2019 (2019.6.)

KIAPS

KOREA INSTITUTE OF ATMOSPHERIC PREDICTION SYSTEMS

Development of Bulk cloud microphysics schemes with prognostic hail in WRF

Soo Ya Bae[1], Song-You Hong[1], and W.-K. Tao[2]

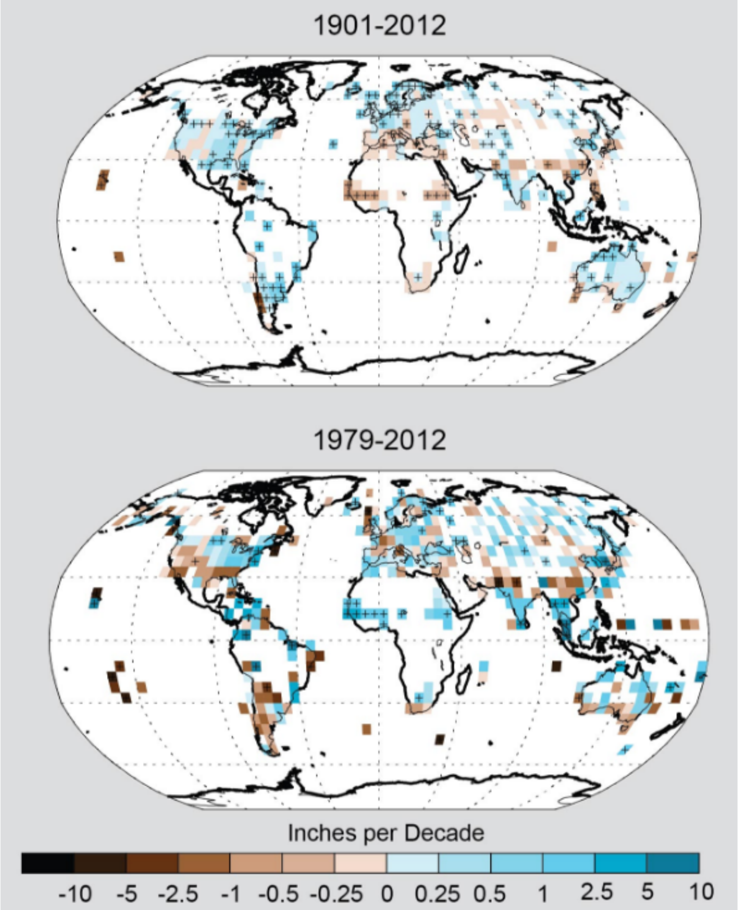
1Korea Institute of Atmospheric Systems (KIAPS)

2NASA/Goddard Space Flight Center, MD, USA

www.kiaps.org

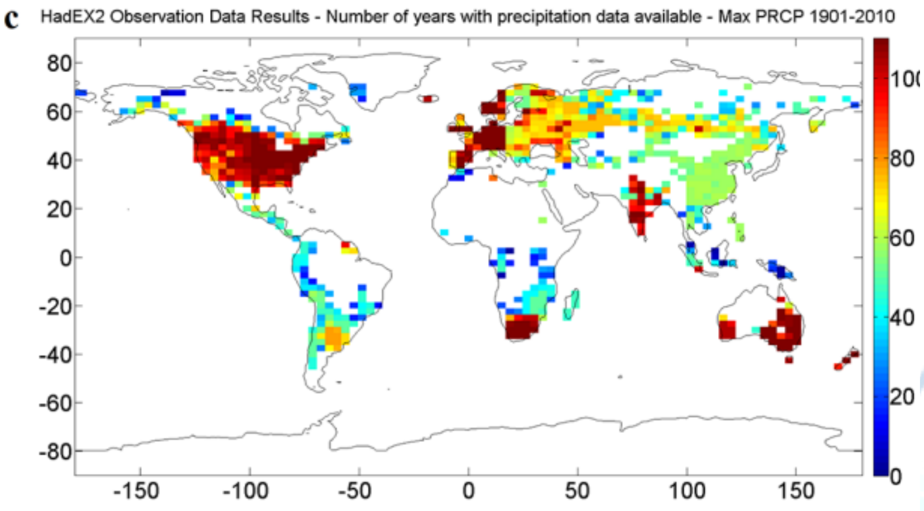
Background : OBS vs NWP

Annual precipitation trends (1901-2012/ 1979-2012)



[NOAA/NCDC]

No. of annual extreme precipitation records in HadEX2 (1901-2010)



[Asadieh and Krakauer, 2015]

- Frequency of extreme precipitation increased based on observations
- However, most of the models produce light precipitation (<10 mm day^{-1}) more often than observed, too few heavy precipitation events and too little precipitation in heavy events (>10 mm day^{-1}) (IPCC, 2007).

Background : Issues in WSM6

- Both hail and/or graupel can occur in real weather events simultaneously, therefore a 4-ICE scheme (cloud ice, snow, graupel, and hail) is required for real time forecasts.
  * severe local thunderstorms, mid-latitude squall lines, and tornadoes

- However, most of microphysics schemes are 3-ICE (cloud ice, snow, and graupel). A few 3-ICE scheme have the option to switch graupel to hail.

- WSM6 show systematic deficiencies, such as too much light precipitation (Shi et al. 2007),

- WSM6 shows an excessive amount of graupel compared to snow (Lin and Colle 2009)

- Dudhia et al. (2008) alleviated the problem of excessive graupel, but this scheme has remained a wider area of light precipitation and lower heavy precipitation (Han et al. 2013)

Bulk cloud microphysics scheme with hail processes

- Governing equation of hail

$$\frac{\partial Q_H}{\partial t} = \underbrace{-V \cdot \nabla_3 Q_H}_{\text{advection}} - \underbrace{\frac{Q_H}{\rho}\frac{\partial}{\partial z}(\rho V_H)}_{\text{sedimentation of hail}} + \underbrace{S_H}_{\text{sink and source of hail}}$$

- The slope of the distribution of hail ($\boldsymbol{\lambda_H}$)

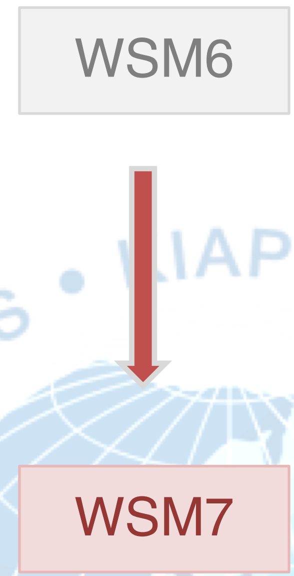
$$\lambda_H = \left(\frac{\pi \rho_H n_{0H}}{\rho Q_H}\right)^{0.25}$$

where, ρ_H: the density of hail in kg/m3
ρ: the density of air in kg/m3
n_{0H}: intercept parameter in m-4

- The mass-weighted mean terminal velocity ($\boldsymbol{V_H}$)

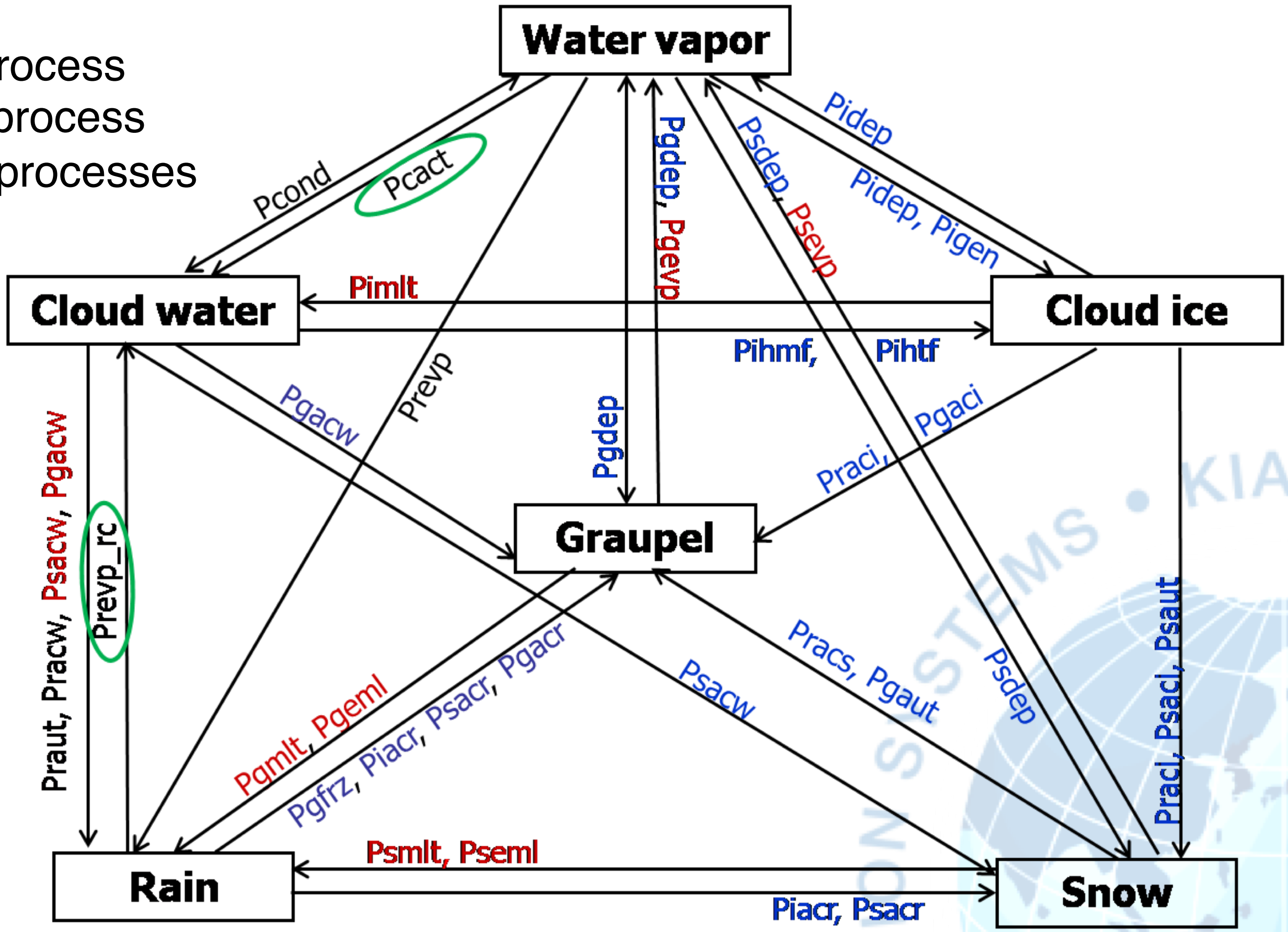
$$V_H = a_H {D_H}^{b_H} \left(\frac{\rho_0}{\rho}\right)^{0.5}$$

where, a_H, b_H: empirical formula
D_H: diameter of hail



Microphysics in WSM6 (Hong and Lim 2006)

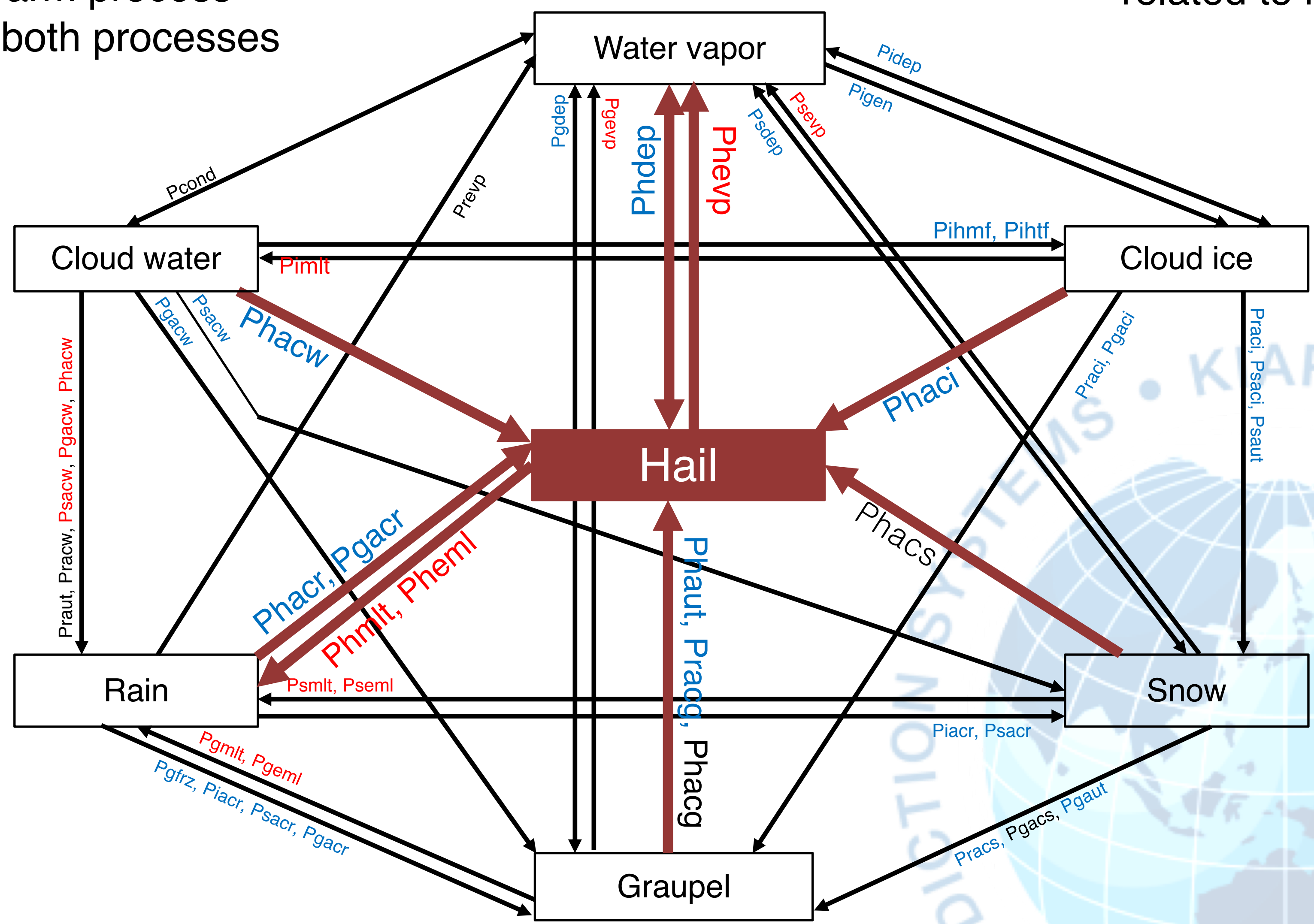
Blue: cold process
Red: warm process
Black: both processes



Microphysics in WSM7 (Bae et al. 2018)

Blue: cold process
Red: warm process
Black: both processes

Processes related to hail



Experimental setup

- Model: WRF v3.7.1
(A reference model of KIM, Korean Integrated Model, Hong et al. 2018)

- [2D idealized squall-line test]

time & domain	
run hour	7 hr
Time step	5 sec
Resolution	1 km, 601 point Top ~ 20 km, 80 levels

	unit	graupel	hail
n0	m^{-4}	4e6	4e4
ρ_X	kg/m^3	500	912
Terminal *velocoty*			
a_X		330	285
b_X		0.8	0.8

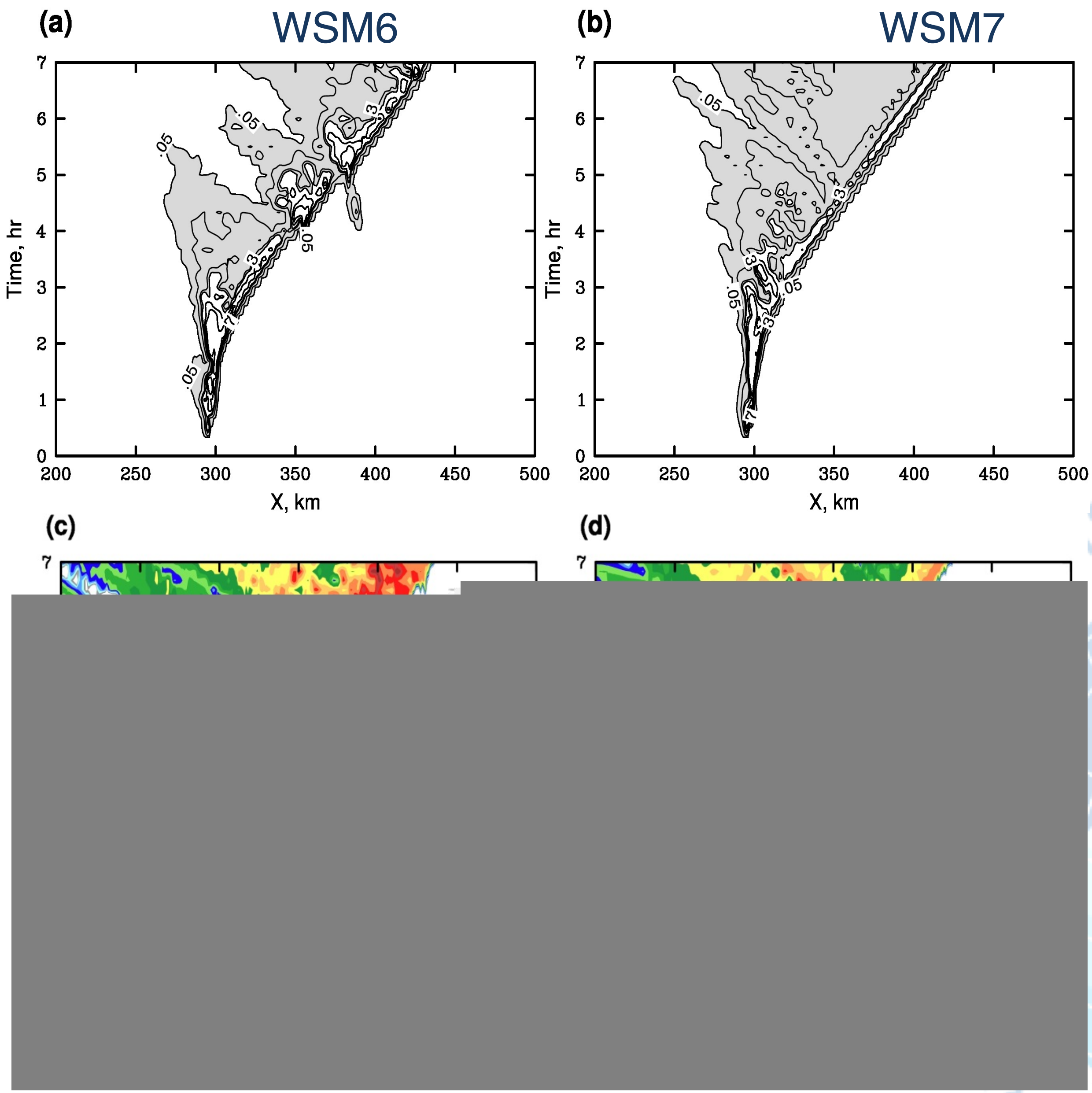
- Experiment name

Name	Description
WSM6	Simulation with WSM6 (3-ICE)
WSM6_H	Simulation with WSM6 switched to hail (3-ICE)
WSM7	Simulation with the WSM7 (4-ICE)

The hovmöller plot of rainfall rate and total reflectivity from WSM6 and WSM7

Rainfall rate

Reflectivity



WSM7 shows a weakened precipitation activities at the front of the leading edge.

Intensity of reflectivity is weaker with separate areas of moderate intensity in WSM7

KIAPS

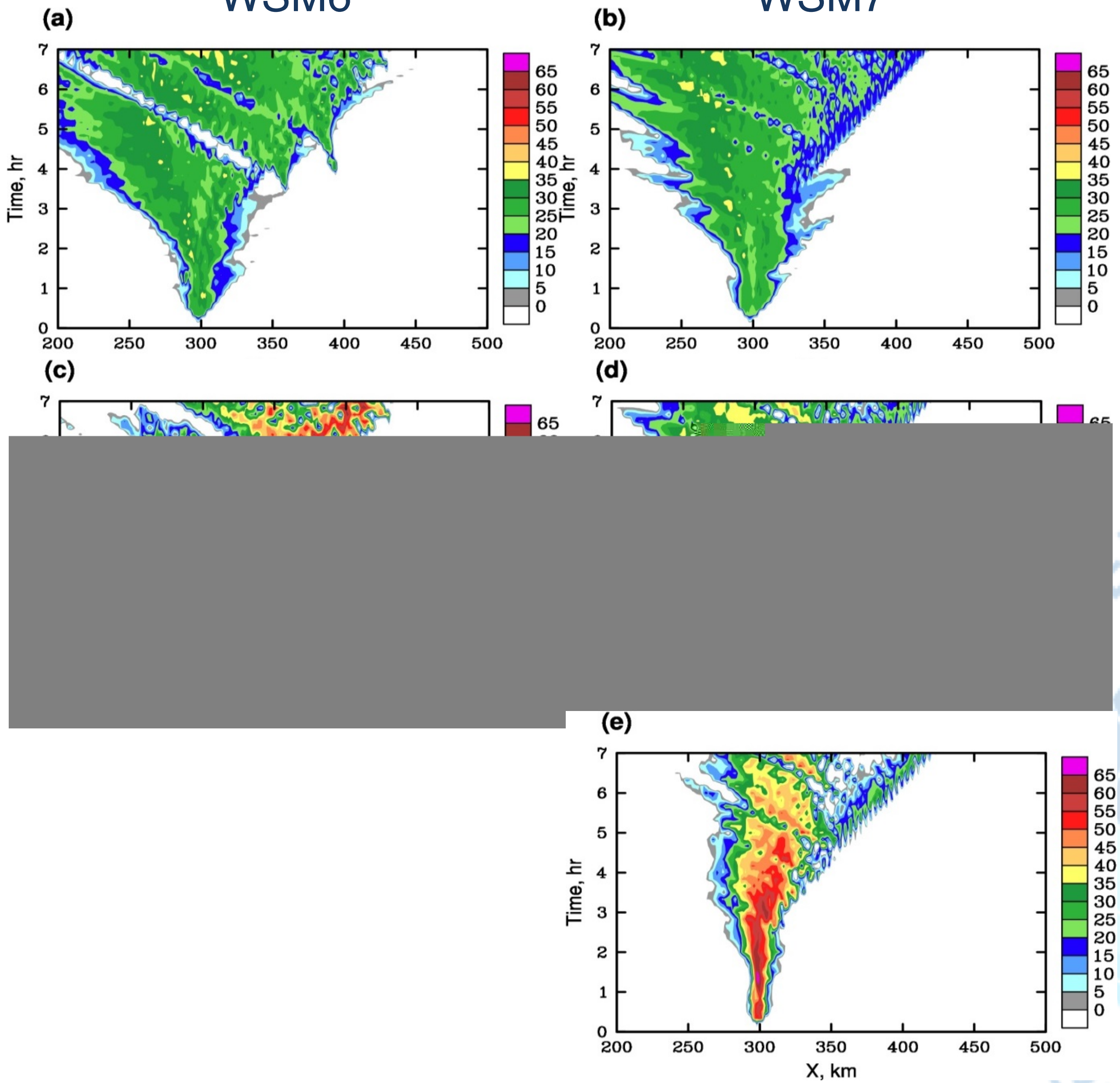
The hovmöller plot of maximum reflectivity of hydrometeors for WSM6 and WSM7

WSM6 | WSM7

snow

graupel

hail



Reflectivity is led by graupel (WSM6) and hail (WSM7)

For snow, intensity in the leading edge is weakened with time

Narrower trailing snow is due to enhanced accretion of snow by hail

Graupel evolves continuously

Mixing ratio of hydrometeors and process rate for WSM6 and WSM7

(average for 0-4 hr and 280-350 km)

- Differences in mixing ratios of hydrometeors

1) Graupel decreases in WSM7, with the compensation of hail but its maximum at lower altitudes
2) Weakened Pgacs increases snow aloft
3) Rain decreases due to reduction of sum of qg and qh at the melting level, which is compensated by falling hail

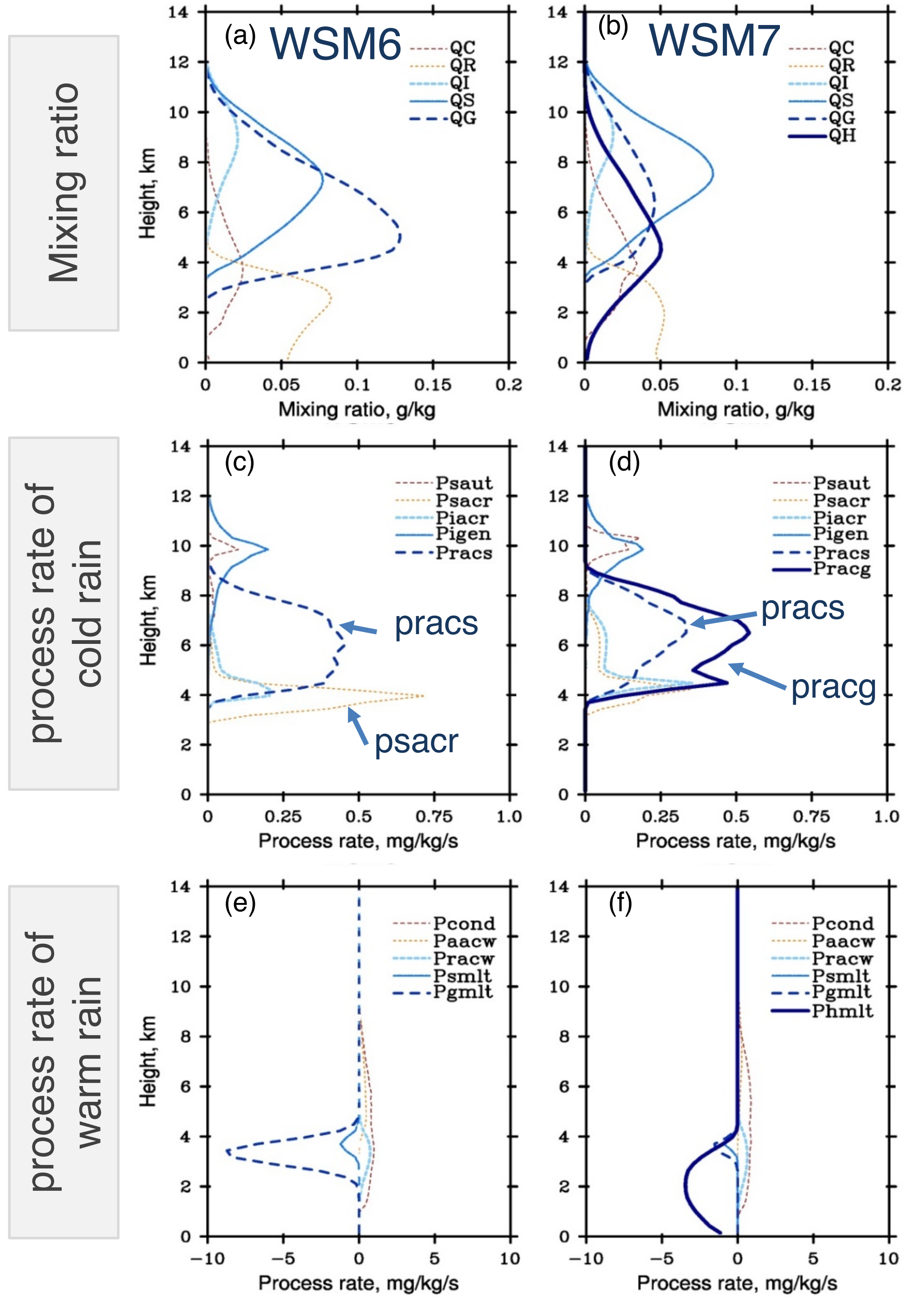
- Main processes

  1) cold processes

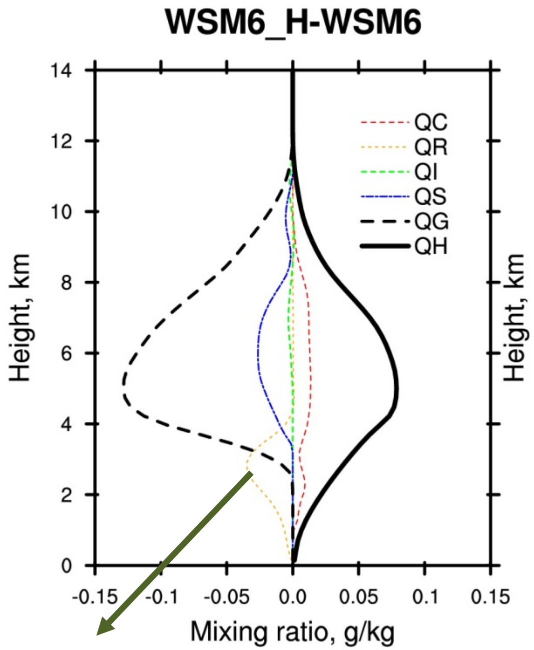
  - WSM6 : accretion related to snow
  - WSM7 : accretion of rain by snow and graupel

  2) warm processes

  - WSM6: melting of graupel
  - WSM7: melting of hail



Impact of hail or graupel specicies : WSM6 vs. WSM6_H



pgmlt in WSM6 > phmlt in WSM6_H
➔ QR decreases around melting level.

	unit	graupel	Hail	Hail/ **graupel**
n0	m^{-4}	4e6	4e4	1/100
ρ	kg/m^3	500	912	
λ_X	m^{-4}	1583	545	
$\mathbf{1/\lambda_X}$		6.3e-4	1.8e-3	2.91
V	$m\ s^{-1}$	2.7	5.2	

intercept parameter (n0) ↓

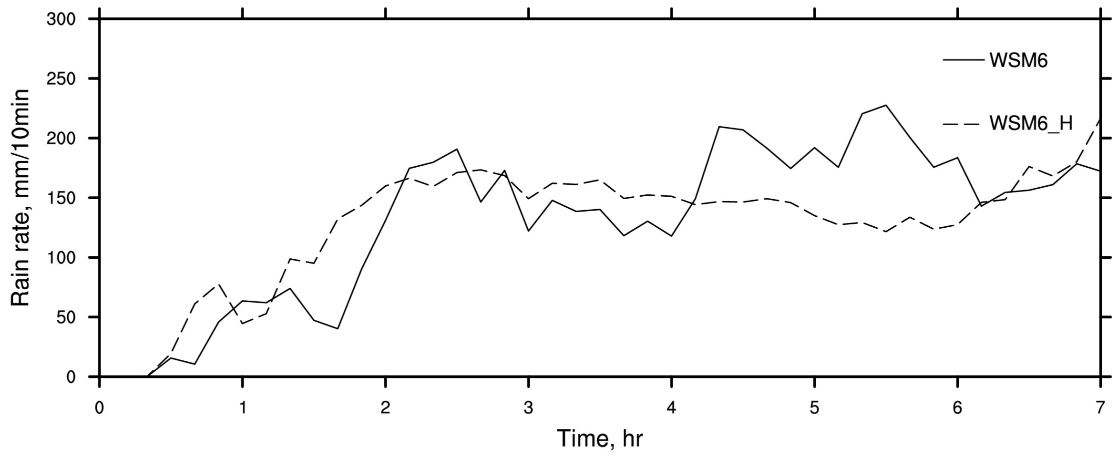
Slope parameter (λ) ↓

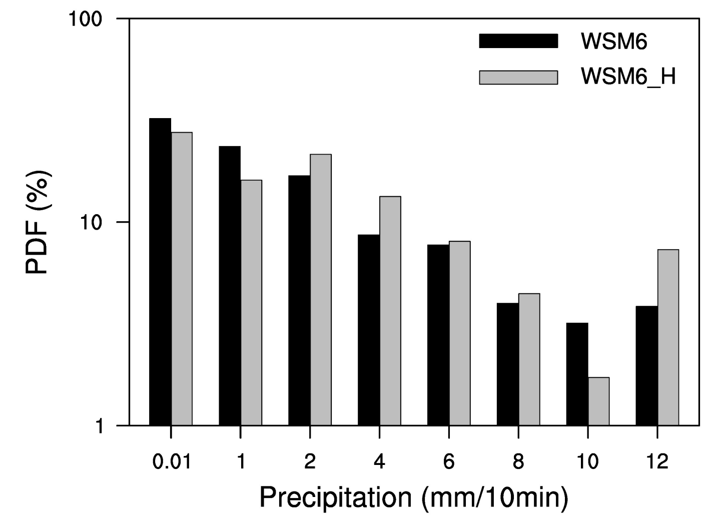
Process rate (Pr) $=f(\frac{1}{\lambda}, n0)$ → Pr ↓

* pgaci, pgacs = f(n0g or n0h)
pgaci: accretion of cloud ice by graupel or hail
pgacs: accretion of snow by graupel or hail

Decreased QG in WSM6 > Increased QH in WSM6_H

Comparison of time-series and PDFs of precipitations between WSM6 and WSM6_H (hail over graupel species)

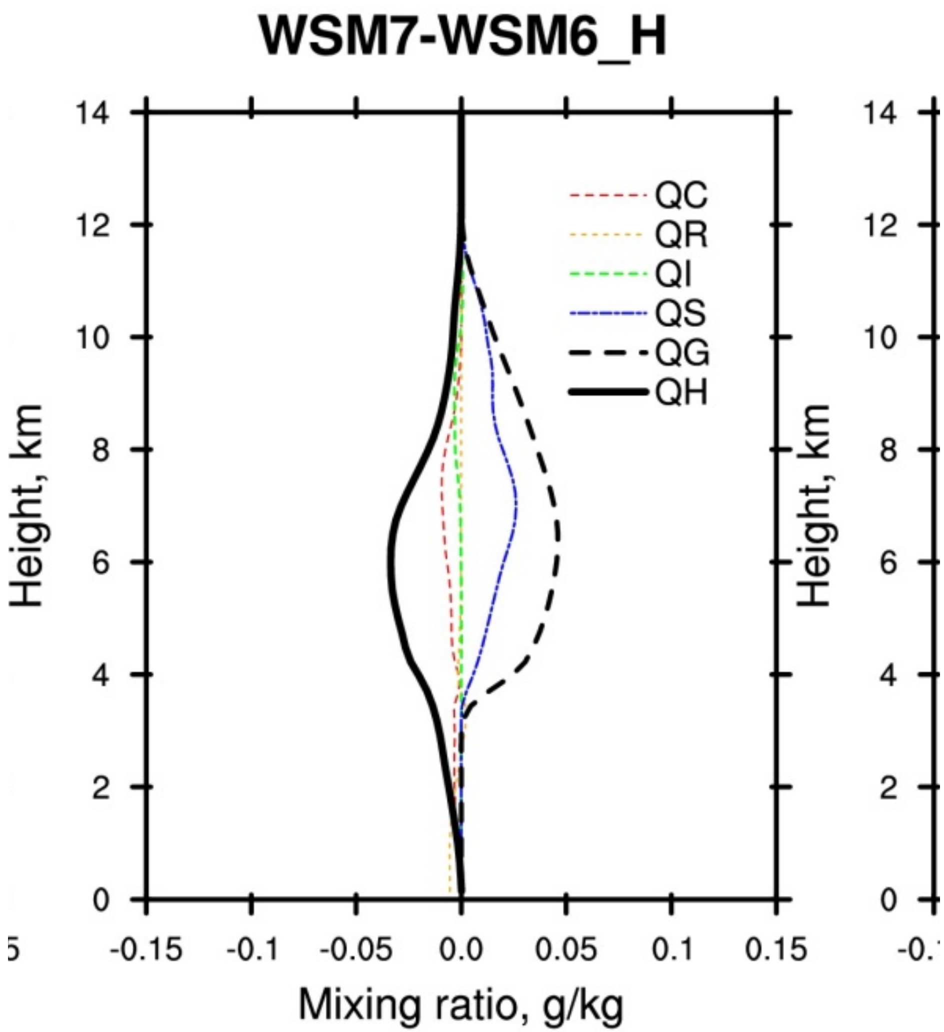




intercept parameter (n0) ↓		Density (ρ_x) ↑
Slope parameter (λ) ↓	>	Slope parameter (λ) ↑
Terminal velocity (V) ↑		Terminal velocity (V) ↓

Faster sedimentation
Enhance heavier precipitation

Impact of hail-related processes



Added hail processes

QH ↓ and QG ↑

Because hail in WSM6_H is divided to graupel and hail in WSM7.

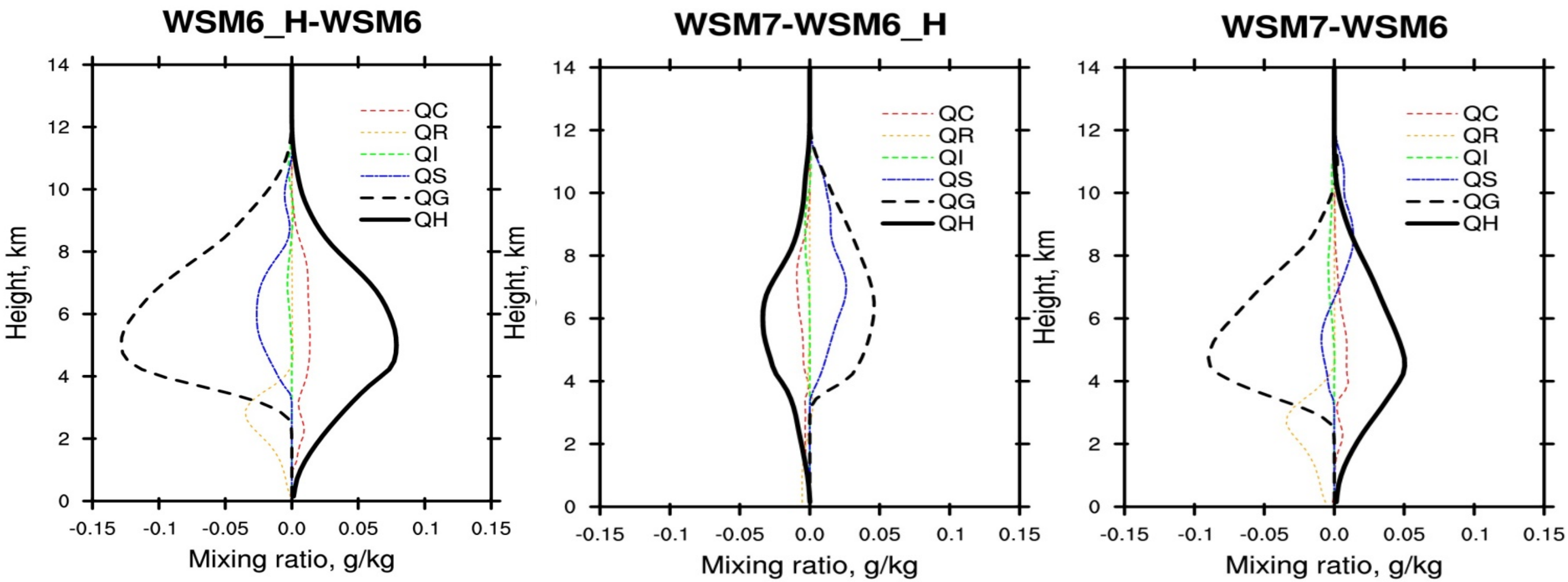
Owing to decreased QH, accretion of snow by hail is less likely to occur

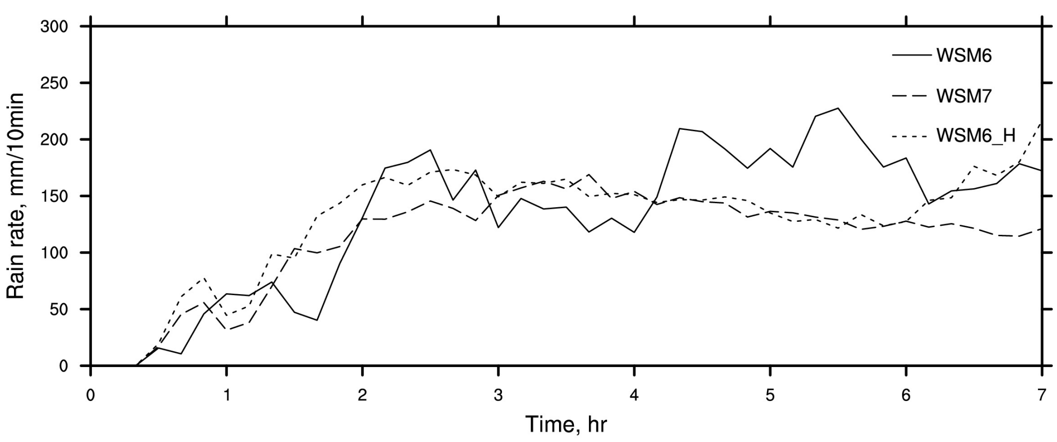
Increased QS and QG lead to more aggregation with cloud water

QS ↑

QC ↓

A summary : 2D idealized tests





Overall impact on vertical distribution is governed by the hail species itself (parameters), but with suppressed hail activities due to microphysics related to hail

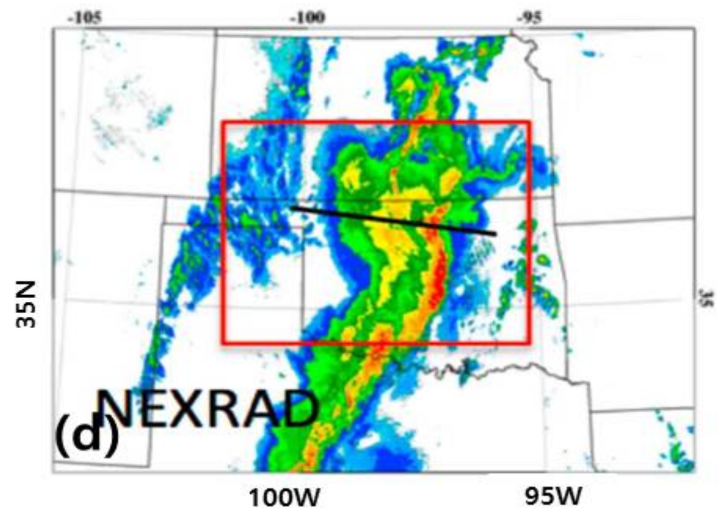
[3D real case]

- Model: WRF v3.7.1 (reference model of KIAPS)

time & domain	
Initial time	00 UTC 20 May, 2011
run hour	36 hr
Time step	18-6-2 sec
Resolution	9-3-1 km, Top ~ 50 hPa, 61 levels

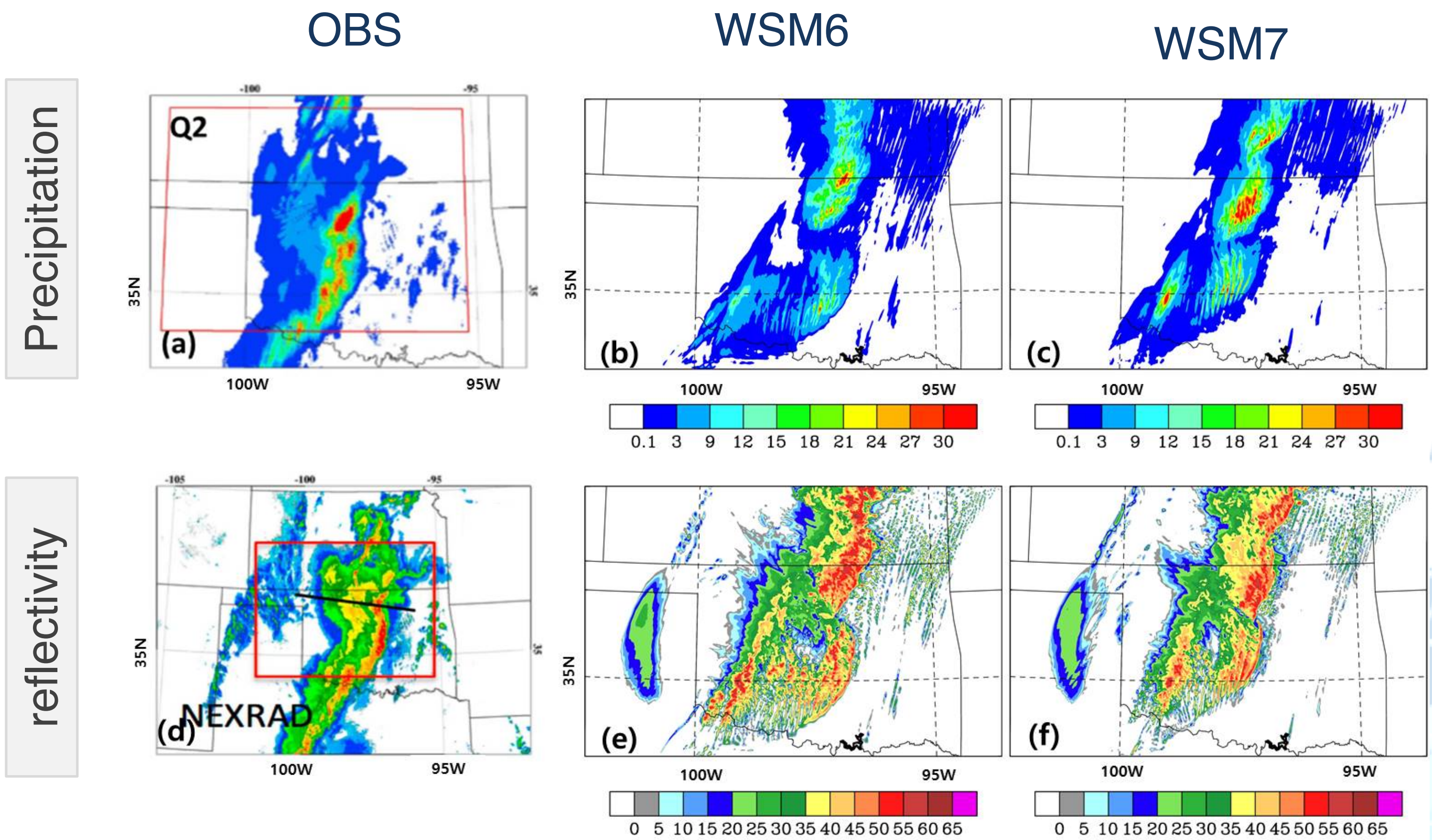
- Experiment

Name	Description
WSM6	Simulation with the WSM6
WSM7	Simulation with the WSM7



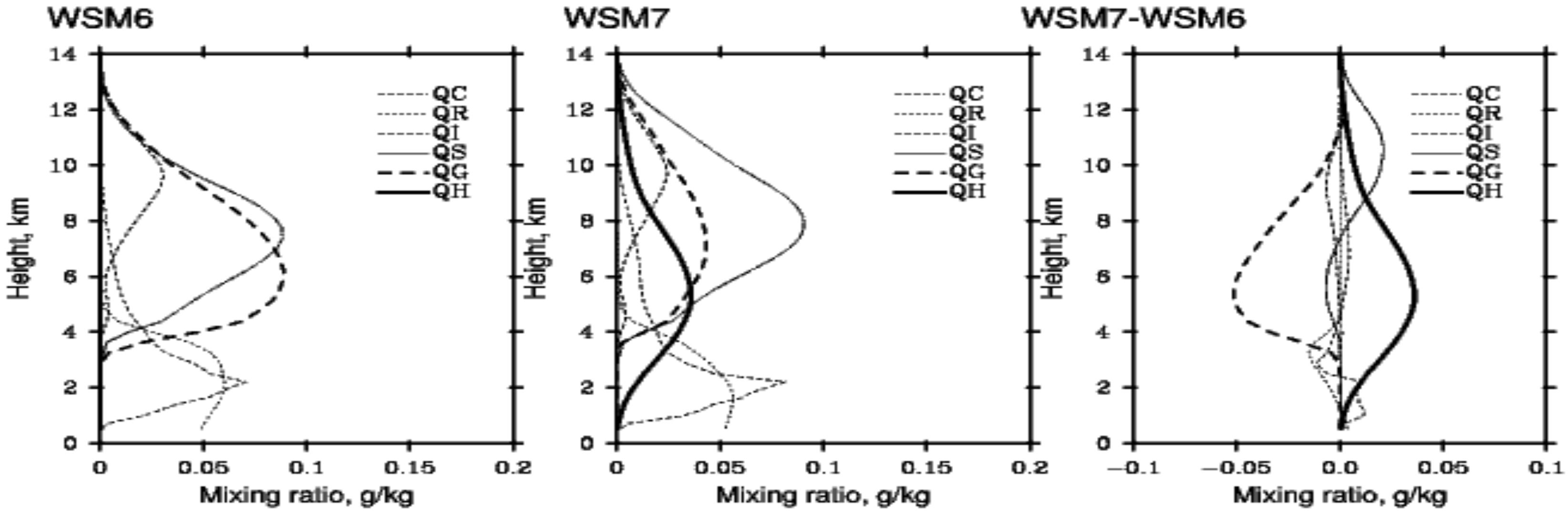
10 UTC on 20 May 2011
(Tao et al. 2016)

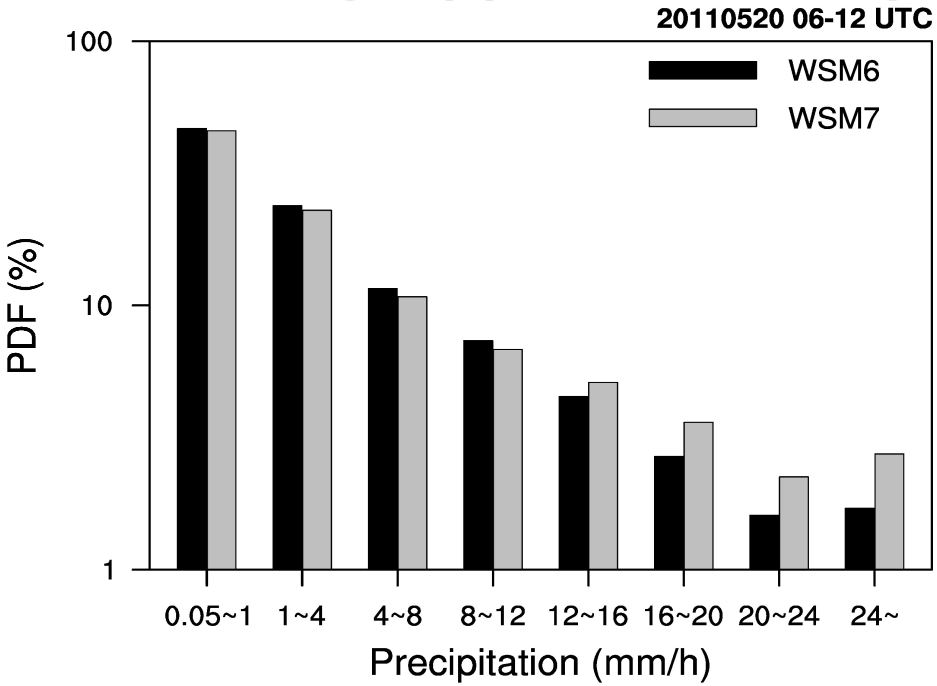
1-hr accumulated precipitation and maximum reflectivity at 10 UTC on 20 May 2011



WSM7 enhances convective activities in the leading edge of the squall line, whereas they are suppressed in the trailing stratiform region

Hydrometeors and precipitation rate





Overall impact is in line with that from 2D experiments, but a more robust increase of heavier precipitation

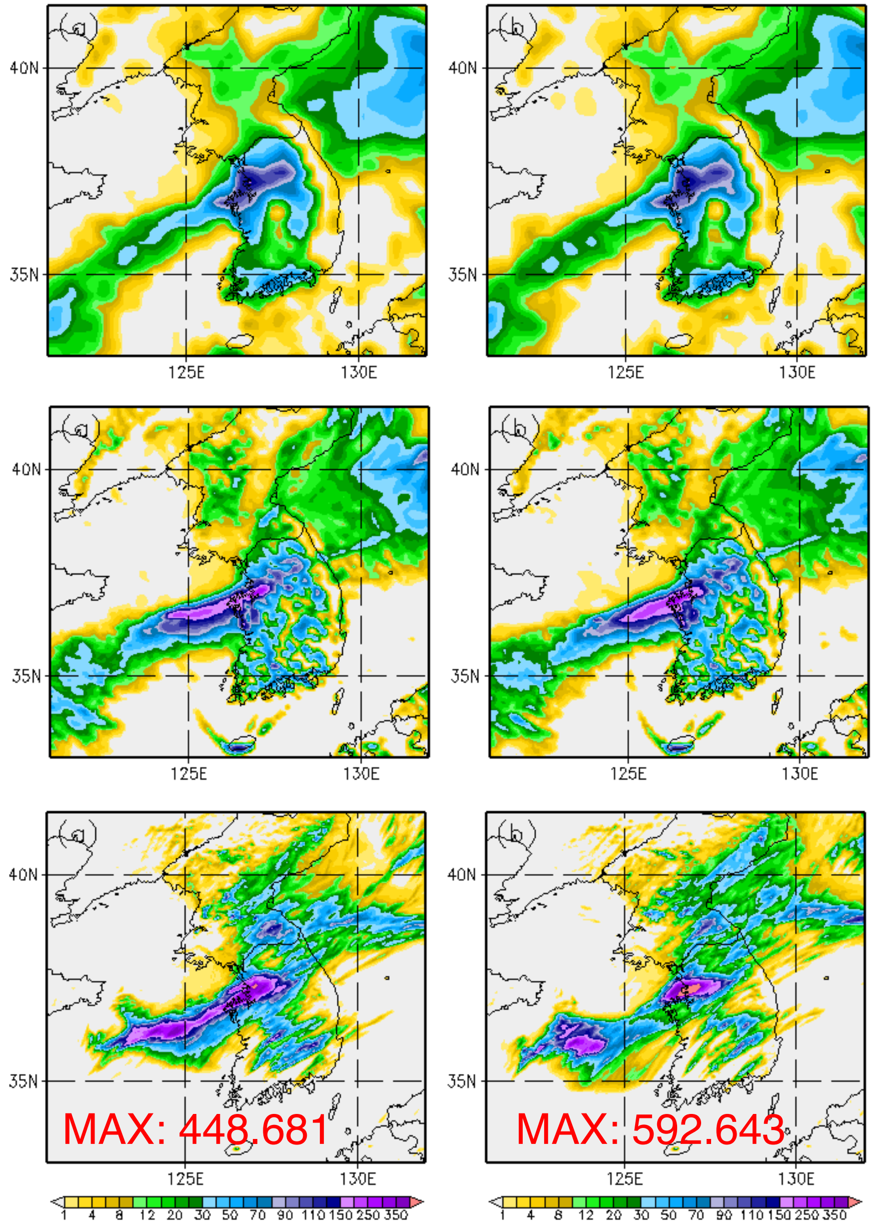
The 24-hr accumulated precipitation for heavy rainfall case

WSM6 | WSM7

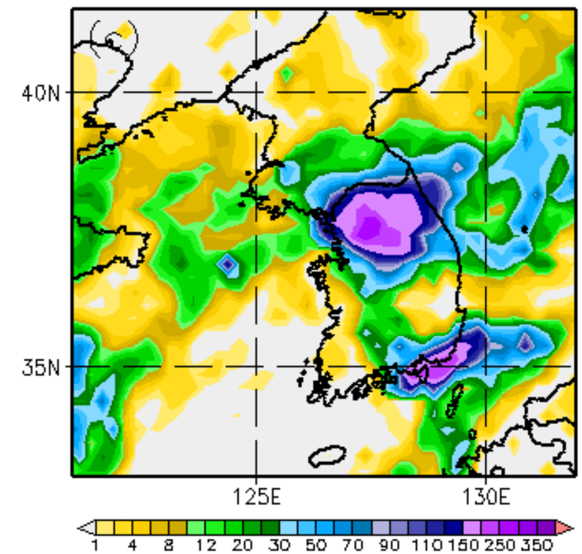
27 km

9 km

3 km



OBS (TMPA)



Impact is significant at higher resolutions.

KIAPS

Thank you for your attention .....!

- WDM7 is also available
- Reference : Bae, Hong, and Tao
  (2018, Asia-Pac. J. Atmos. Sci.)

Recommendations, in particular, grid size less than 5 km

WSM6 ➔ WSM7, WDM6➔ WDM7

YSU PBL ➔ SHIN-HONG PBL

참고

HAIL 절편에 대한 민감도 실험

Hail의 절편에 대한 민감도 실험: Hovmöller plot and timeseries of precipitation rate

n0h: intercept parameter of hail

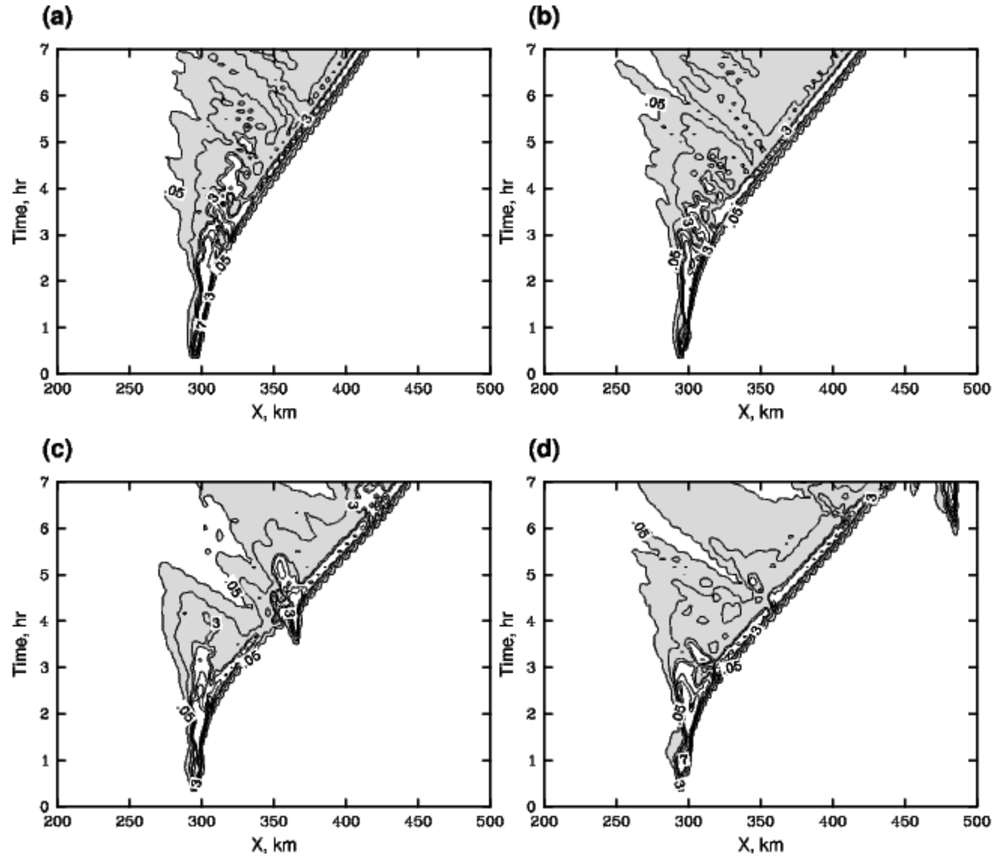
n0h이 커질수록
- hail의 크기가 작아짐
- slope parameter 증가

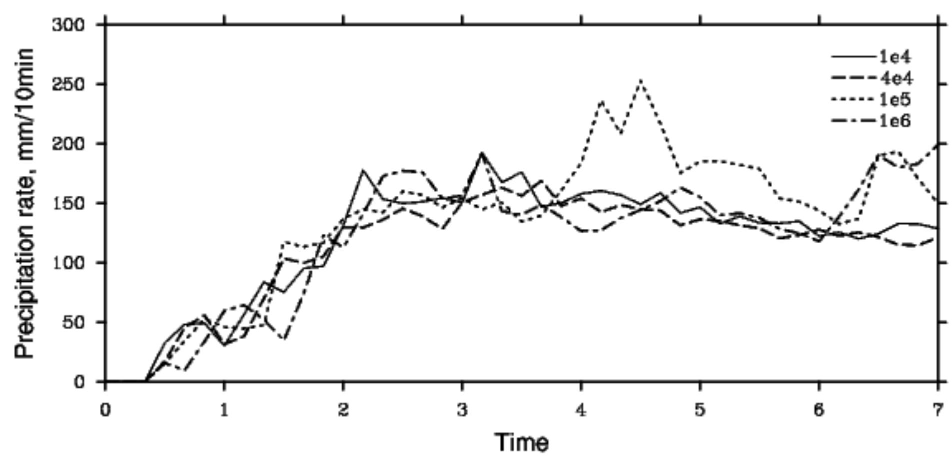
  $\lambda = \left(\frac{\pi \rho_h n0h}{Q_h \rho}\right)^{0.25}$
- process rate=$f(\frac{1}{\lambda}, n0h)$

  ➔ hail 관련 과정의 변화율 증가
  (∵ rslope의 변화정도 << n0h 변화정도)

민감도 실험
- org: 4e4

		n0h
large hail	(a)	1e4
Moderate	(b)	4e4
small	(c)	1e5
GSFC	(d)	1e6





Hail의 절편에 대한 민감도 실험: timeseries of QS, QG, and QH

n0h: intercept parameter of hail

n0h이 커질수록
- hail의 크기가 큼
- slope parameter 증가

$$\lambda = \left(\frac{\pi \rho_h n0h}{Q_h \rho}\right)^{0.25}$$

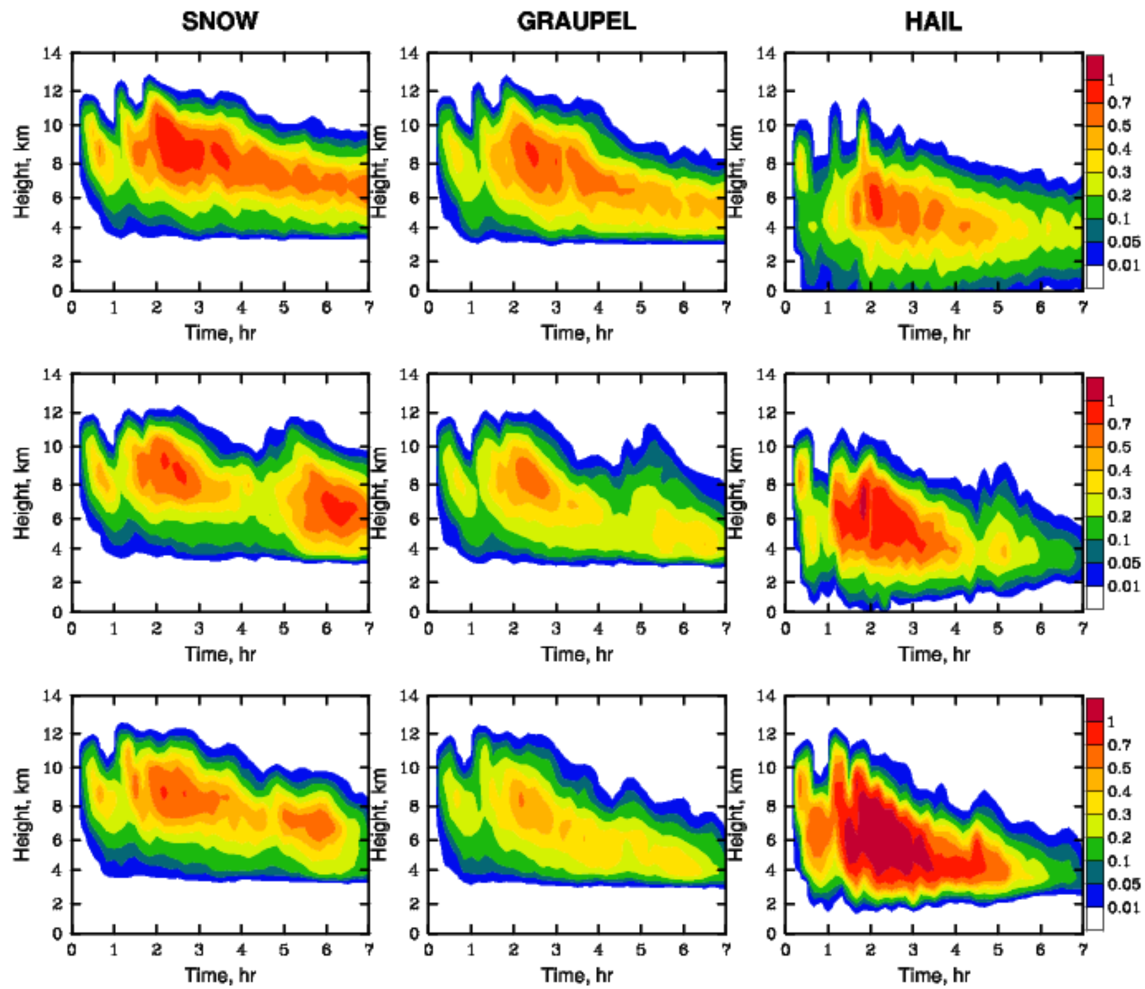
- process rate=$f(\frac{1}{\lambda}, n0h)$

➔ hail 관련 과정의 변화율 증가
(∵ rslope의 변화정도
<< n0h 변화정도)

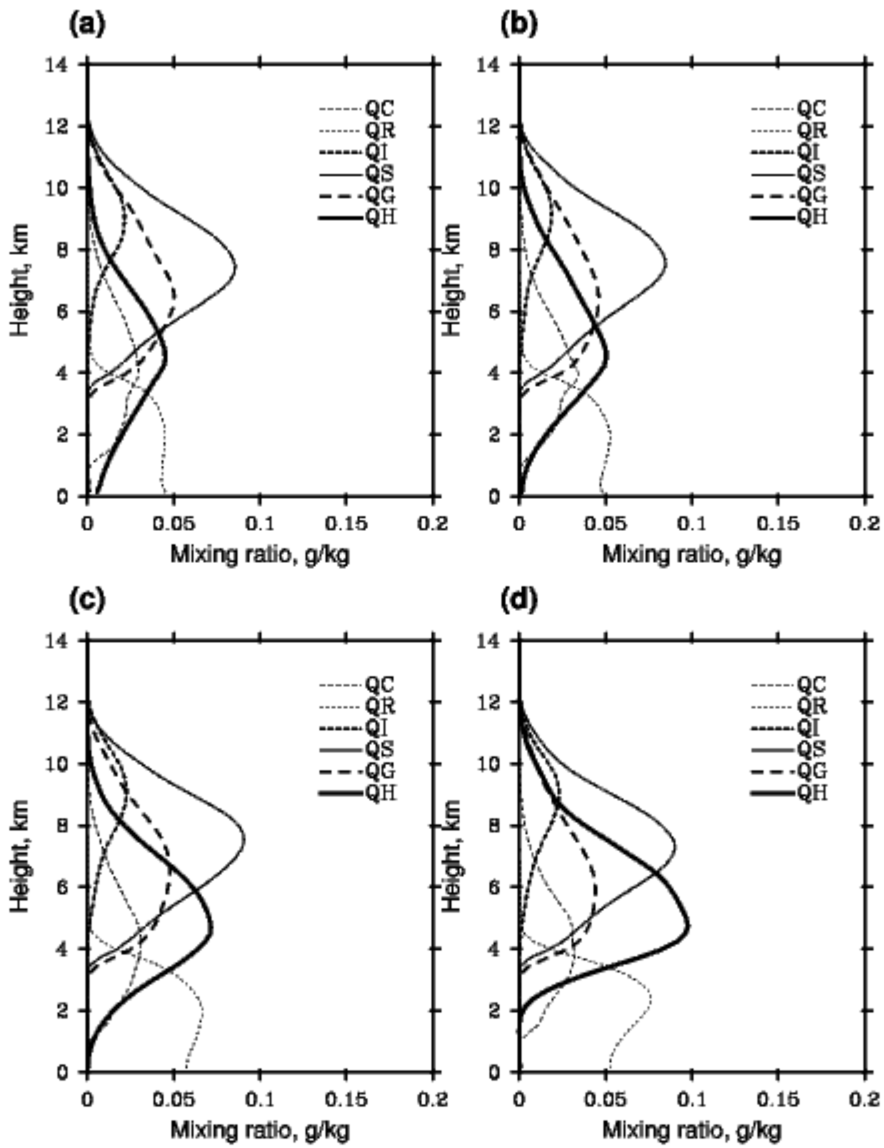
민감도 실험
- org: 4e4

	n0h
Top	1e4
Middle	1e5
bottom	1e6

- n0h 증가함에 따라
snow, graupel → hail로의 전환율 증가
hail 생성 위치 상승
대체적으로 강한 강수 증가



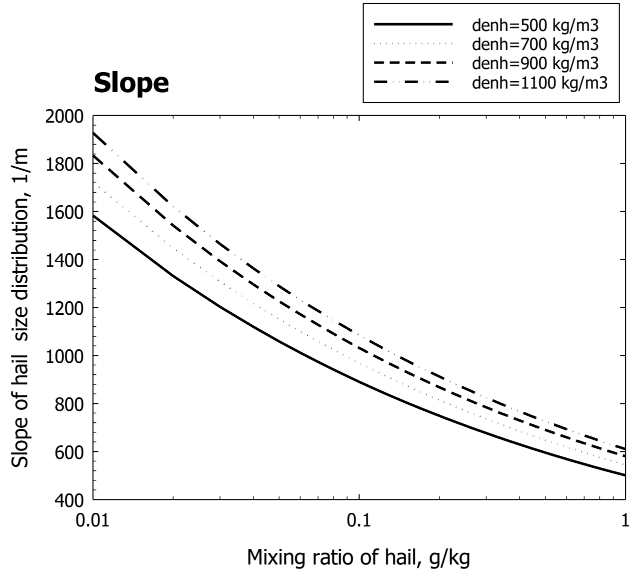
Hail의 절편에 대한 민감도 실험: 수상들의 수직분포



n0h 증가함에 따라,

Rain: 2-4 km의 QR 증가
Hail: QH 증가. 상층부에서 만들어지는 hail 증가

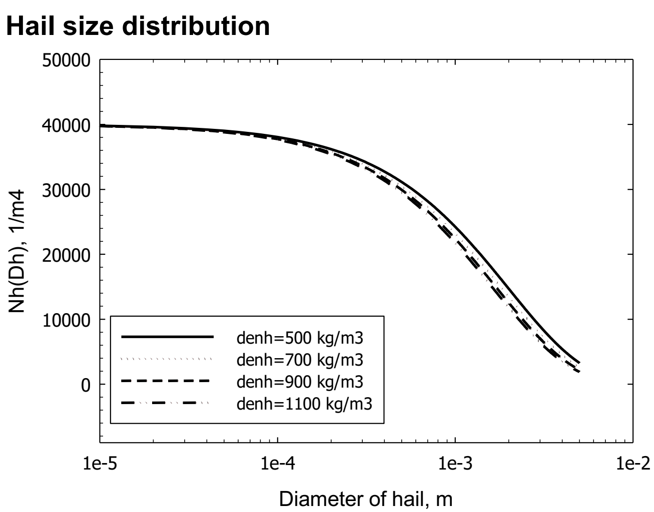
HAIL 밀도에 대한 분석

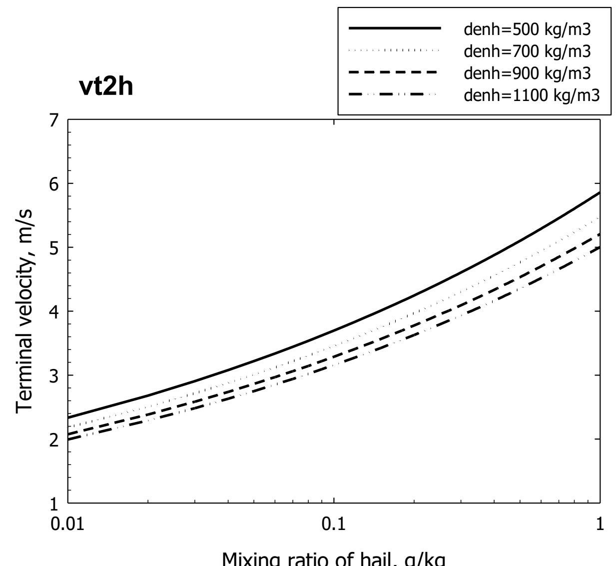


Density of hail (denh) ↑

Slope parameter ↑
(Nh 감소=N0h/lh)

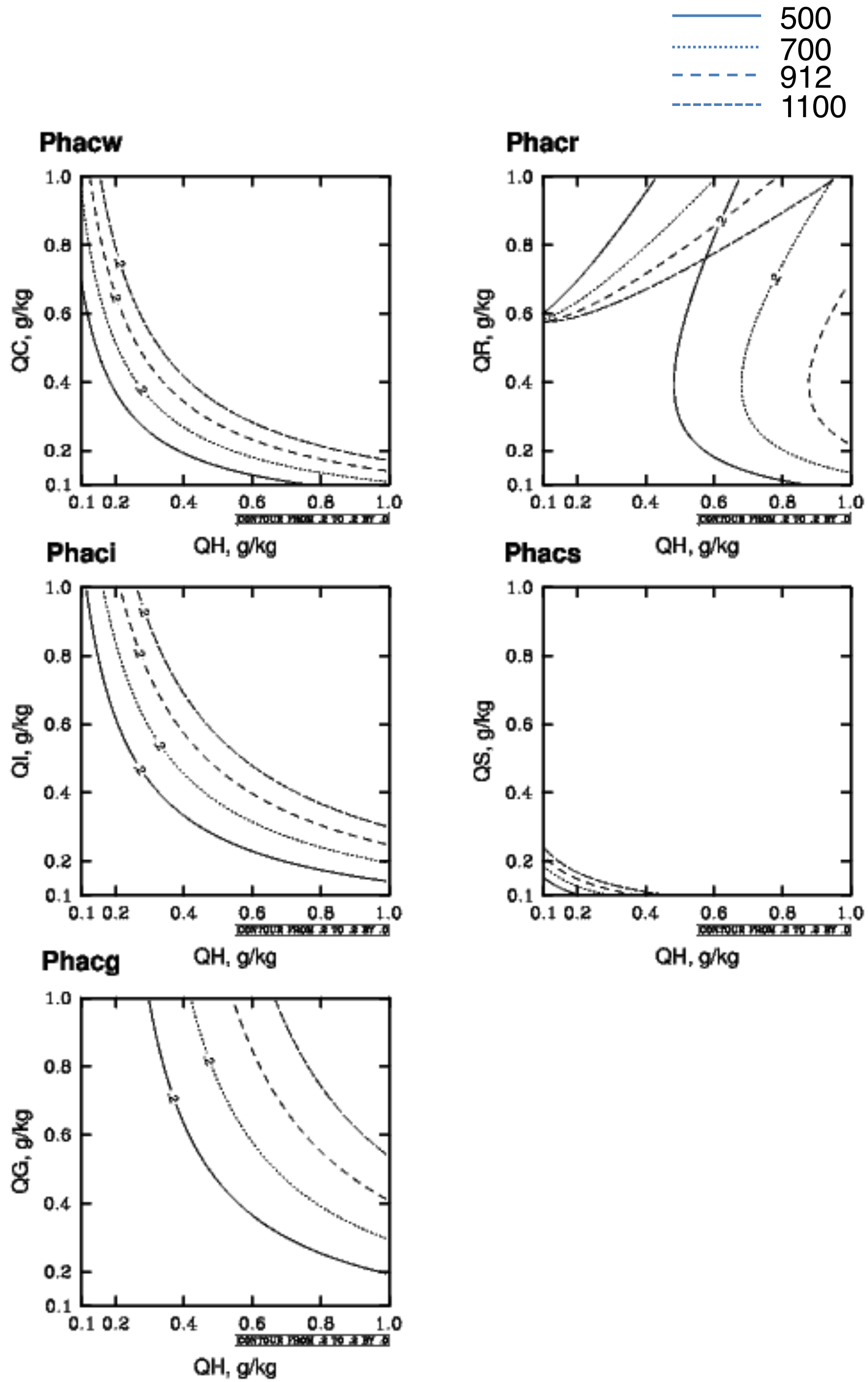
Number-weighted-mean terminal velocity ↓





T<T0: phacw, phacr, phaci, phacs, phacg, phdep
T≥T0: phacw, Phmlt, phevp, pheml

Process rate 비교



Hail density 증가 → accretion rate of X by hail (exception rain) 감소 → QH 감소

Phacg 감소 → QG 증가

같은 농도일 때,

Phacg > Phaci > Phacw > Phacs

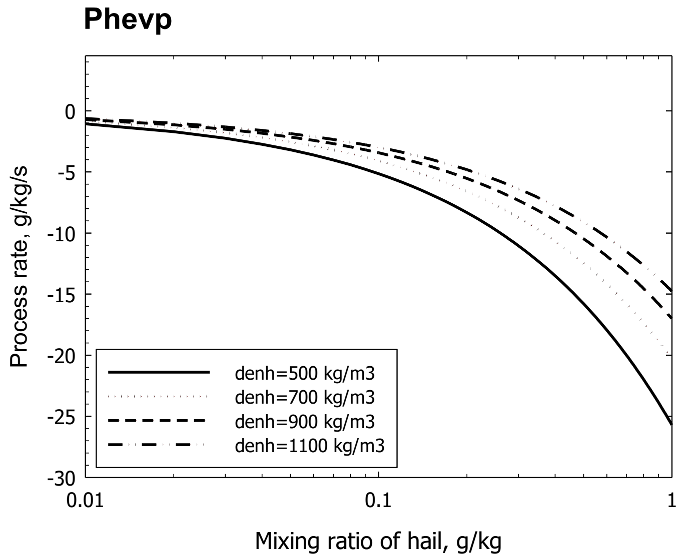
* Phacs에서 vt2avg 적용하면 process rate 커짐

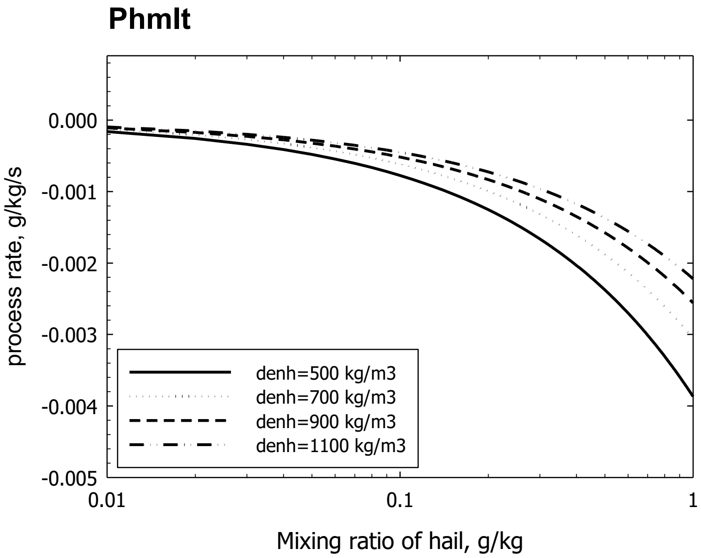
Process rate 비교

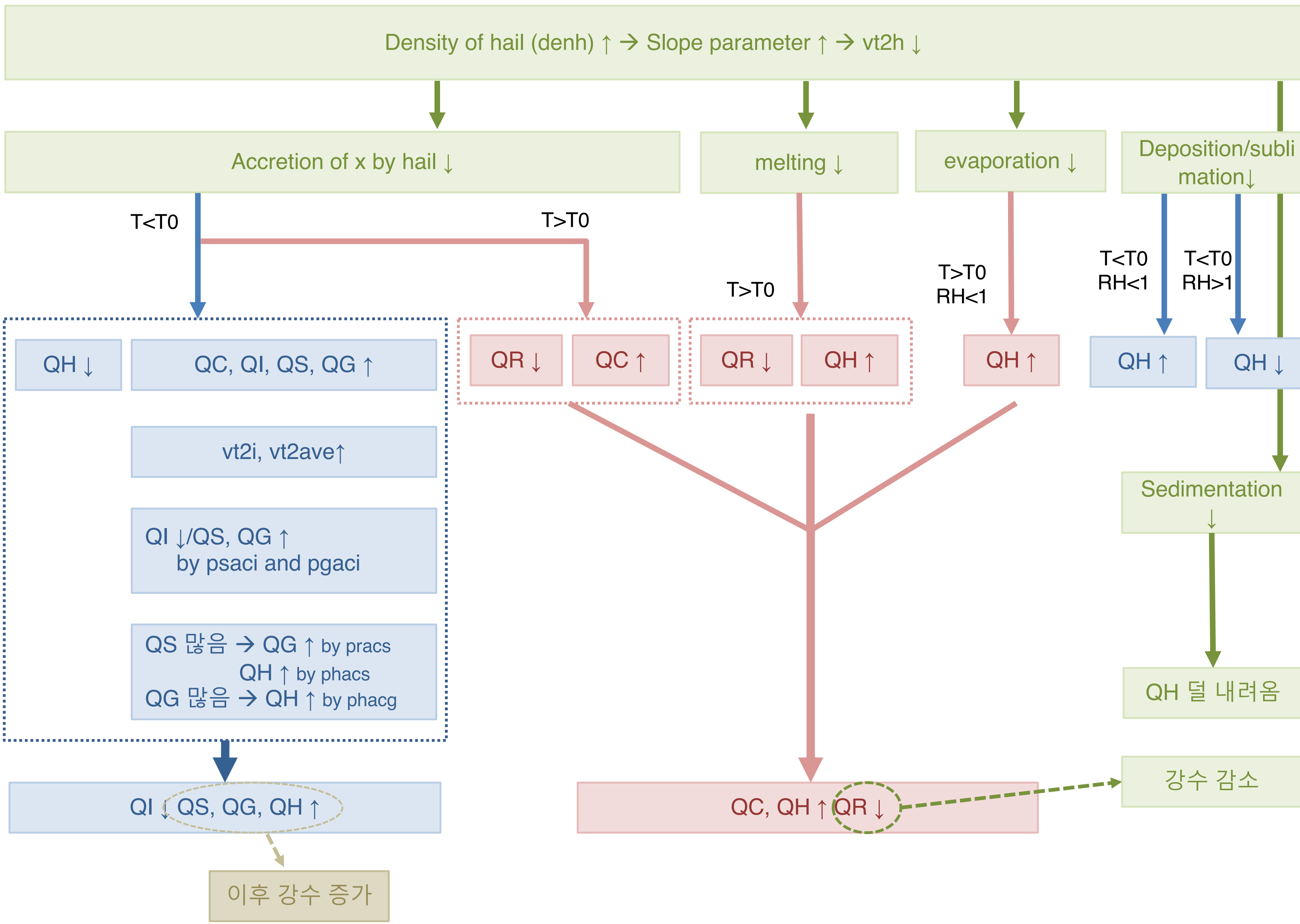
T=280 K
Den = 1.0

Phevp = (rh-1)*X
RH=0.99
Qr=0.1 g/kg

Phmlt = (t0c-T)*X
T=280 K






Density of hail (denh) ↑ → Slope parameter ↑ → vt2h ↓
Accretion of x by hail ↓
melting ↓
evaporation ↓
Deposition/sublimation↓
T<T0
T>T0
T>T0
T>T0 RH<1
T<T0 RH<1
T<T0 RH>1
QH ↓
QC, QI, QS, QG ↑
vt2i, vt2ave↑
QI ↓/QS, QG ↑ by psaci and pgaci
QS 많음 → QG ↑ by pracs
QH ↑ by phacs
QG 많음 → QH ↑ by phacg
QR ↓
QC ↑
QR ↓
QH ↑
QH ↑
QH ↑
QH ↓
Sedimentation ↓
QH 덜 내려옴
강수 감소
QI ↓ QS, QG, QH ↑
이후 강수 증가
QC, QH ↑ QR ↓