Evaluation of WRF cloud microphysics scheme using radar observations

Ki-Hong Min[1,2,3] and Gyuwon Lee[1,2]

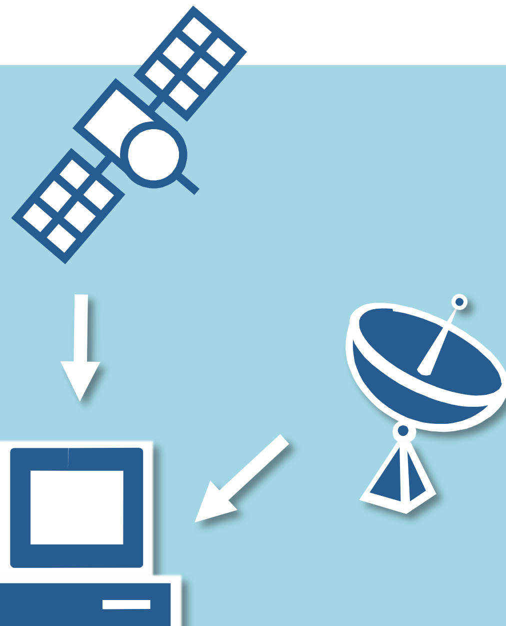
[1]Dept. of Astronomy & Atmospheric Sciences, Kyungpook National University
[2]Center for Atmospheric Remote Sensing, Kyungpook National University
[3]Dept. of Earth, Atmospheric, and Planetary Sciences, Purdue University

1. Motivation & Objectives

Need for accurate weather info

Uncertainty o
f clouds in N
WP

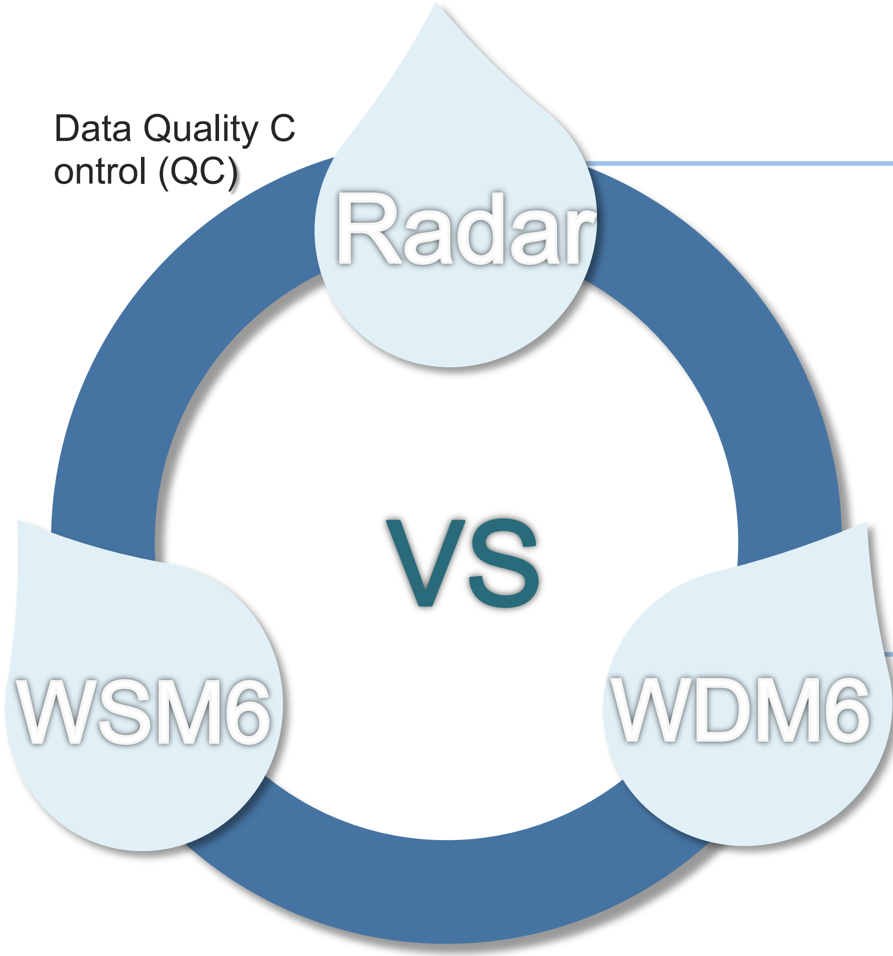
Next-gen.
NWP model d
evelopment



Evaluate cloud microphysics (MP)

Improve MP/NWP

2.1 Concept and Data



CFAD (Contoured Frequency by Altitude Diagram)

-Radar (dBZ)
-WRF (qrain, qgraup, qsnow)

➔ **Bright Band / Melting Level**

Time-Height Cross Section

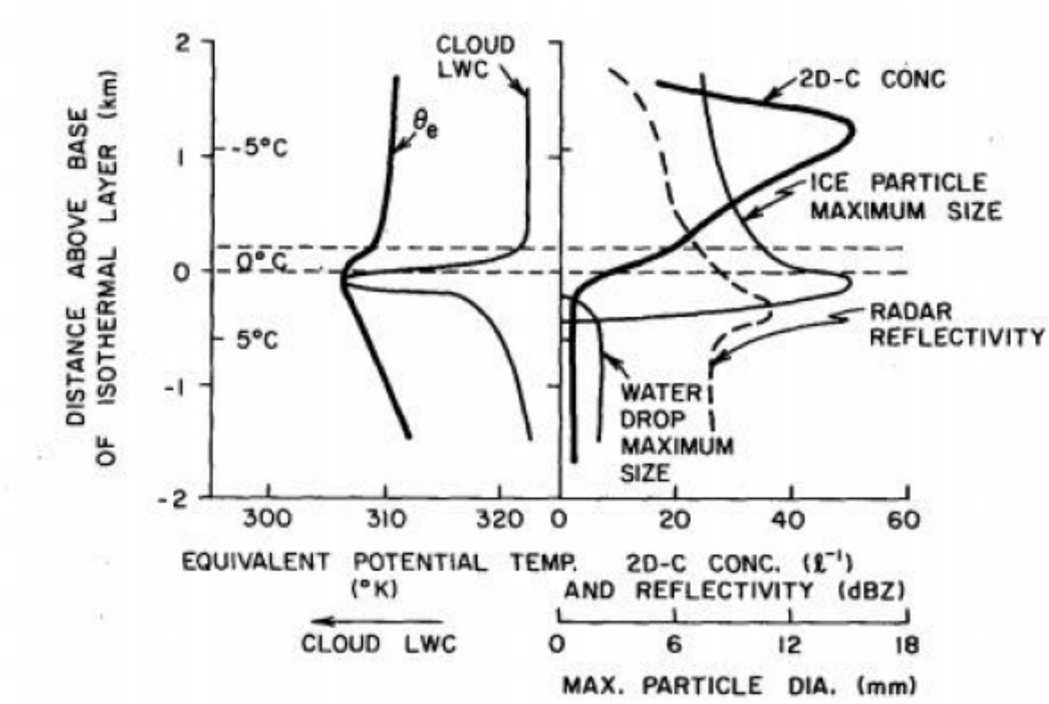
-Radar (dBZ)
-WRF (qrain, qgraup, qsnow)

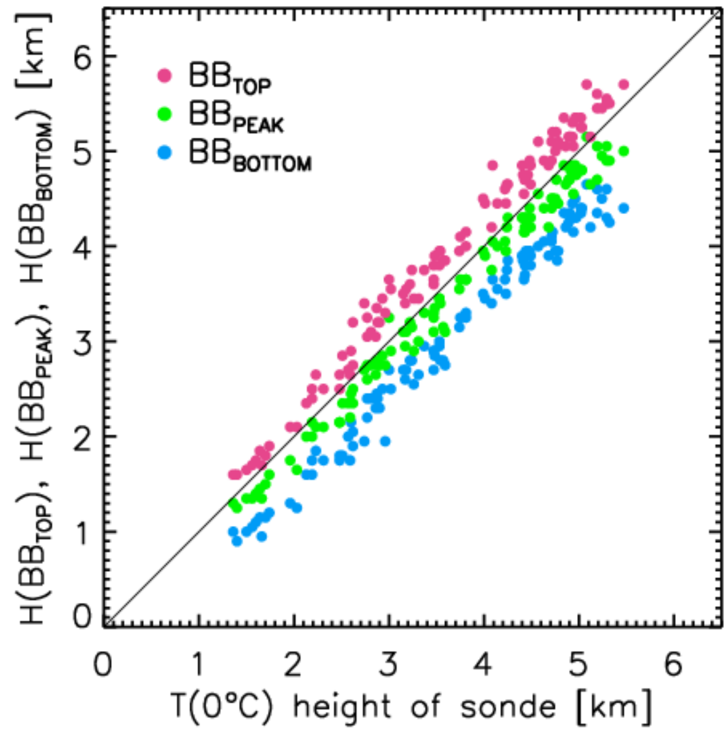
Vertical Profile

-WRF (temperature, relative humidity, qv, qrain, qgraup, qsnow, qcl, qice)

Koch et al.(2005) & Stoelinga (2005): Using simulated reflectivity products to compare m
odel fields with radar have advantage over radar estimated precipitation fields because t
here is less uncertainty involved in the calculation.

2.2 Background





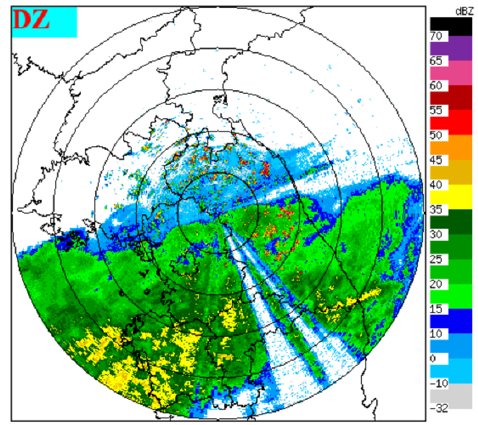
Schematic vertical profile illustrating significant trends of various microphysical and state parameters through a typical melting layer as deduced by synthesizing the observations (Stewart et al. 1984; Berenguer and Zawadzki 2009).

5-yr climatology in Korea (Lee 2012). The 0°C level occurs above 190 m of the bright band peak reflectivity height (±0.13 km).

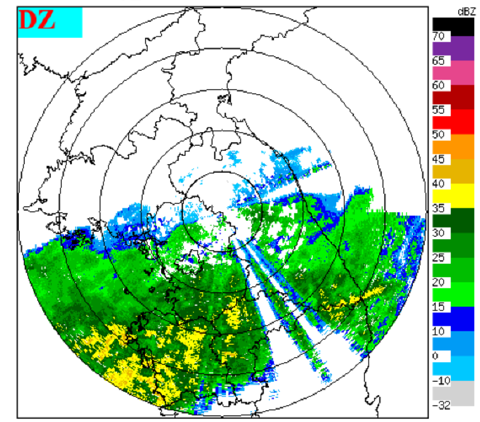
2.3 Radar Data Processing

UF Data
↓
Data QC
(KNU fuzzy algorithm)
↓
Convert PPI to CAPPI
↓
Radar Calibration
(bias removal)
↓
Resolution Matching
(4km and 12km)
↓
Data Extraction
(< radius 100km)
↓ ↓
CFAD Refle ctivity | Time-height Cross-section

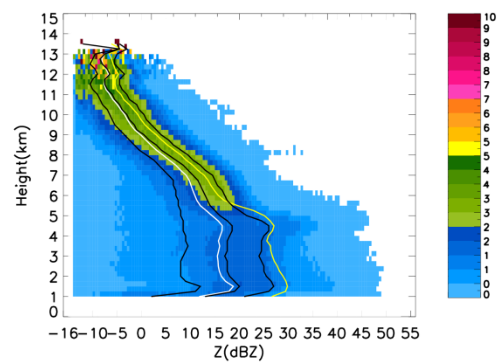
Raw



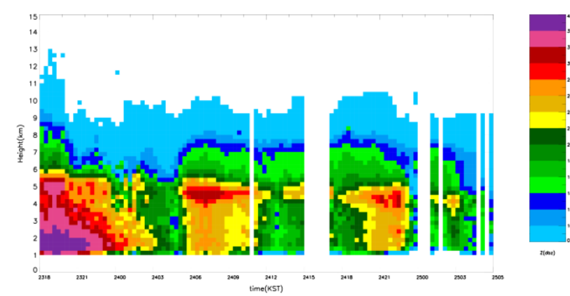
QC



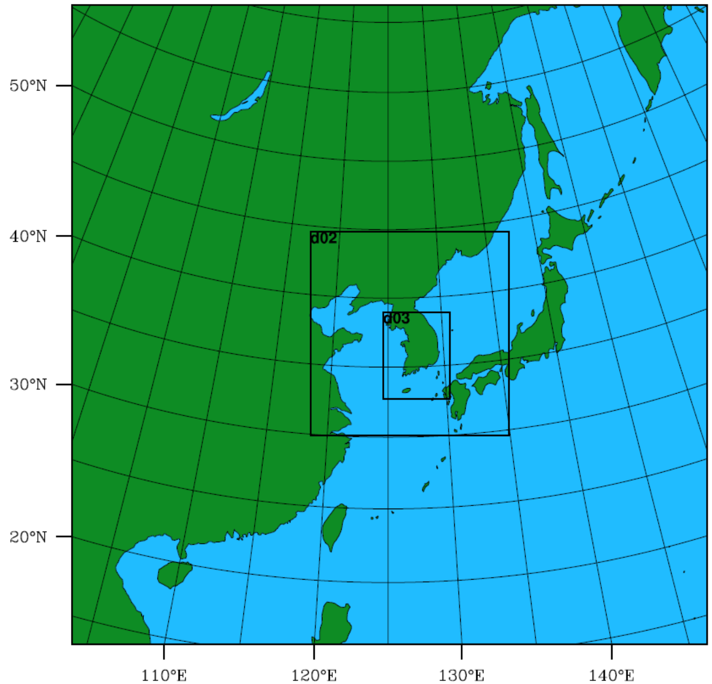
CFAD



Time-height



2.4 WRF v3.5 Model



I.C. & B.C.: FNL (NCEP Final Analysis)
from GFS (Global Forecast System)

- Resolution : 1°× 1°
- Time interval : 6 hourly
- 26 pressure levels (1000-10hPa ; excluding surface)

Domains

- Grid points : 140 × 146 × 60 (D01)
  130 × 136 × 60 (D02)
  130 × 169 × 60 (D03)
- Resolution : 36km × 36km (D01)
  12km × 12km (D02)
  4km × 4km (D03)

Schemes	WSM6	WDM6
Mass variables	q_v q_c q_r q_i q_s q_g	q_v q_c q_r q_i q_s q_g
Number variables		N_n N_c N_r

N_n : CCN number
N_c : cloud droplets number concentration
N_r : rain droplets number concentration

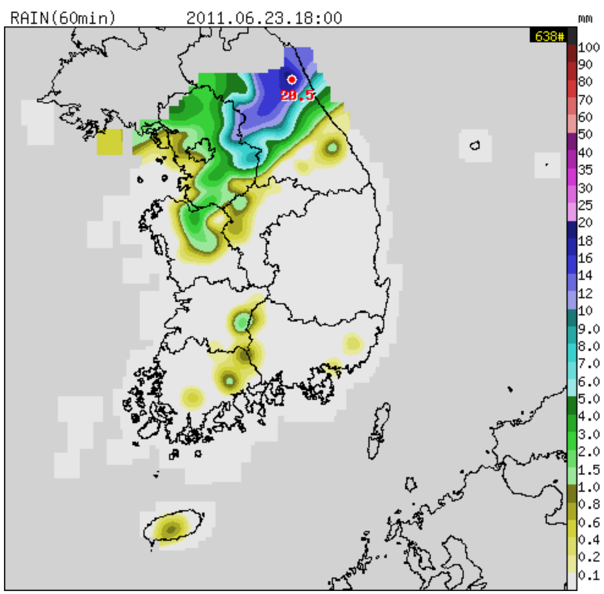
3. Selected cases for this study

Case Number	Period	Characteristic
1	6/24/2011 – 6/25/2011	Summer Monsoon
2	8/14/2011	Scattered Convection
3	7/3/2011 – 7/4/2011	Summer Monsoon
4	8/11/2011	Scattered Convection

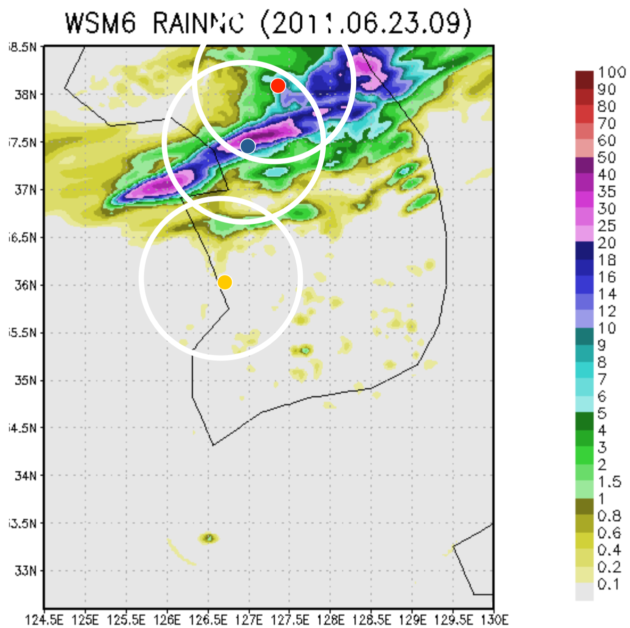
Case 1) Changma Front (00KST 24 – 03KST 25 June 2011)

60 min. accumulated rainfall of AWS, WSM6 & WDM6

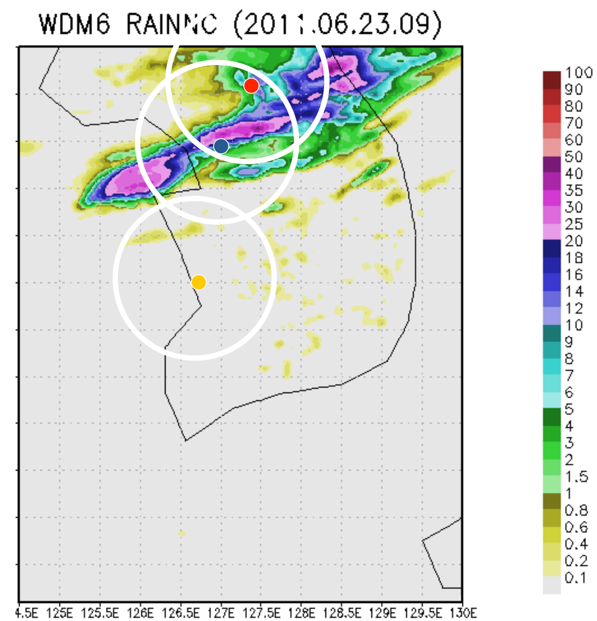
AWS



WSM6



WDM6

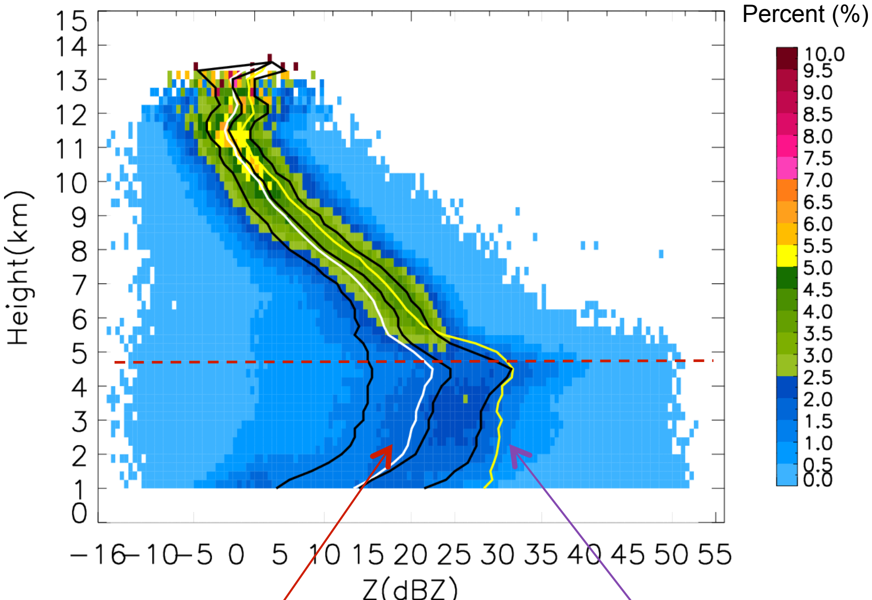


- GDK (1000m)
- KWK (600m)
- KSN (34m)

Case 1) GDK : CFAD of Reflectivity

radar 0˚C
model 0˚C

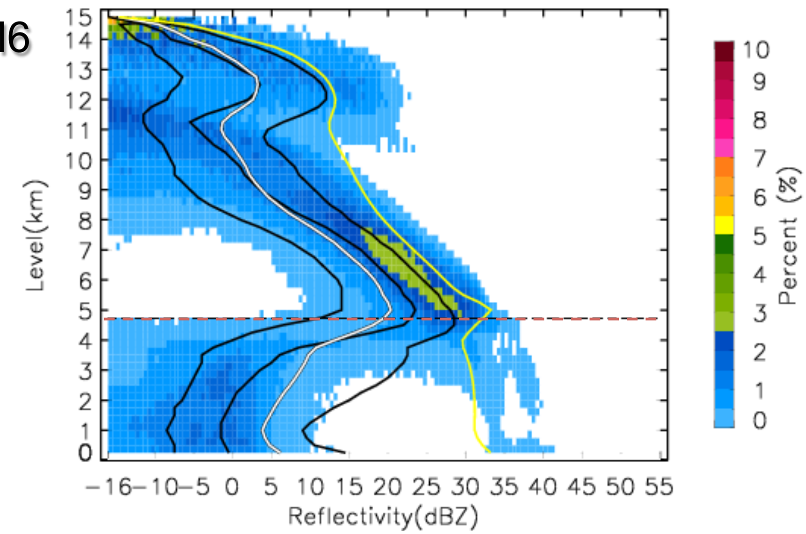
Radar (dz=250m,radius=100km)



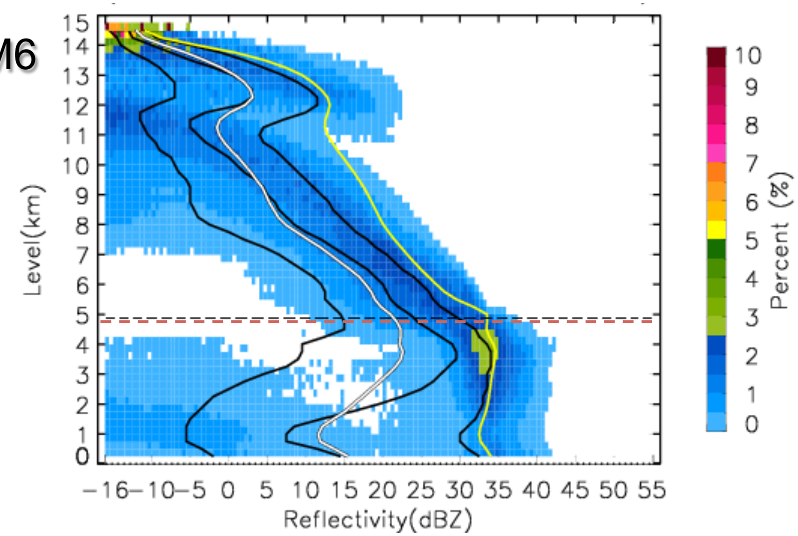
$$\overline{dBZ_k} = \frac{1}{N_k}\sum_{i=1}^{n} dBZ_i$$

$$\overline{dBZ_k} = 10\times\log_{10}\left(\frac{1}{N_k}\sum_{i=1}^{n}10^{0.1\times dBZ_i}\right)$$

WSM6



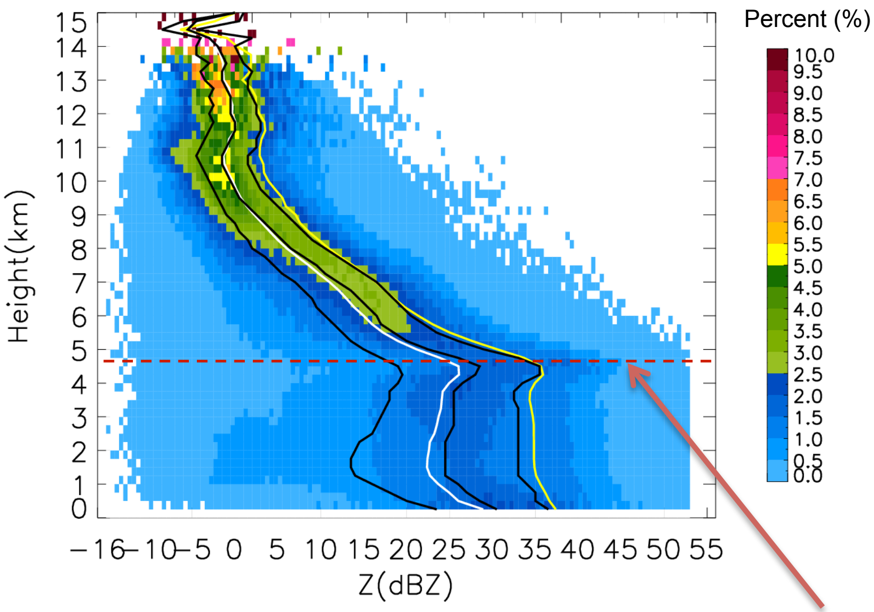
WDM6



Case 1) KSN : 반사도 CFAD

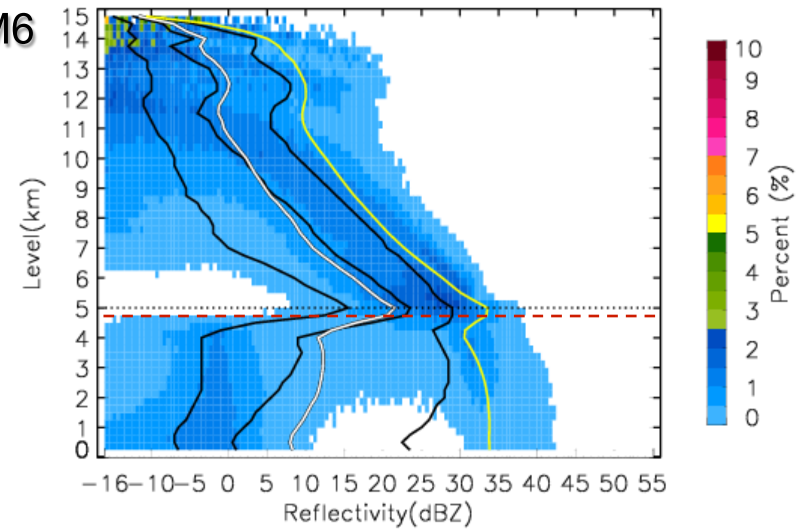
radar
model

Radar

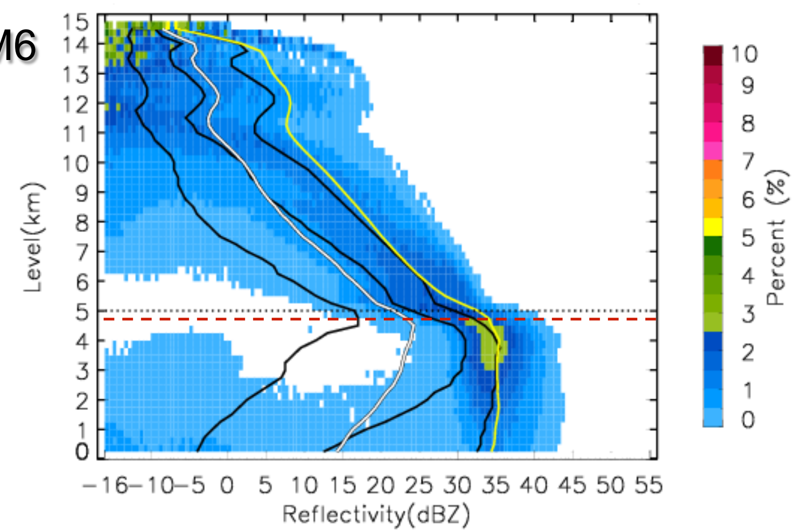


KSN 0˚ C

WSM6

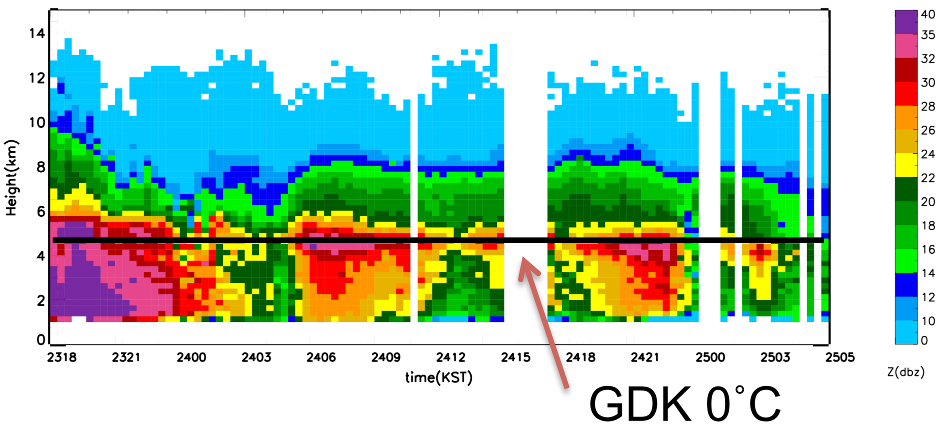


WDM6

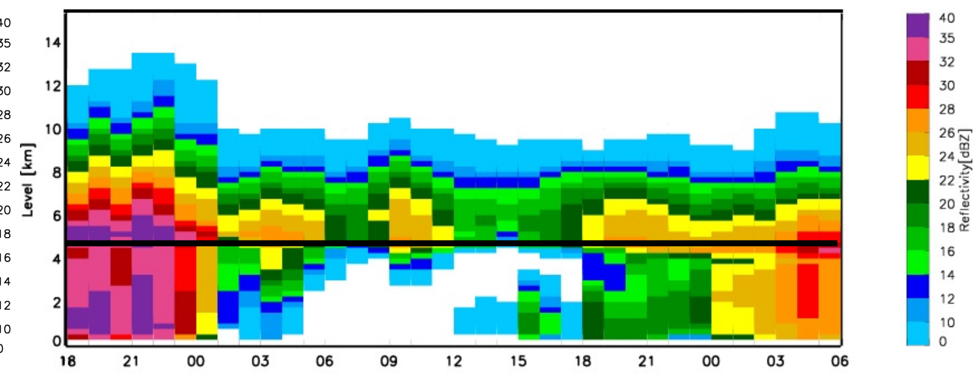


Case 1) GDK : Time-Height Cross Section of Reflectivity

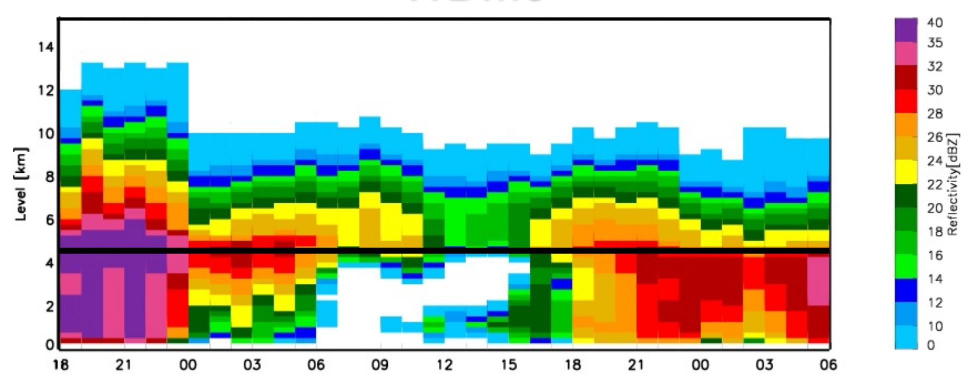
Radar



WSM6

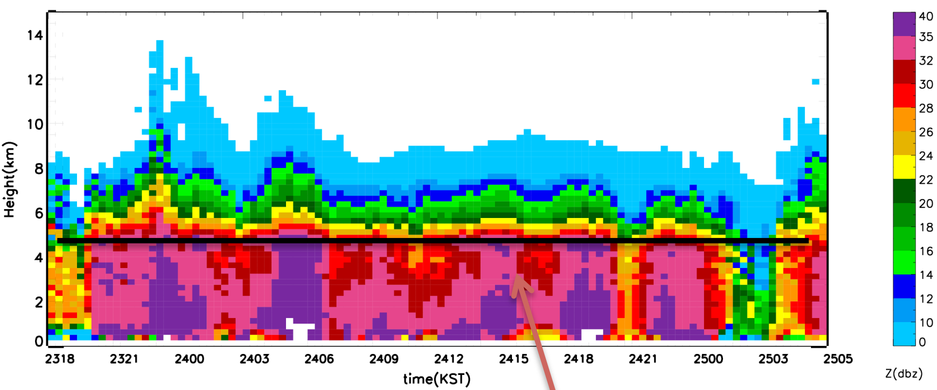


WDM6



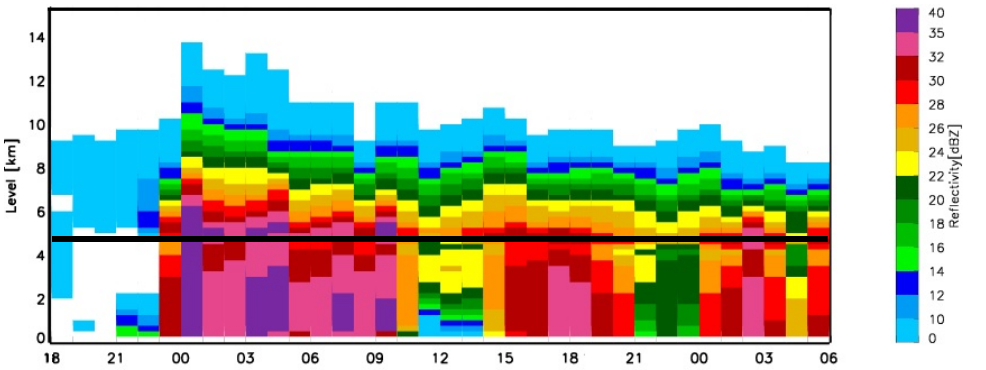
Case 1) KSN : Time-Height Cross Section of Reflectivity

Radar

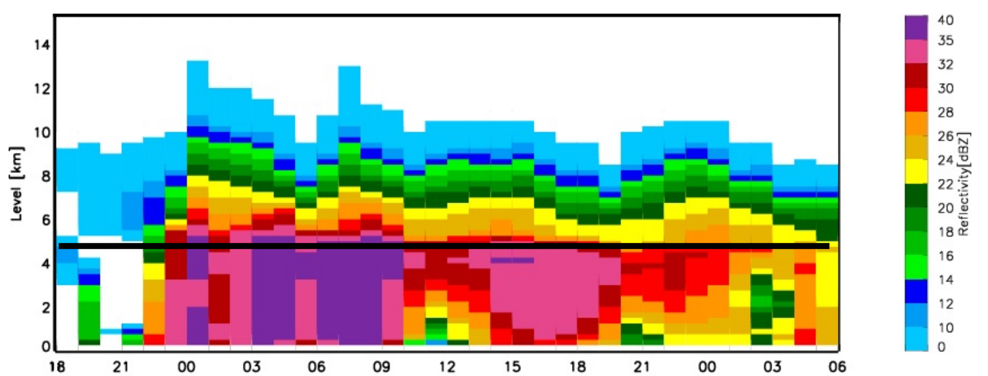


KSN 0˚C

WSM6



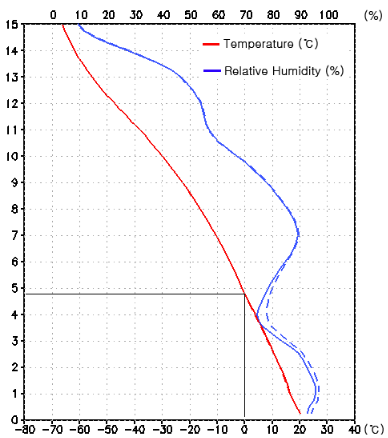
WDM6



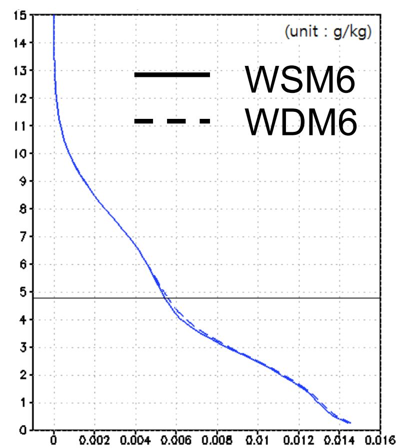
Case 1) GDK : Vertical Mean Profile

WRF

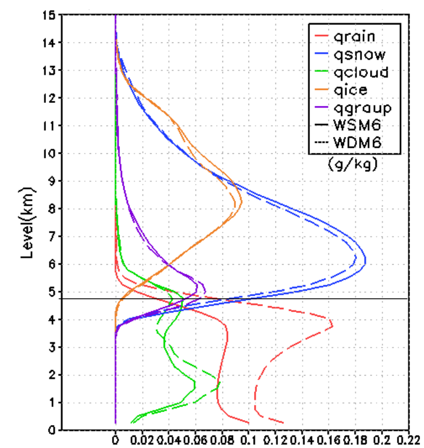
Temperature & Relative Humidity



Q Vapor



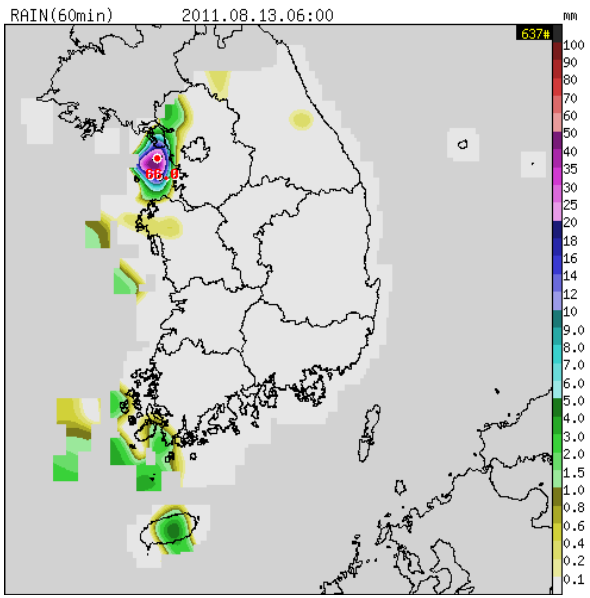
Hydrometeors



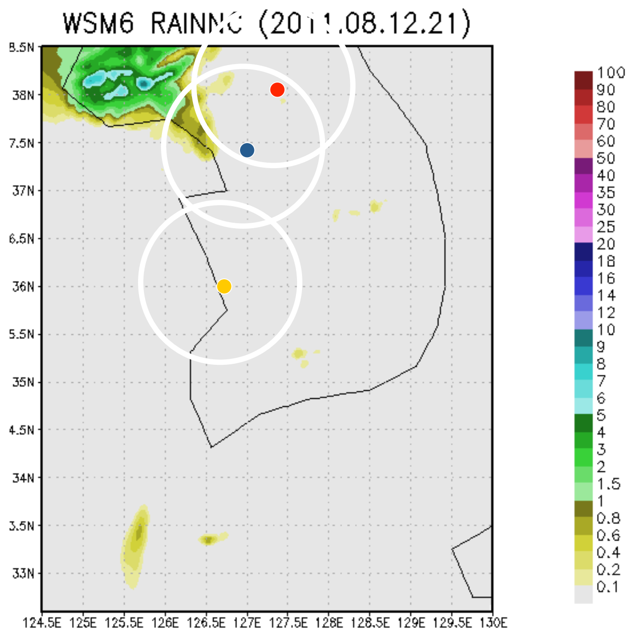
Case 2) Scattered Convection (00KST 14 – 24KST August 2011)

60 min. accumulated rainfall of AWS, WSM6 & WDM6

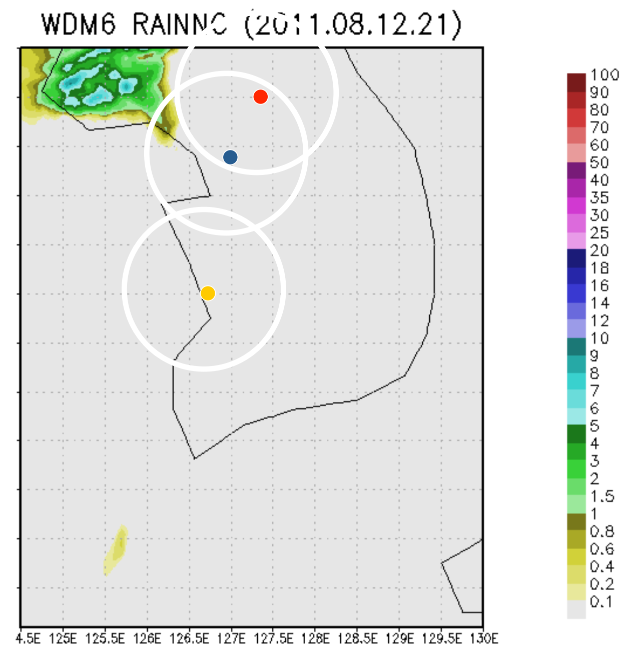
AWS



WSM6



WDM6

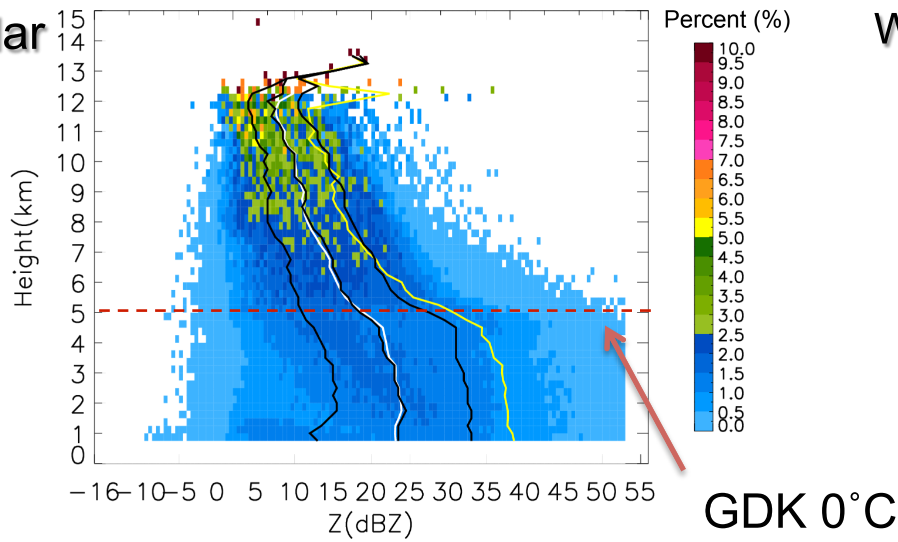


- GDK (1000m)
- KWK (600m)
- KSN (34m)

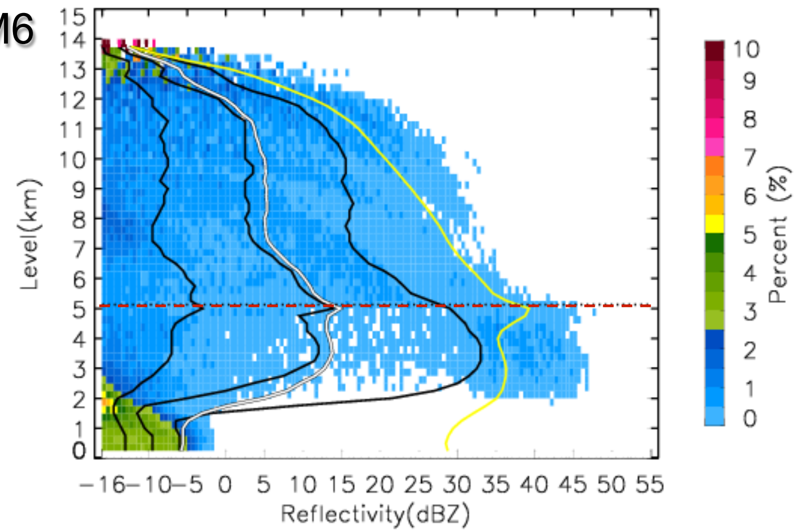
Case 2) KWK : CFAD of Reflectivity

radar
model

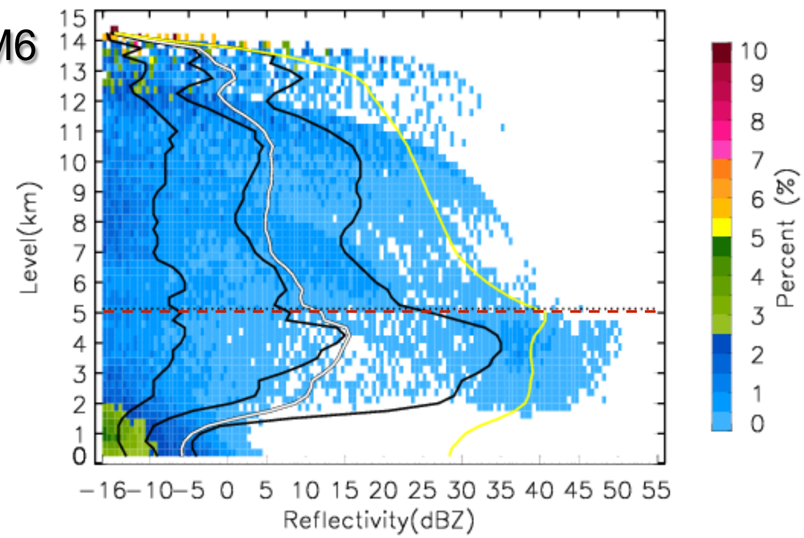
Radar



WSM6

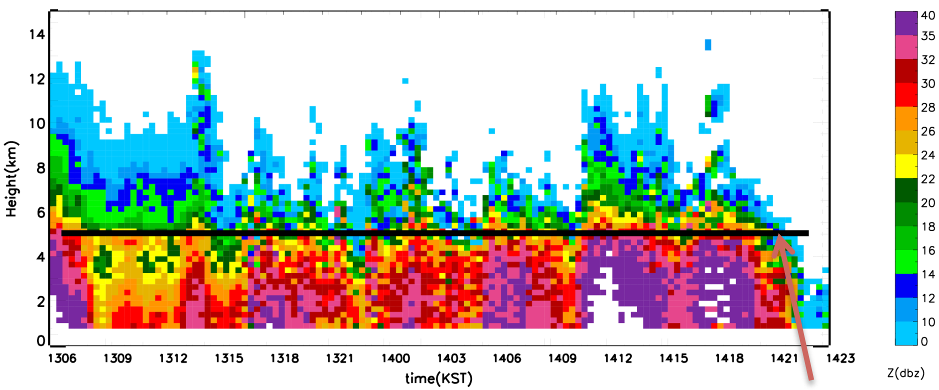


WDM6

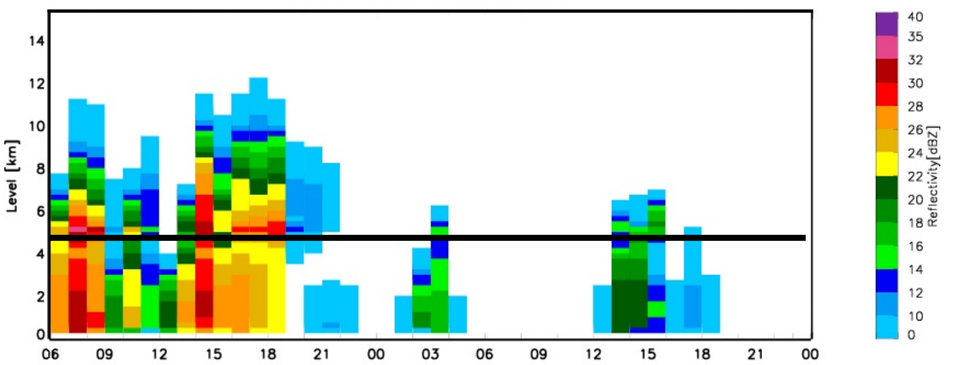


Case 2) KWK : Time-Height Cross Section of Reflectivity (4km)

Radar

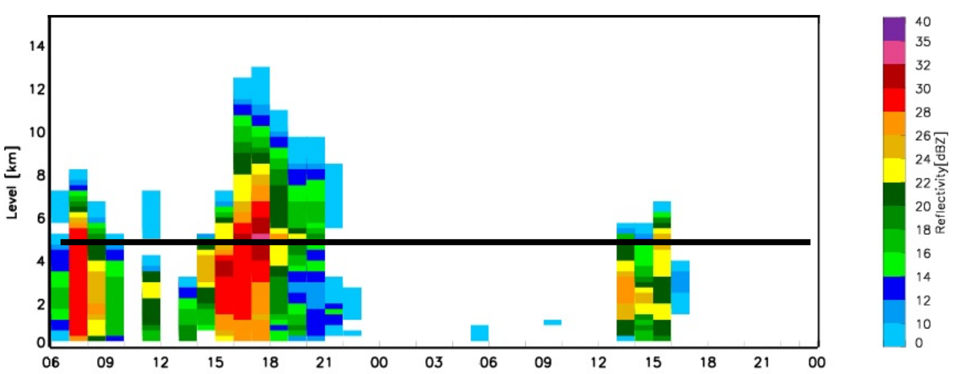


WSM6



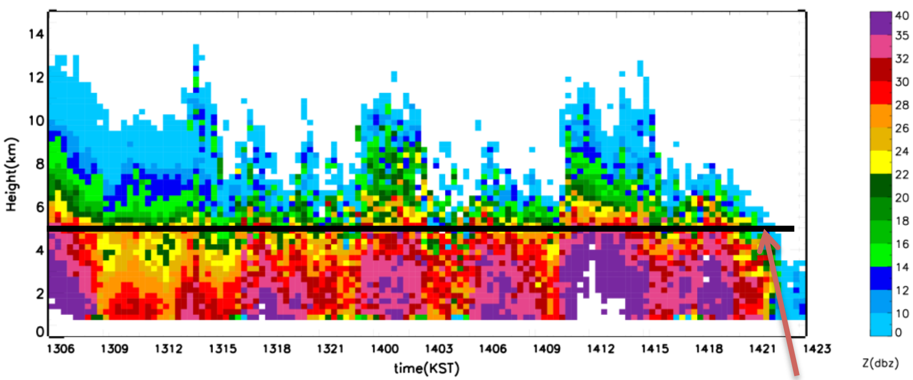
GDK 0˚C

WDM6

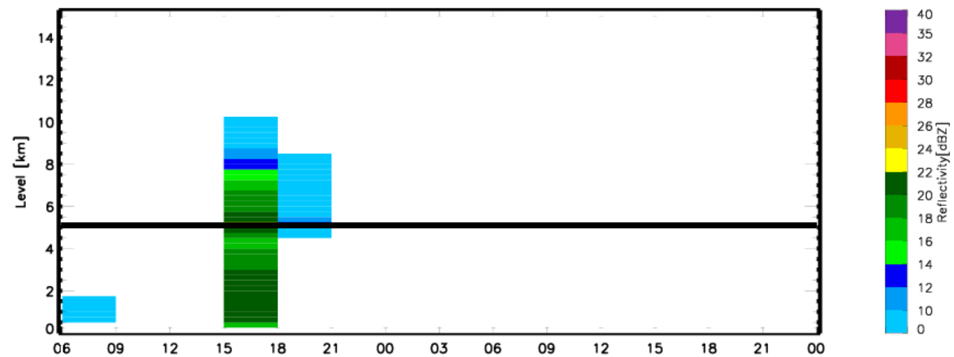


Case 2) KWK : Time-Height Cross Section of Reflectivity (12km)

Radar

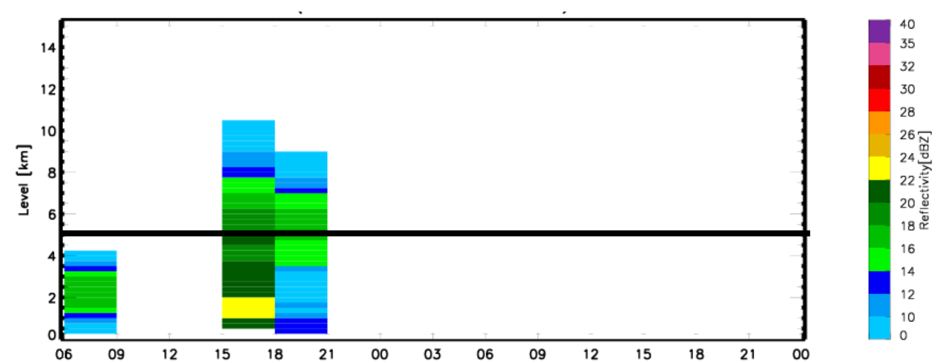


WSM6



GDK 0˚C

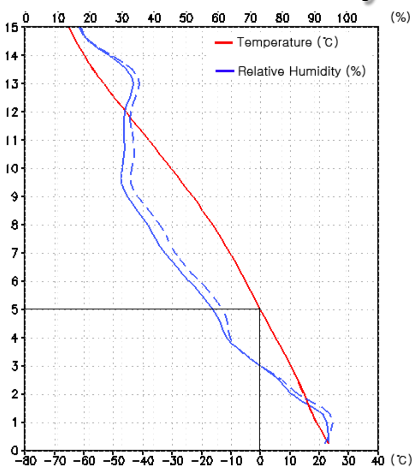
WDM6



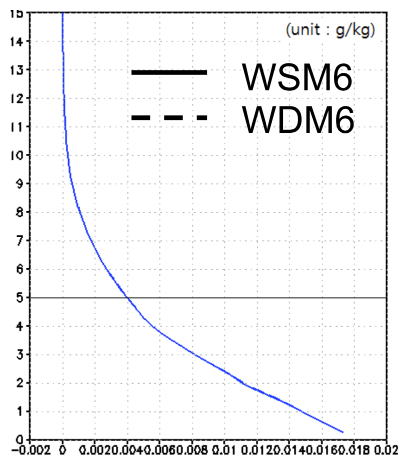
Case 2) KWK : Vertical Mean Profile

WRF

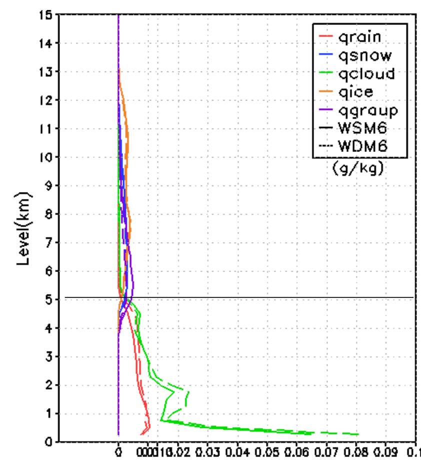
Temperature & Relative Humidity



Q Vapor



Hydrometeors



4. Melting Level Height of Radar vs. WSM6/WDM6

		CASE1	CASE2	CASE3	CASE4	Mean
Average height (km)	Radar	4.63	5.0	5.1	X	
	WSM6	4.97	5.2	5.3	5.2	
	WDM6	4.8	5.23	5.17	5.2	
Bias (km)	Radar	-	-	-	-	
	WSM6	0.34	0.2	0.2	-	0.25
	WDM6	0.17	0.23	0.07	-	0.16

➢ Both schemes have a tendency to over estimate the height of the melting level when compared to radar observations, but the margin of error is small. However, the identification of B-B location was not distinct showing the growth of ice/snow particles needs to be improved.

5. Summary & Conclusion

- We evaluated WSM6 and WDM6 cloud microphysics schemes using AWS rainfall data, radar CFAD and time-height cross sections, and with the moisture profile for the summer 2011 mons oon and convective cases.

- **Monsoon Case:**

- WSM6 scheme has a negative bias - a tendency to simulate reflectivity much smaller than the r adar reflectivity below 5 km.

- WDM6 scheme has a positive bias - a tendency to simulate reflectivity greater than the radar, b ut is in better agreement with the observations.

➡ From the moisture profile, this tendency is due to WSM6 simulating too little raindrops (q_{rain}) compared to WDM6 below 5 km (0^{o}C isotherm layer), which is related to the lack of sedimen tation process of water in WSM6.

- **Convection Case:**

- Due to the phase error of location and timing, CFAD did not reveal any meaningful characteristics between WSM6 and WDM6, and there was an underestimate of precipitation.

➡ Both WSM6 and WDM6 have limitations in simulating summertime convective rain, and th ere exist a resolution dependency in simulating summer precipitation.

- This study shows the possibility of utilizing radar data to validate mesoscale model's output an d cloud microphysics schemes.

- There are many rooms for improvement of NWP model's temperature profile, hydrometeor types, and various precipitation aspects (timing, location, and intensity etc.) using radar data.

THANK YOU FOR LISTE NING!

Outline

- Introduction
- Methodology
- Selected Cases
- Preliminary Results
- Discussion
- Future Work

2.5 WRF Reflectivity Calculation

(Koch et al., 2008)

	Rain drops	Snow	Graupel
Shape	Spheres of constant density		
Density	$\rho_r = \rho_l$ = 1000 $kg\ m^{-3}$	ρ_s = 100 $kg\ m^{-3}$	ρ_g = 400 $kg\ m^{-3}$
Distribution	$N(D)=8\times10^{6}\times e^{-\lambda D}\ m^{-4}$	$N(D)=2\times10^{6}\times e^{-0.12T}\ m^{-4}$	$N(D)=4\times10^{6}\times e^{-\lambda D}\ m^{-4}$
Variable	qrain (q_r)	qsnow (q_s)	qgraup (q_g)

Calculation of Z_r for rain drops

$$Z_r = \Gamma(7) N_0 \lambda^{-7}$$

where,

$\Gamma(7)=720$

Γ : gamma function

Calculation of Z_i for ice particle

$$Z_i = \Gamma(7) N_0 \lambda^{-7} (\rho_s/\rho_l)^2 \alpha$$

$$\alpha=(\rho_l/\rho_i)^2 (|K|_i^2/|K|_l^2)=0.224$$

$\lambda=(\pi N_0 \rho_l/\rho_a q_r)^{1/4}$ for rain drops

$\lambda=(\pi N_0 \rho_i/\rho_a q_i)^{1/4}$ for ice particles

dielectric factor of ice : $|K|_i^2$ =0.176

dielectric factor of liquid water : $|K|_l^2$ = 0.930

ρ_a : density of dry air

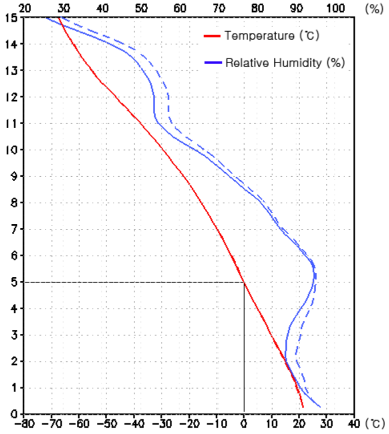
ρ_i : density of ice particles

q_i : snow or graupel mixing ratio

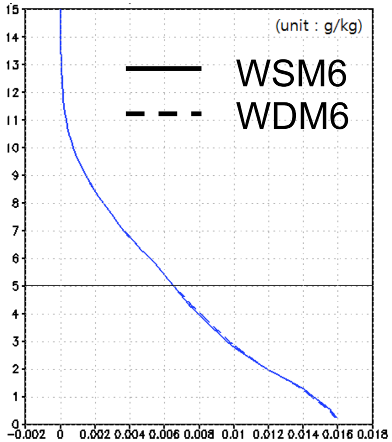
Case 1) KSN : Vertical Mean Profile

WRF

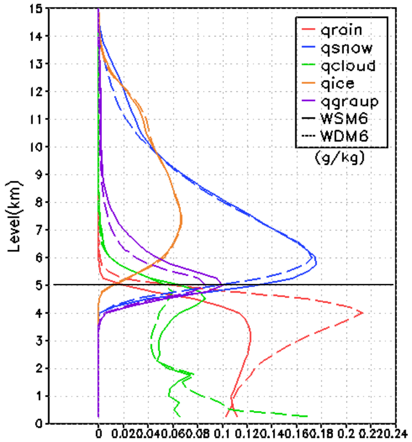
Temperature & Relative Humidity



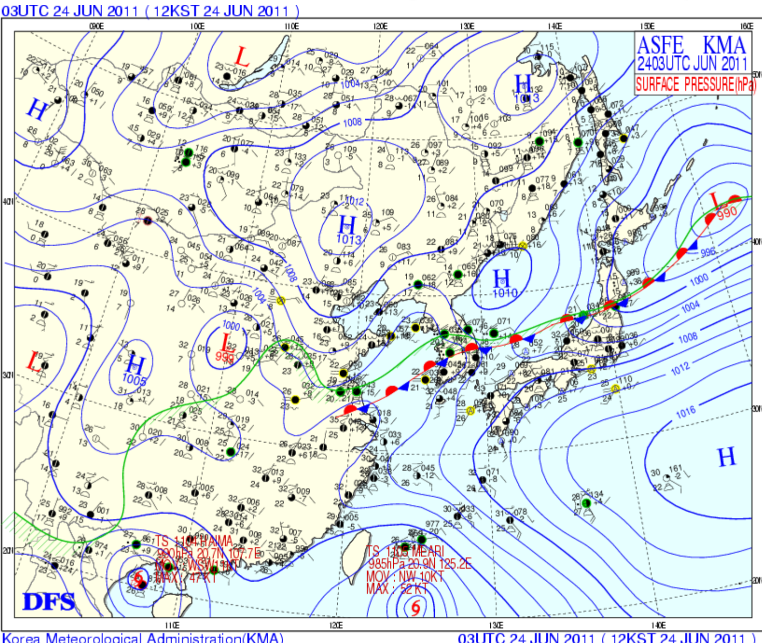
Q Vapor

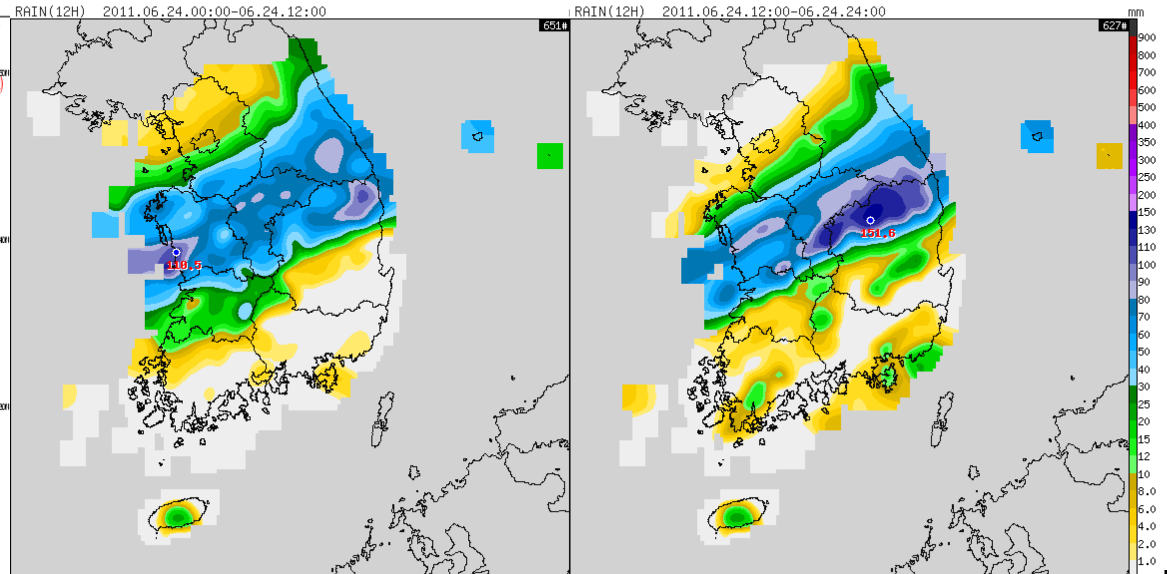


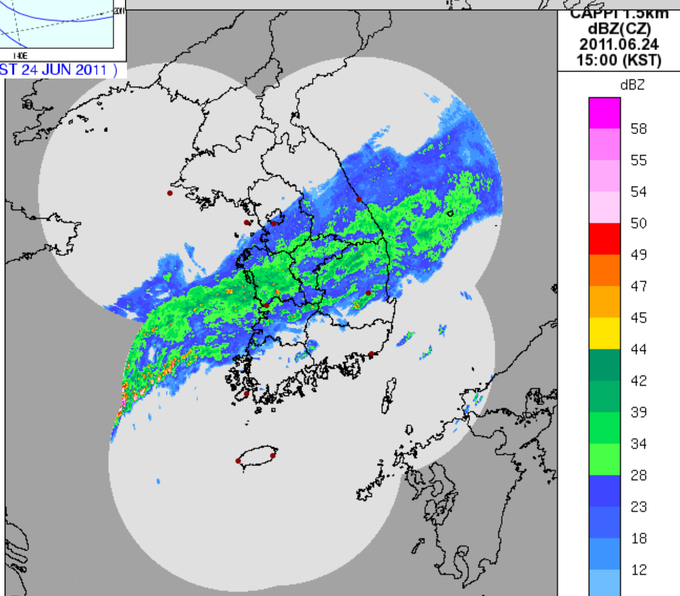
Hydrometeors

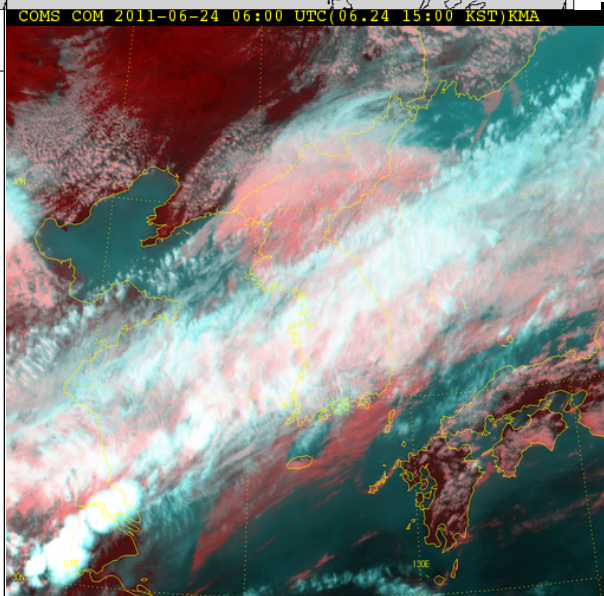


Case 1 : Changma Front (00KST 24 – 03KST 25 June 2011)

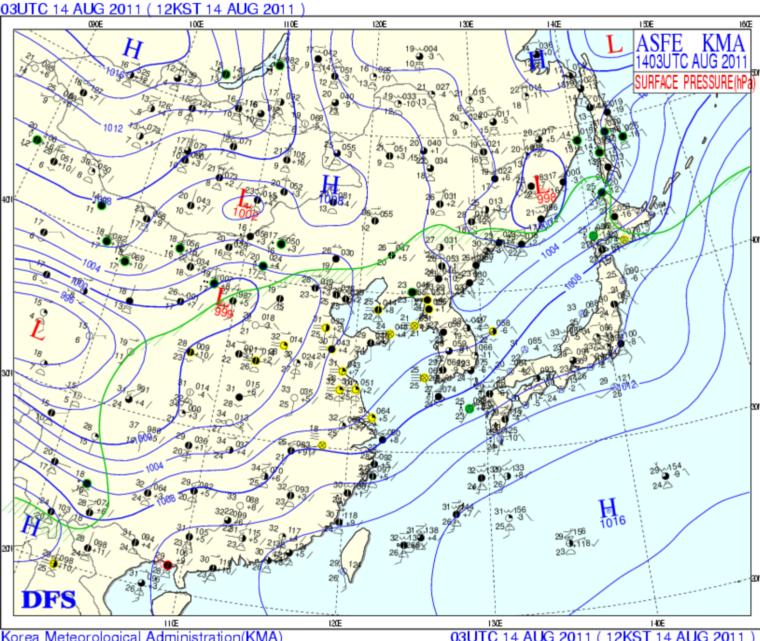


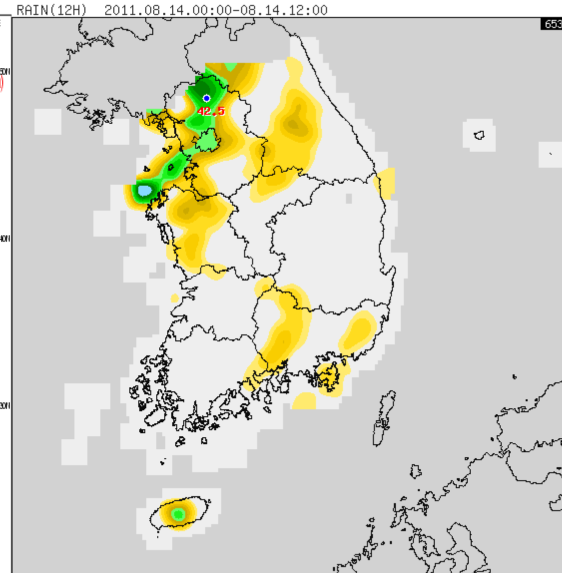


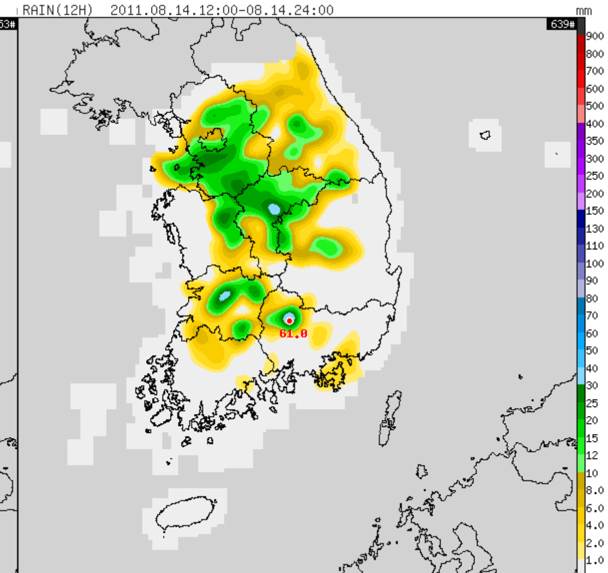


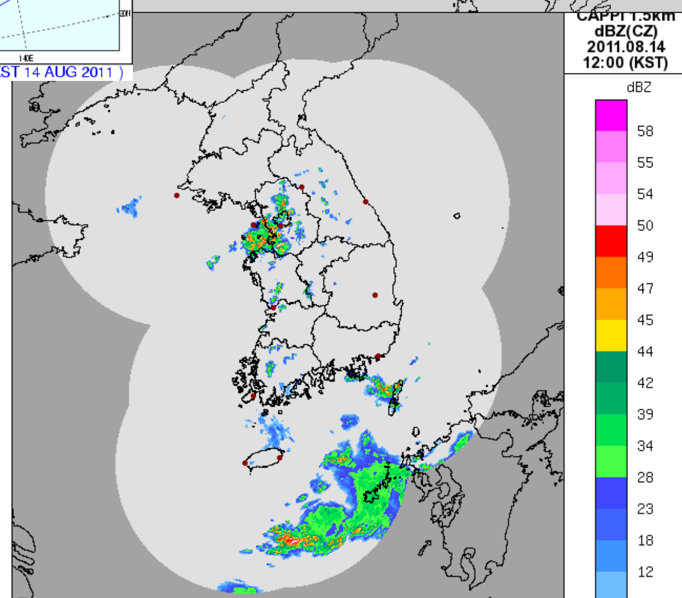


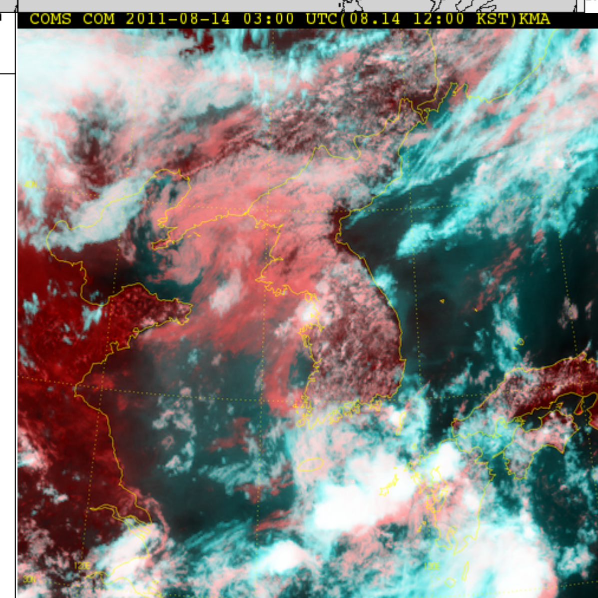
Case 2 : Scattered Convection (00KST 14 – 24KST August 2011)



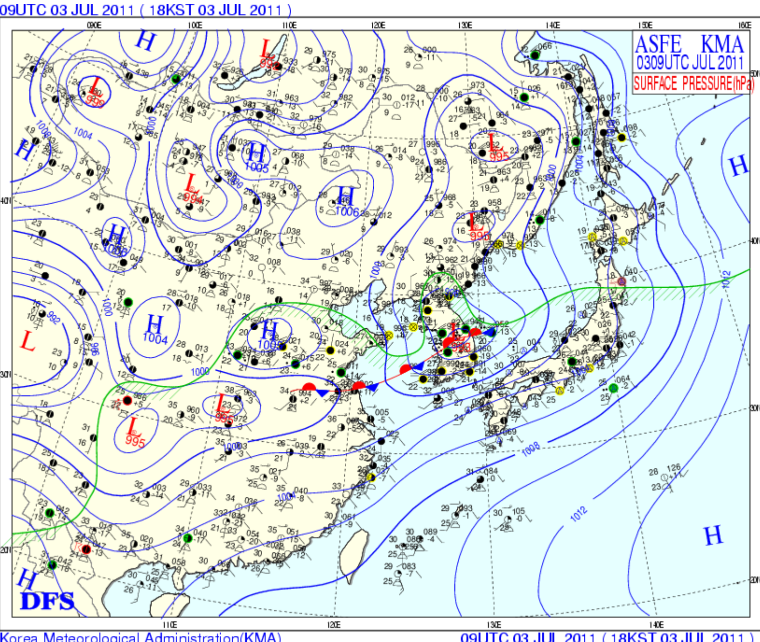


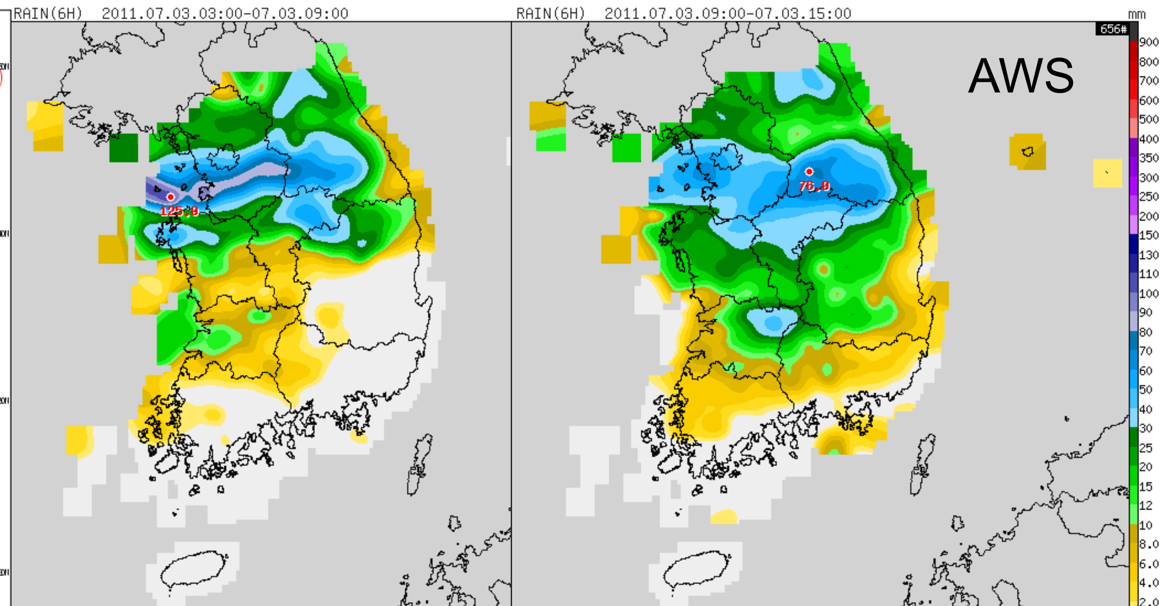


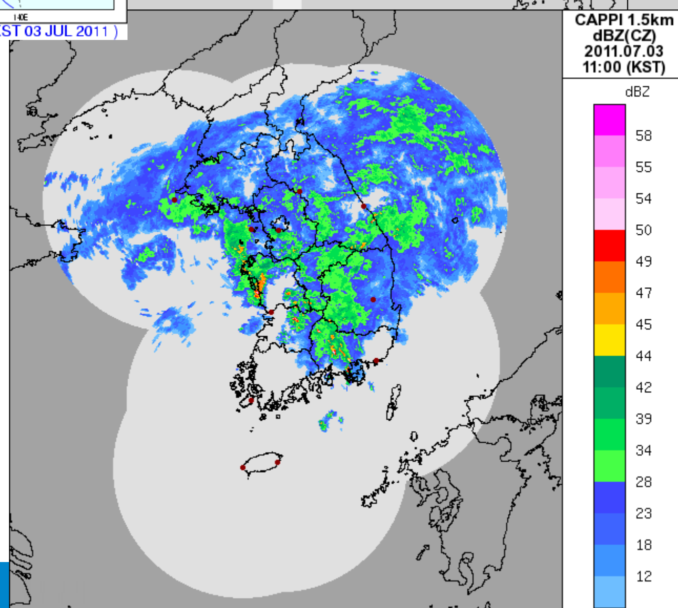


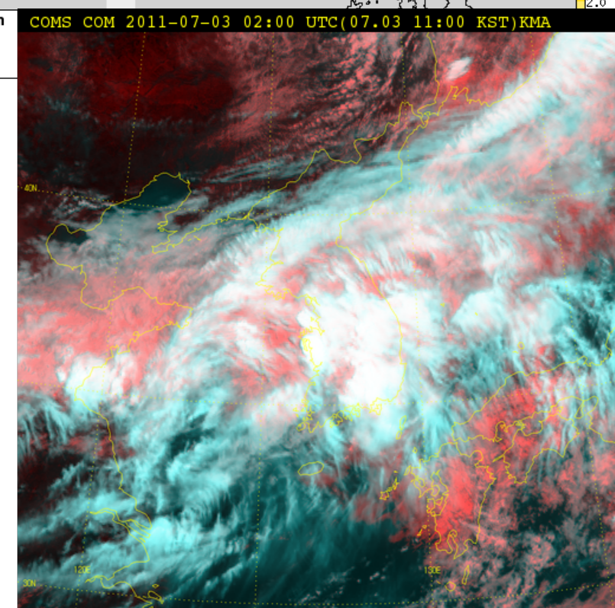


Case 3 : Changma Front (03KST 03 – 06KST 04 July 2011)

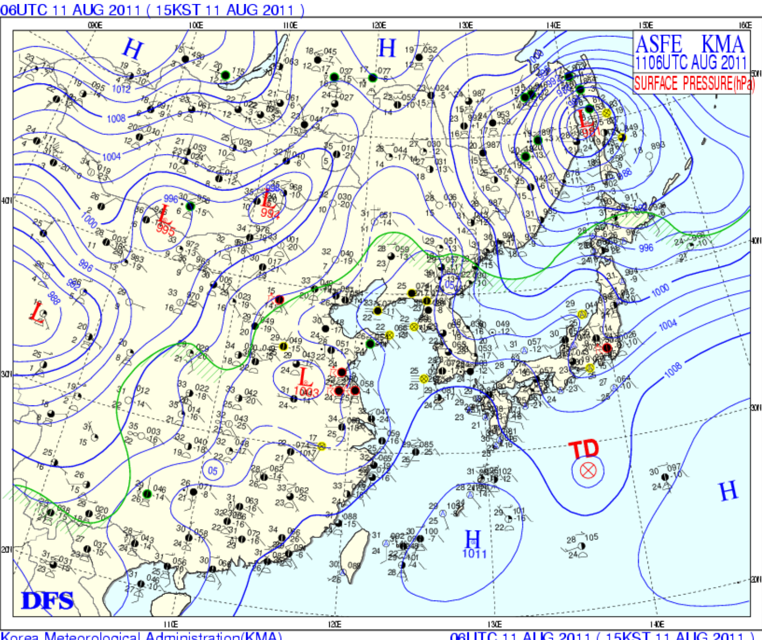


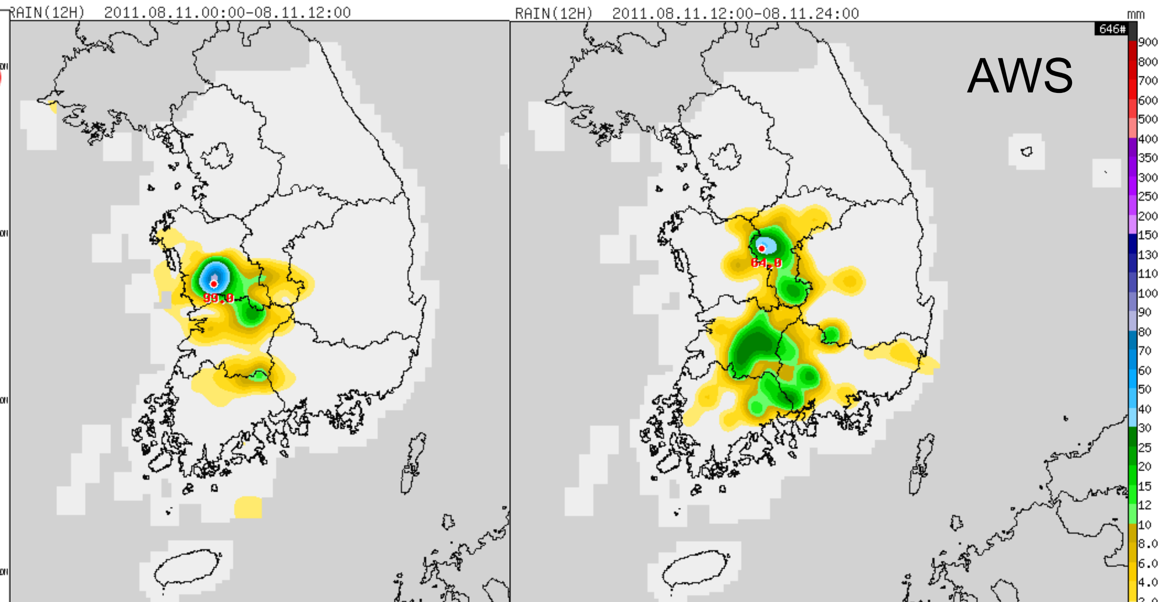


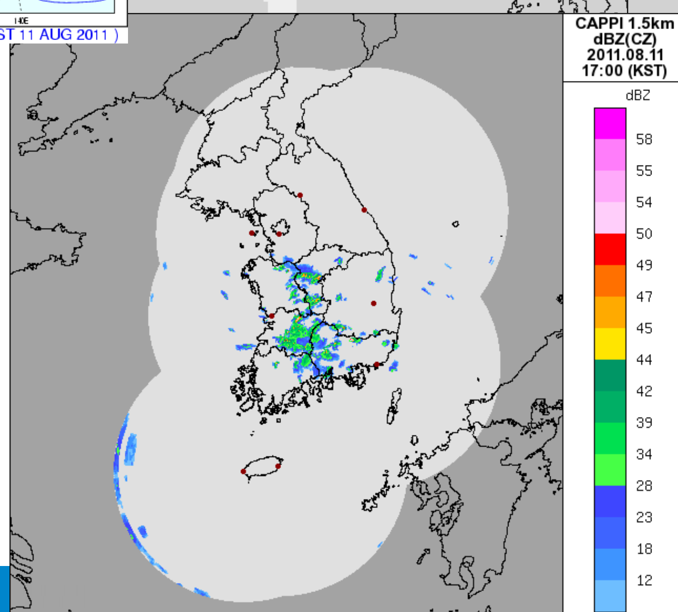


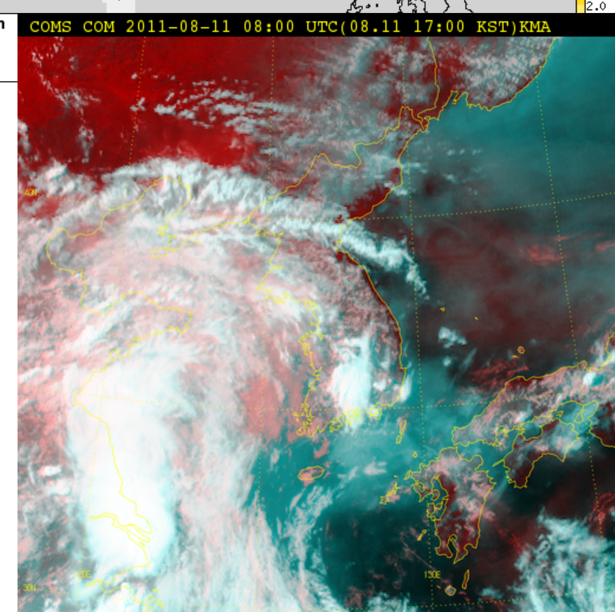


Case 4 : Scattered Convection (03KST 11 – 20KST 11 August 2011)









4. Melting Level Height of Radar vs. WSM6/WDM6

		CASE1	CASE2	CASE3	CASE4
GDK	Radar	4.7	5.0	5.1	
	WSM6	4.8	5.2	5.2	
	WDM6	4.8	5.2	5.2	
KSN	Radar	4.7	X	X	X
	WSM6	5.2	5.2	5.5	5.2
	WDM6	4.9	5.3	5.5	5.2
KWK	Radar	4.5	X	5.1	
	WSM6	4.9	5.2	5.2	
	WDM6	4.7	5.2	5.2	

- Both schemes systematically over estimate the location of the melting level when compared to radar observations.

5.2 Future Work

- Analyze additional cases
- Statistically evaluate WSM6/WDM6 M-P scheme
- Diagnose and improve M-P scheme to improve NWP
- Assimilate radar derived profile to NWP

2.5 WRF Model Configuration

Model	WRF v3.5
Cumulus parameterization	Kain-Fritsch
Microphysics	**WRF Single Moment 6-class (WSM6) WRF Double Moment 6-class (WDM6)**
Long-wave radiation	Rapid Radiative Transfer Model (RRTM)
Short-wave radiation	Dudhia
Surface-layer physics	Monin-Obukhov Similarity
Land surface	NOAH LSM
PBL	YSU scheme
Horizontal grid spacing	36km (D01) - 12 km (D02) - 4 km (D03)
Vertical level	**60 (top at 50 hPa)**
Initial & Boundary Conditions	**1°×1° FNL analysis fields obtained from EMC/NCEP**