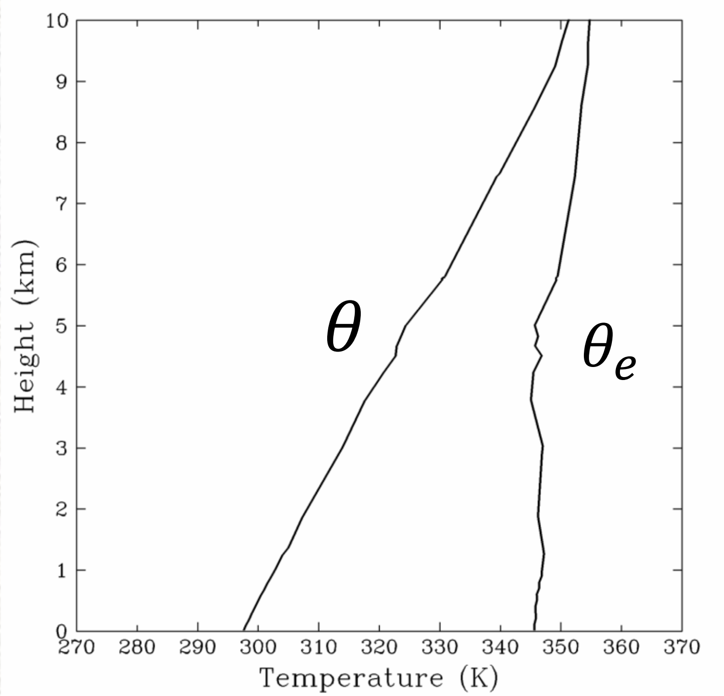
Banciao Sounding (062500Z)

Data below 1km was replaced by Damsui station.



LCL: 172m

CAPE: 1.4 $m^2 s^2$



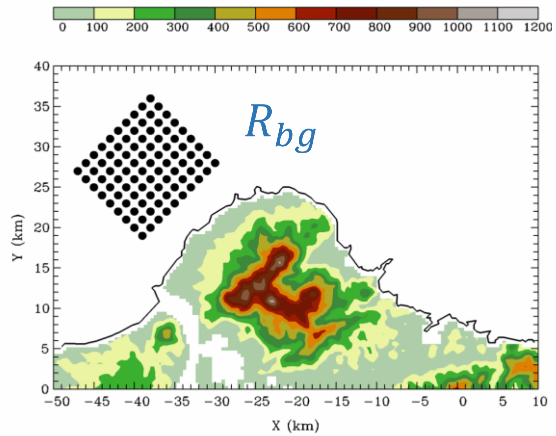
Saturated Brunt–Vaisala frequency $\mathrm{N_m} = 4.6 \times 10^{-3}$

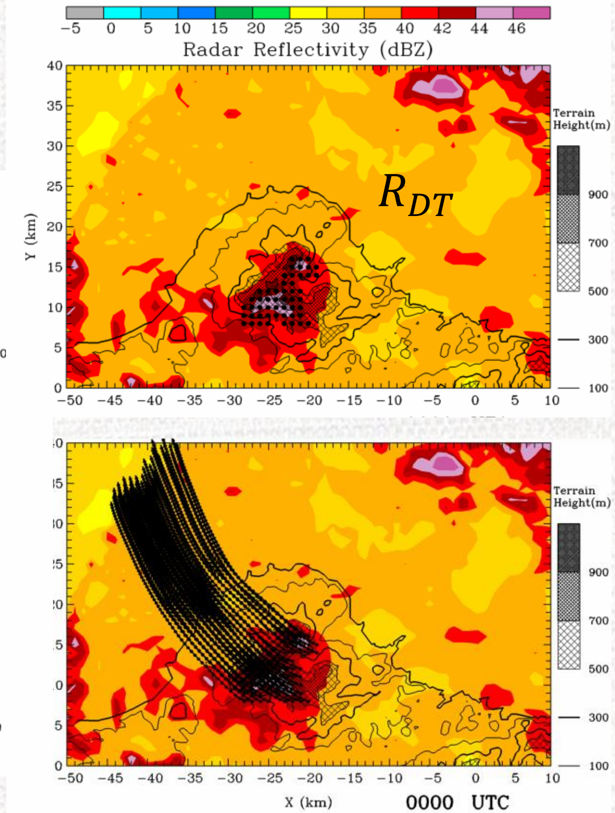
Wind speed at 1 km (dual-Doppler): 20~23m/s

Fr number ($U/N_m H$)= **4.3-5**

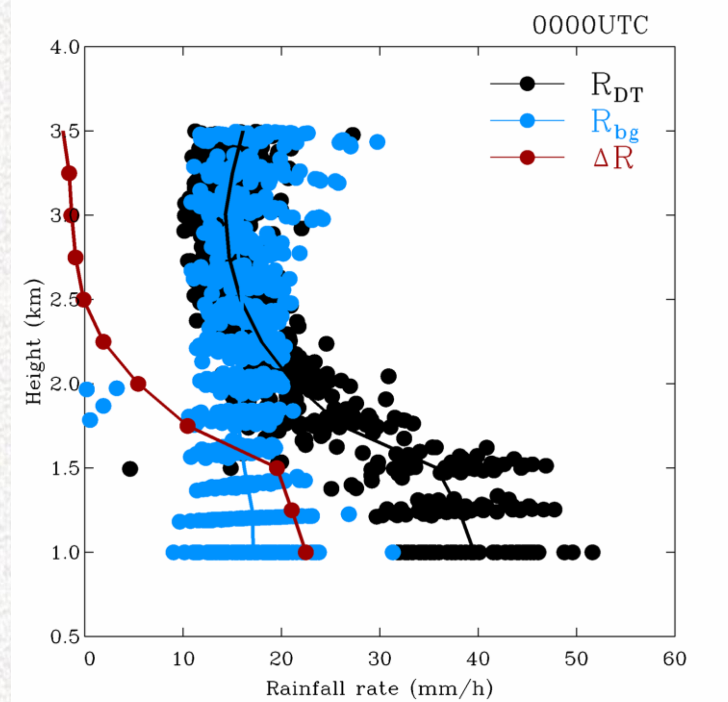
Large Fr flow regime

Case study – Quantitatively estimation





$\Delta R = R_{DT} - R_{bg}$



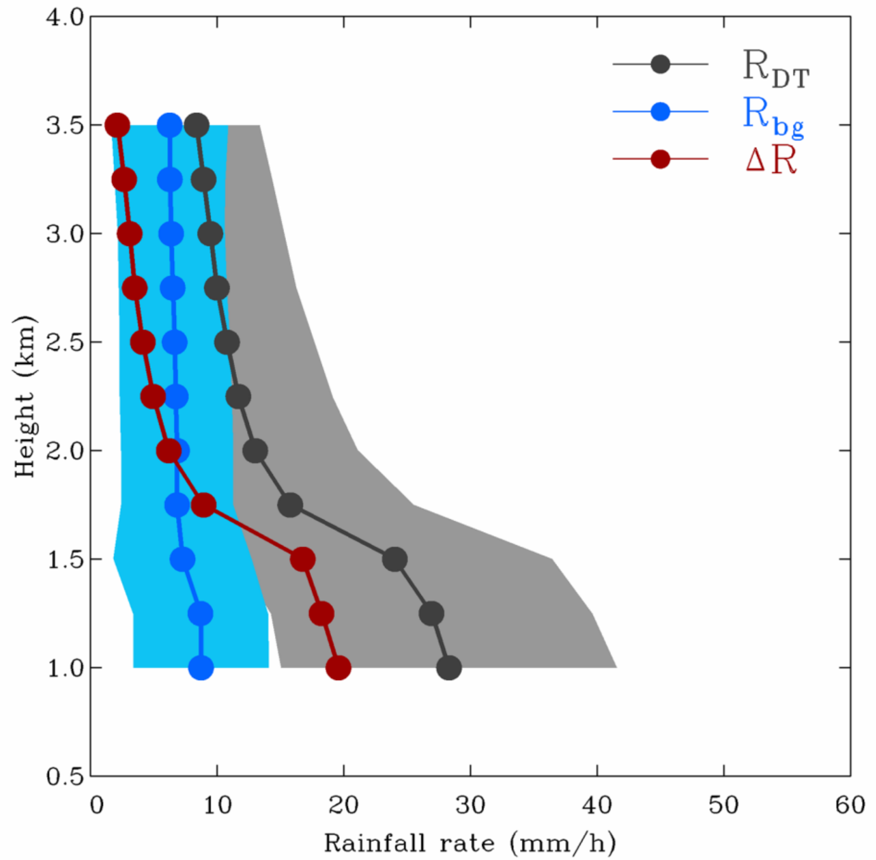
Backtrack hydrometeors :
Using **horizontal/vertical wind** and **terminal velocity**(computed from reflectivity) to track hydrometeors from Mt. Da-Tun(sea) at 1km to represent orographically enhanced precipitation, R_{DT}(background precipitation, R_{bg}).

Backtrack interval : 30s
Trajectory interval : 10-20 min

Case study – Quantitatively estimation

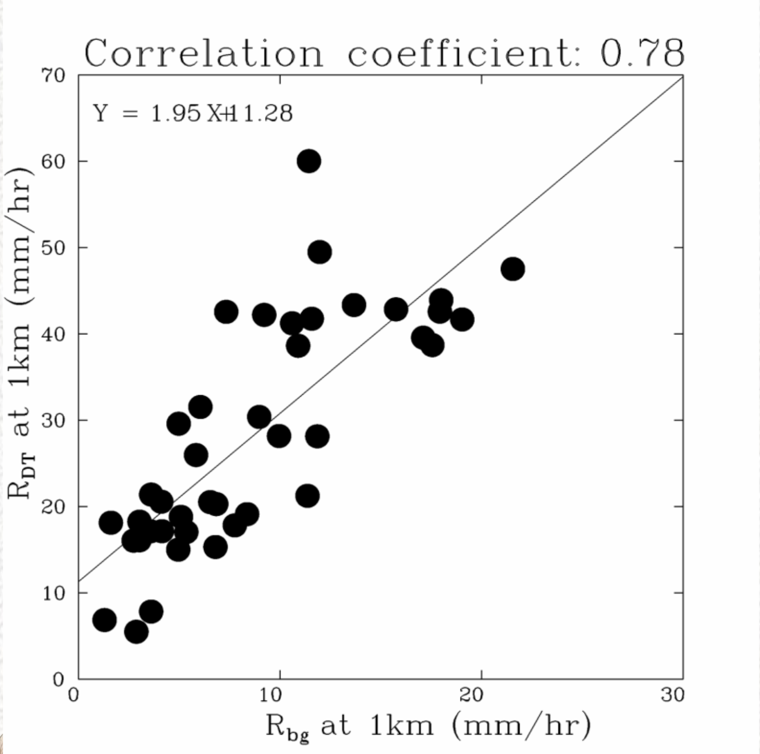
Mean R_{DT}, R_{bg} and ΔR in the period of analysis time

Shading highlights the range of ± one standard deviation

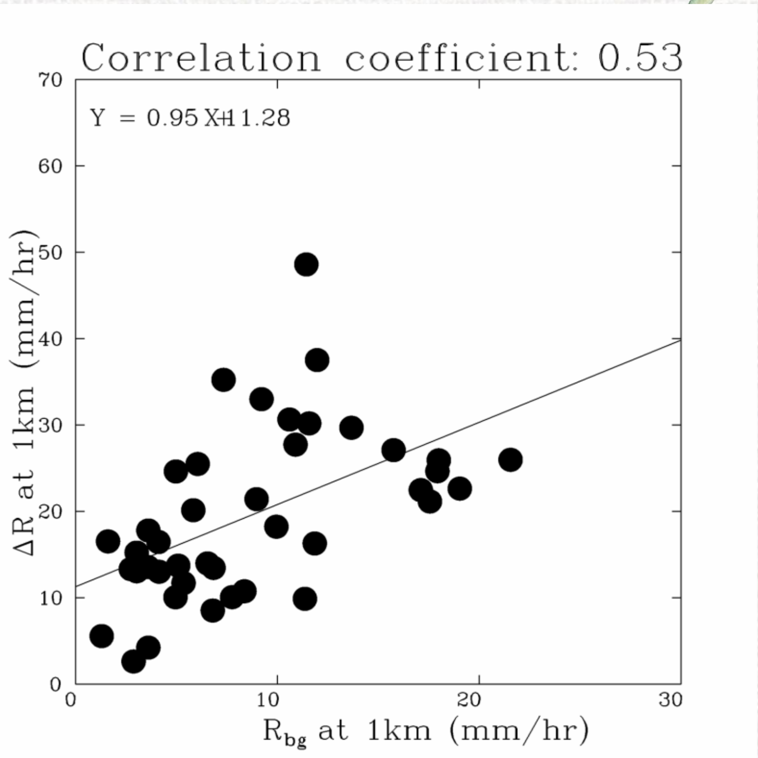


Case study – Quantitatively estimation

R_{bg} vs R_{DT}



R_{bg} vs ΔR



Enhanced rainfall is **2-3 times** greater than the background rainfall

Greater background rainfall -> Stronger enhancement

Case study – Quantitatively estimation

Diagnostic model of orographic precipitation

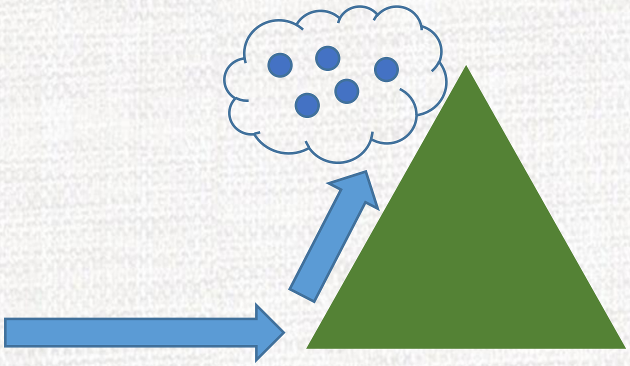
(Sinclair 1994; Cheng 2015)

$$\frac{dq_s}{dt} = -\lambda(p)F(p)\omega(p)\ \left(\frac{Kg/Kg}{s}\right)$$

q_s: *Saturation mixing ratio*

$$\begin{cases} \lambda(p) = \left(\dfrac{RH(p)-0.6}{0.4}\right)^{\frac{1}{2}} \\[2ex] F(p) = \dfrac{q_s T_s}{P_s}\left(\dfrac{LR - C_p R_V T_s}{C_p R_V {T_s}^2 + q_s L^2}\right) \\[2ex] \omega(p) = \omega_s\left(\dfrac{P-P_t}{P_s-P_t}\right)^{\tan({}^{\gamma\pi}/_{4})} \end{cases}$$

$\gamma = 1.5$



$W = V_h * \nabla H$

Case study – Quantitatively estimation

Diagnostic model of orographic precipitation

(Sinclair 1994; Cheng 2015)

Model setting :

① Domain: 60x60 km^2

② Horizontal resolution: 1km

③ Vertical resolution: 100 m

④ Time step : 10s

Input data :

① Sounding : Interpolate Banciao sounding into hourly data

② Upstream wind : mean dual- Doppler derived wind

Model output :

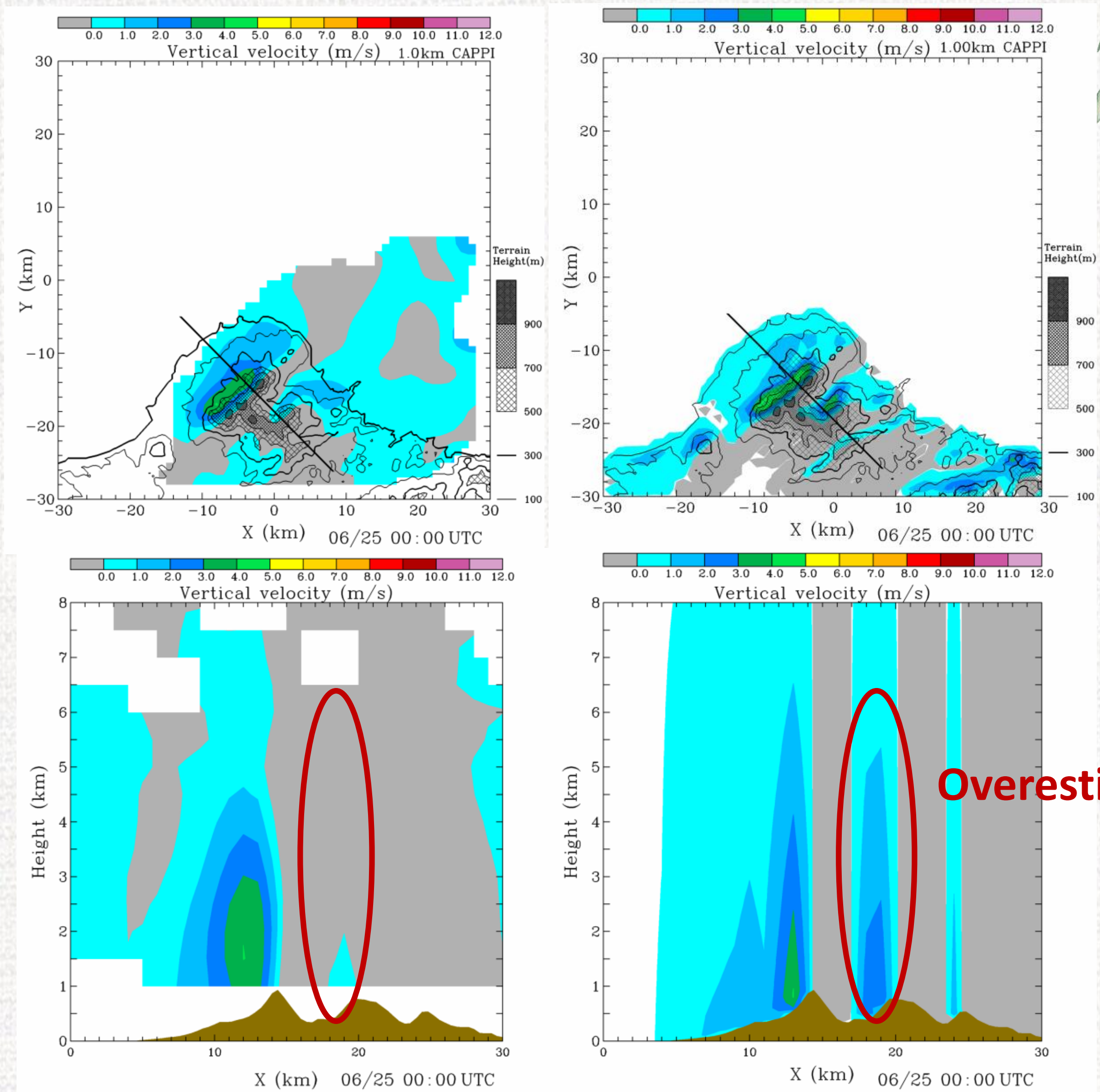
① Rainfall rate (mm/hr)

② Liquid water content M_f (g/kg)

Case study – Quantitatively estimation

Vertical velocity

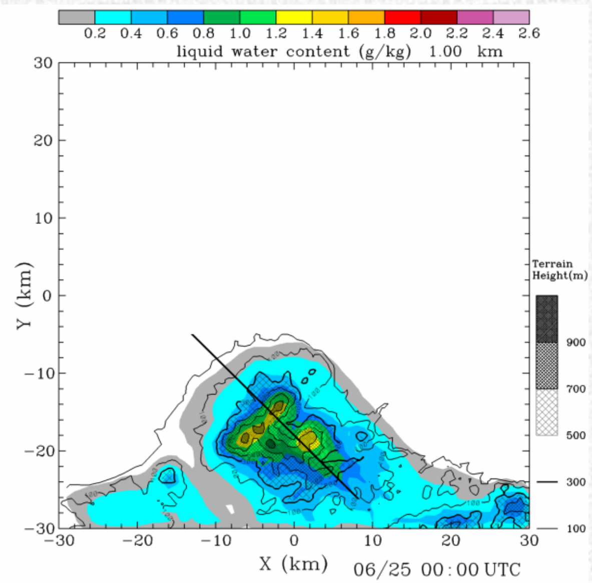
Observation | **Model**

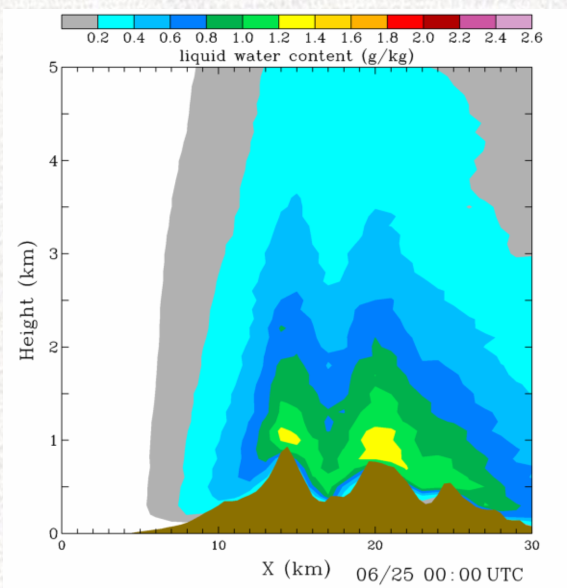


Case study – Quantitatively estimation

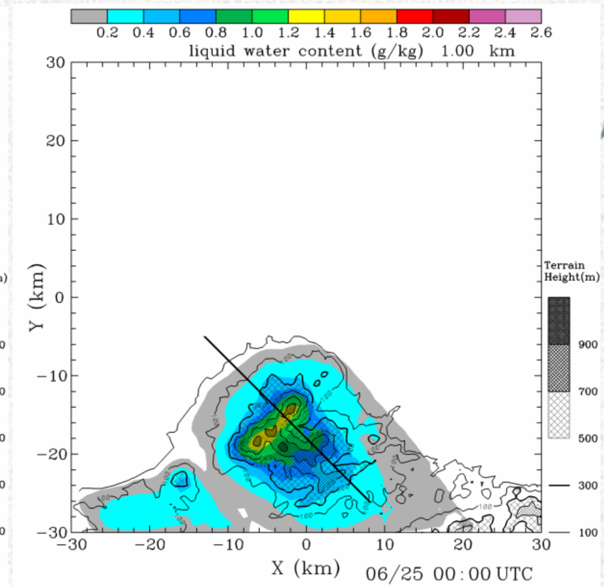
Liquid water content

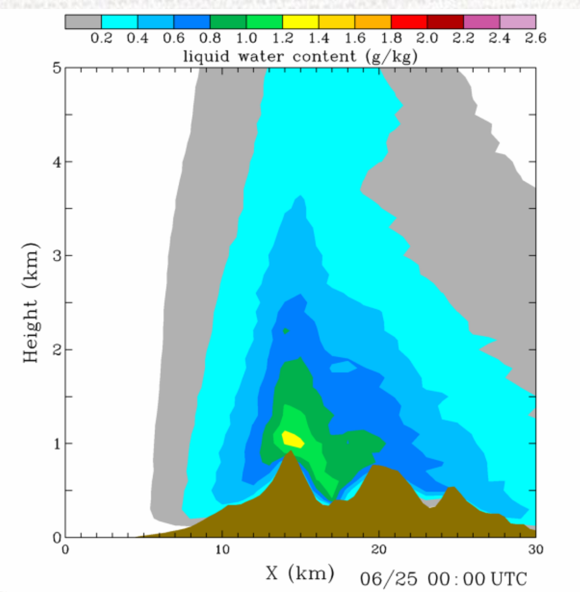
Original





Revised





Case study – Quantitatively estimation

Particles remove cloud droplets by accretion at a rate :
(Passarelli and Boehme 1983; Yu and Cheng 2013)

$$\frac{dR}{dz} = \frac{\pi}{4}\underbrace{D^2 V_t N}_{\text{seeder}}\underbrace{M_f}_{\text{feeder}}$$

D: diameter (mm)
V_t: terminal velocity(m/s)
N : number concentration
M_f: liquid water content (g/m^3)

Rainfall rate (R_{bg}): $\frac{\pi}{6} D^3 V_t N \rho_w$

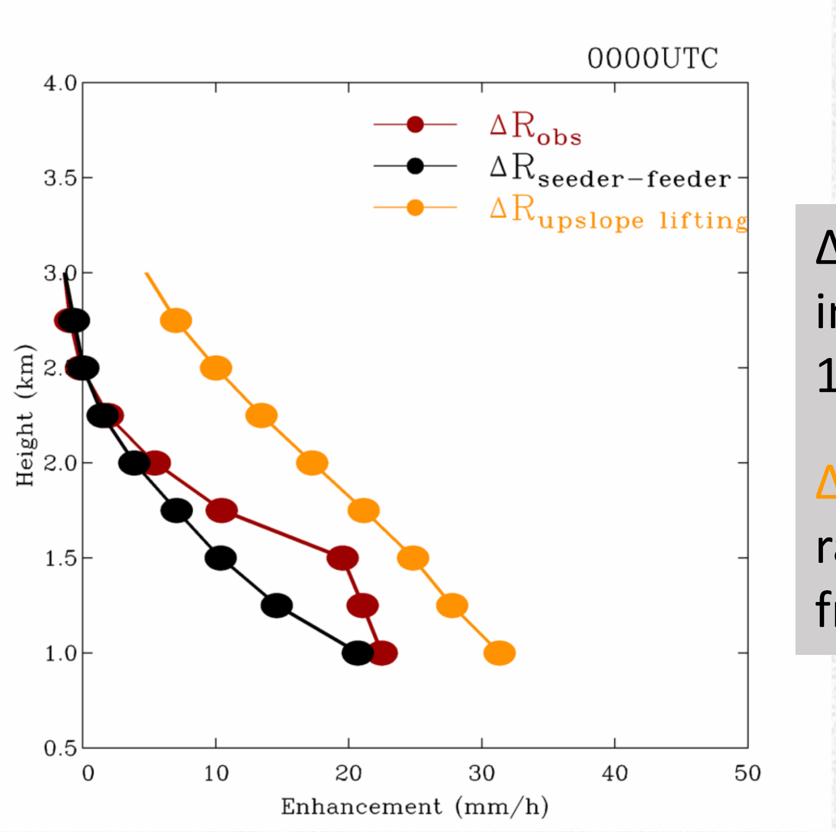
$D = 9.6578947*10^{-2} {R_{bg}}^{0.14}$ (Sekhon and Srivastava 1971)

$$\boxed{\frac{dR}{dz} = \frac{3R_{bg}M_f}{2\rho_w D}}$$

Assumption:
① Background precipitation is monodisperse with perfect collection

② Diameter and terminal velocity of the feeder cloud droplets are neglected

Case study – Quantitatively estimation

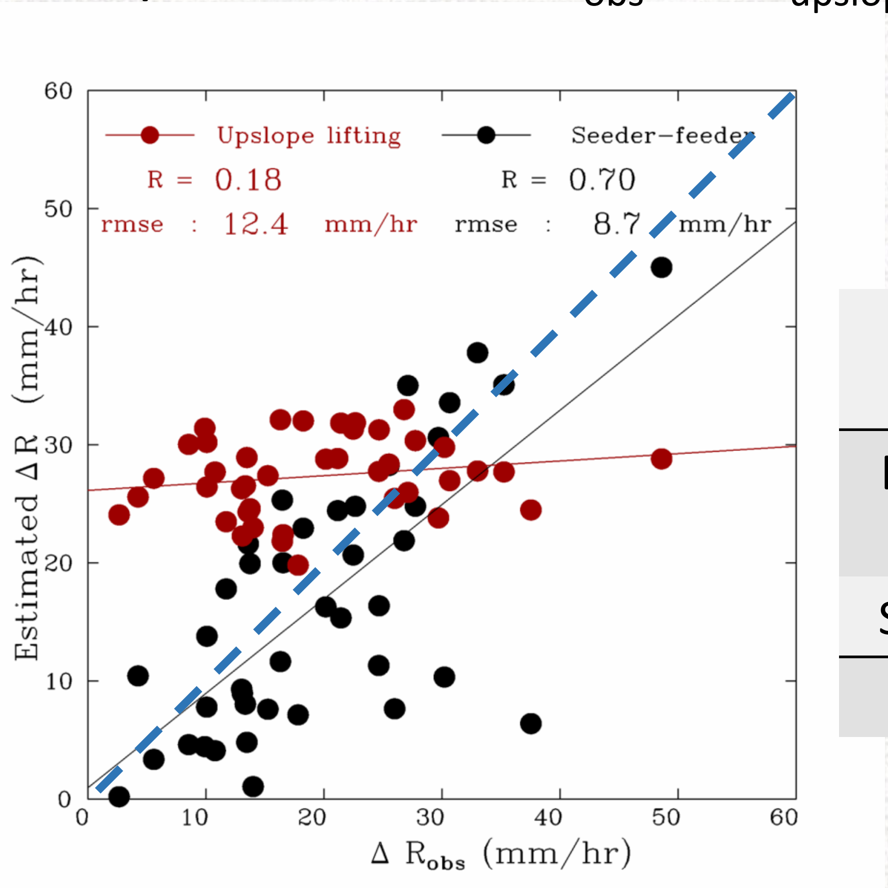


$\Delta R_{\text{seeder-feeder}}$:
integrate rainfall rate from 3km to 1km using theoretical accretion rate

$\Delta R_{\text{upslope lifting}}$:
rainfall generated by upslope lifting from model

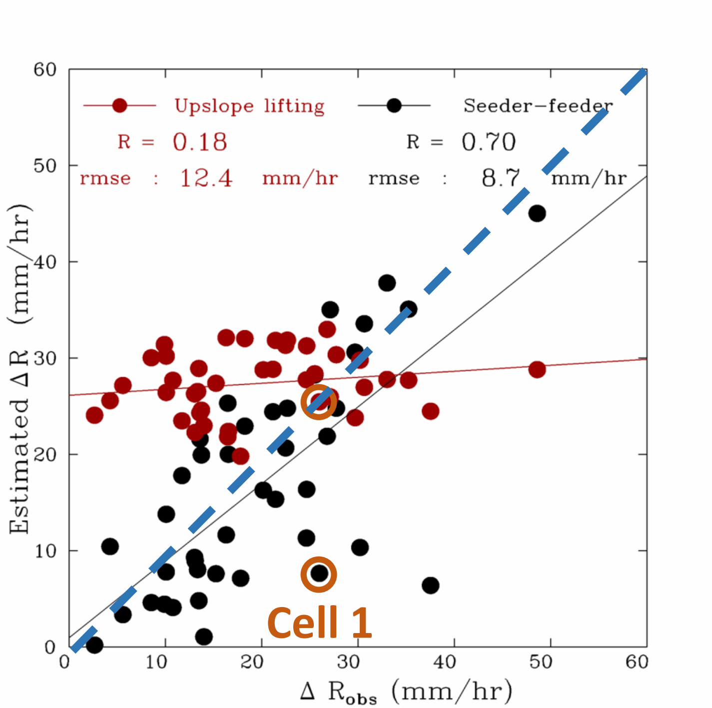
Case study – Quantitatively estimation

Compare between ΔR_{obs} 、$\Delta R_{upslope\ lifting}$ 、$\Delta R_{seeder\text{-}feeder}$

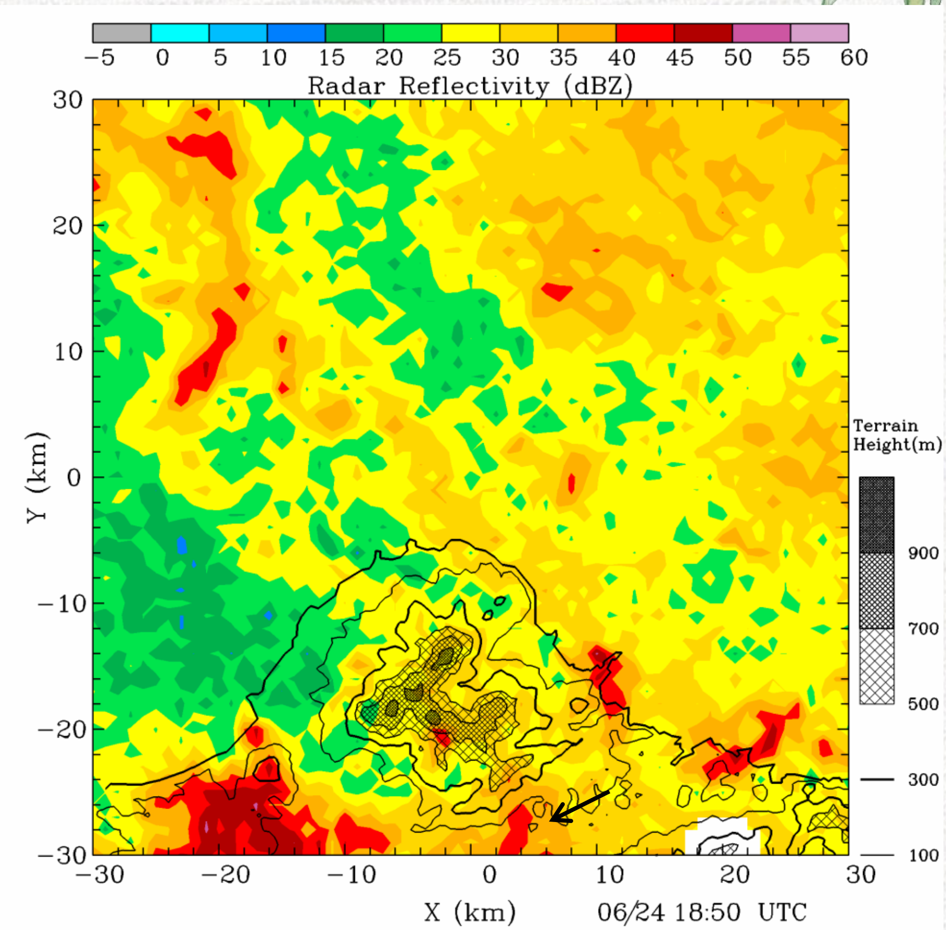


RMSE (mm/hr)	Upslope lifting	Seeder-feeder
Embedded-cell stage	14.6	10.1
Stratiform stage	9.4	6.8
Total	12.4	8.7

Case study – Convective cell



Cell 1

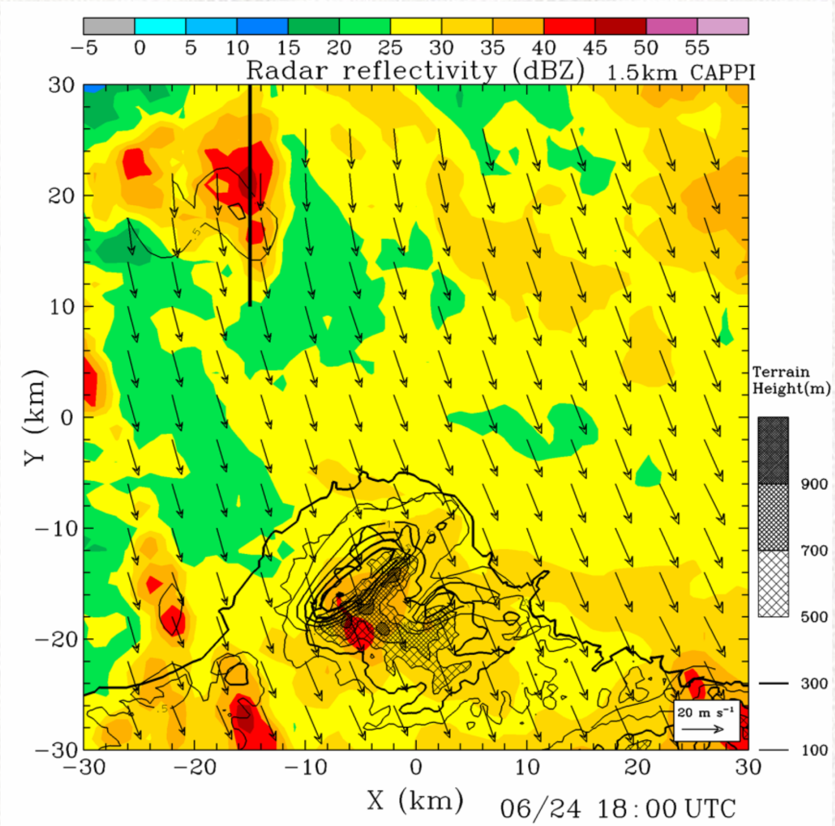


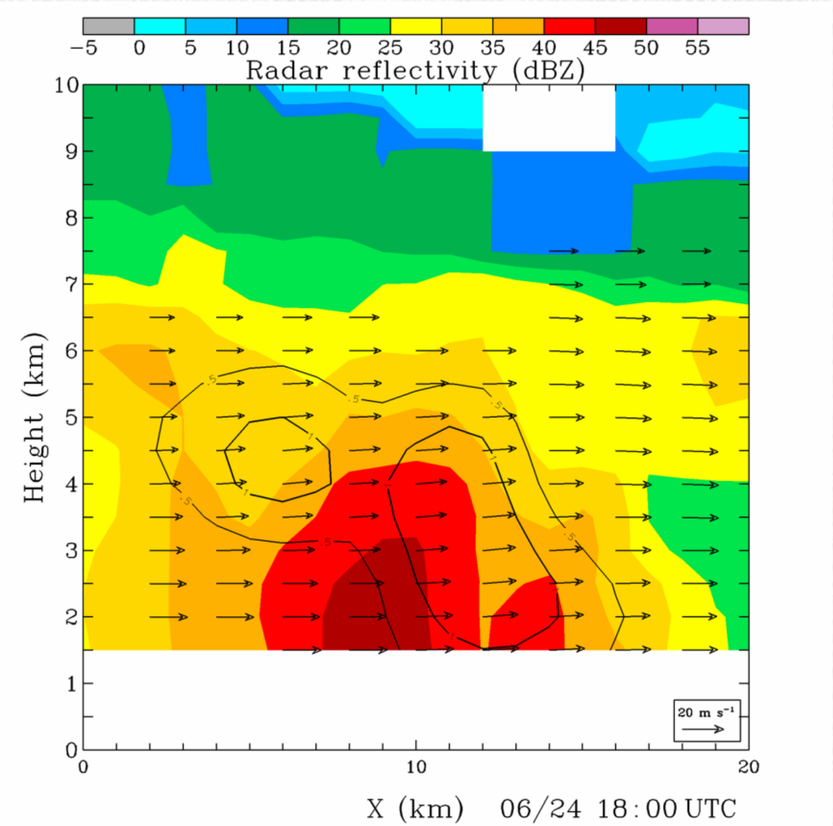
Moving speed : 18.9 m/s
Moving direction : 165.7∘

Case study – Convective cell

Cell 1

Contour : vertical velocity
(interval : 0.5 m/s)





Case study – Convective cell

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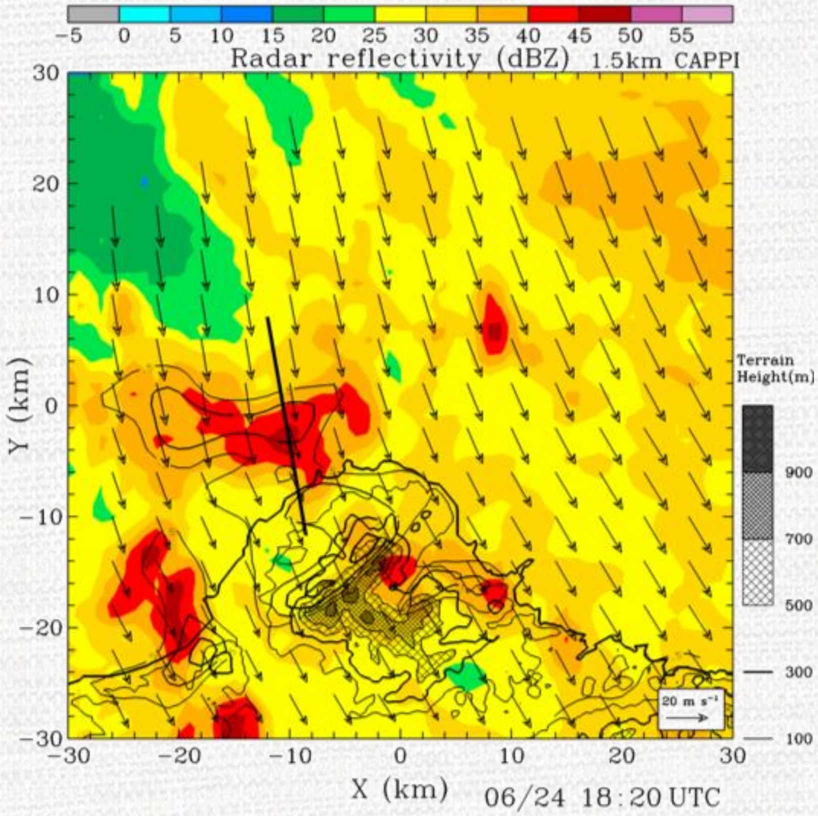

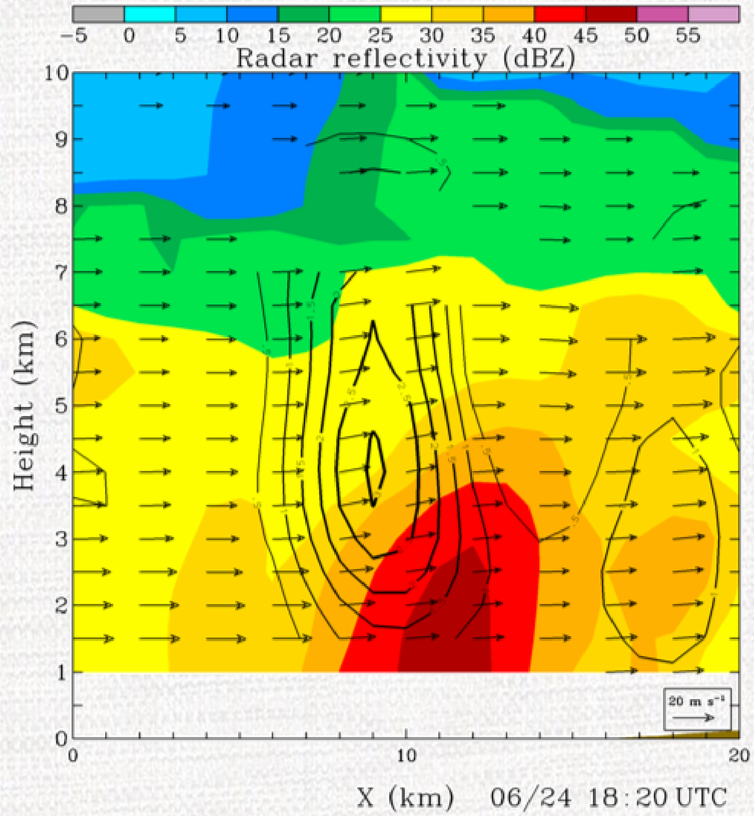

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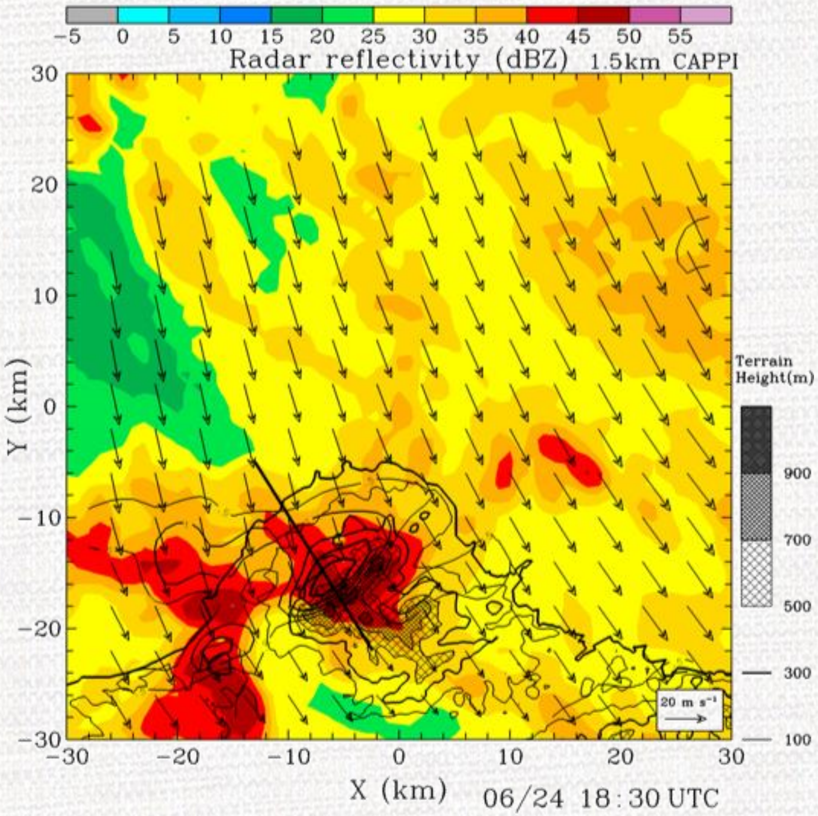

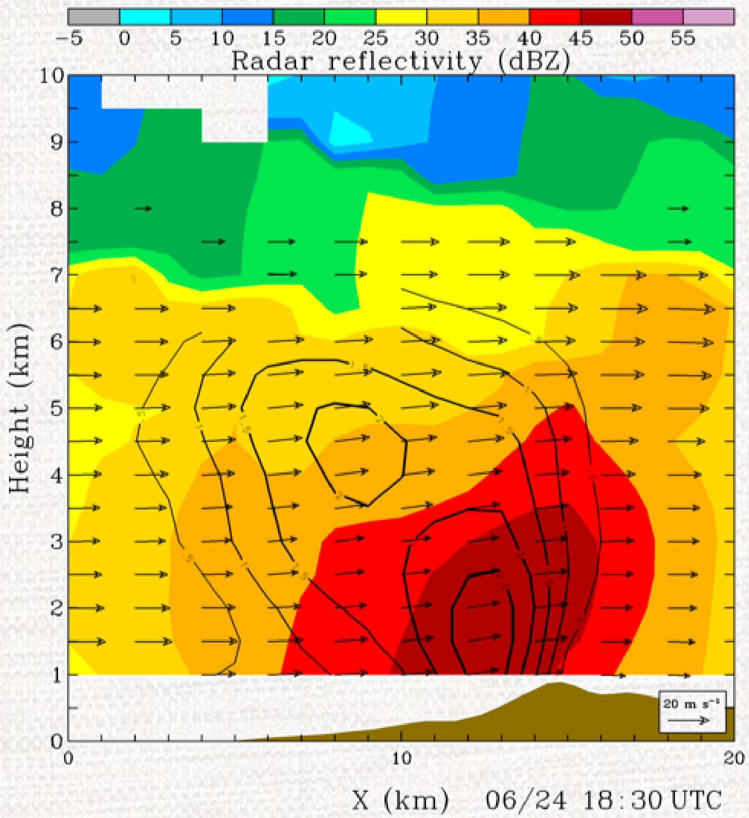

Strong-echo region (>40dBZ) deepened and widened

Summary

1. The layer of orographic enhancement of precipitation was primarily confined to the lowest 3 km, with most pronounced enhancement below 2 km.

2. The orographic enhanced rainfall is 2-3 times greater than the background rainfall, which is comparable to previous studies.

3. Theoretical calculation of seeder-feeder process can better quantify the rainfall enhancement than upslope lifting.

4. In the embedded-cell stage, the error of seeder-feeder calculation is larger than the stratiform stage.

5. When convective cells moved into Mt. Da-Tun, the strong echo region deepened and widened. The rainfall enhancement of convective cells cannot be simply explained by seeder-feeder process.

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THANK YOU