Structure of latent heating rate in the severe convective environment-
WRF Simulation using Microphysical Process from WDM6

A.Madhulatha[1,2], Jimy Dudhia[3], Rae-Seol Park[2] and M. Rajeevan[4]

1 India Meteorological Department(IMD), India (Current Affiliation)
2 Korea Institute of Atmospheric Prediction systems(KIAPS), South Korea
3 National Center for Atmospheric Research(NCAR), USA
4 Ministry of Earth Sciences(MoES), India

madhulatha11@gmail.com

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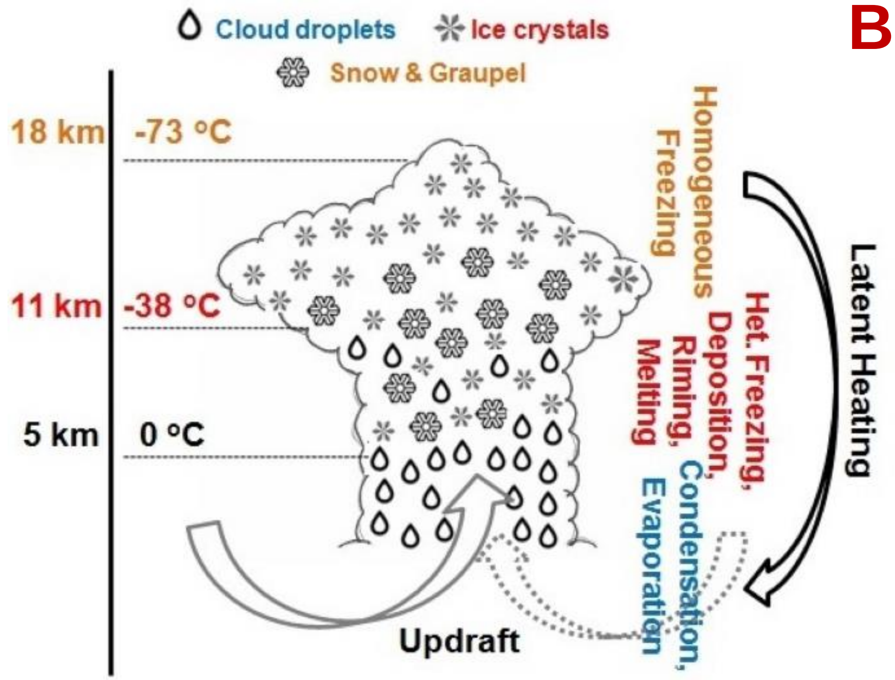
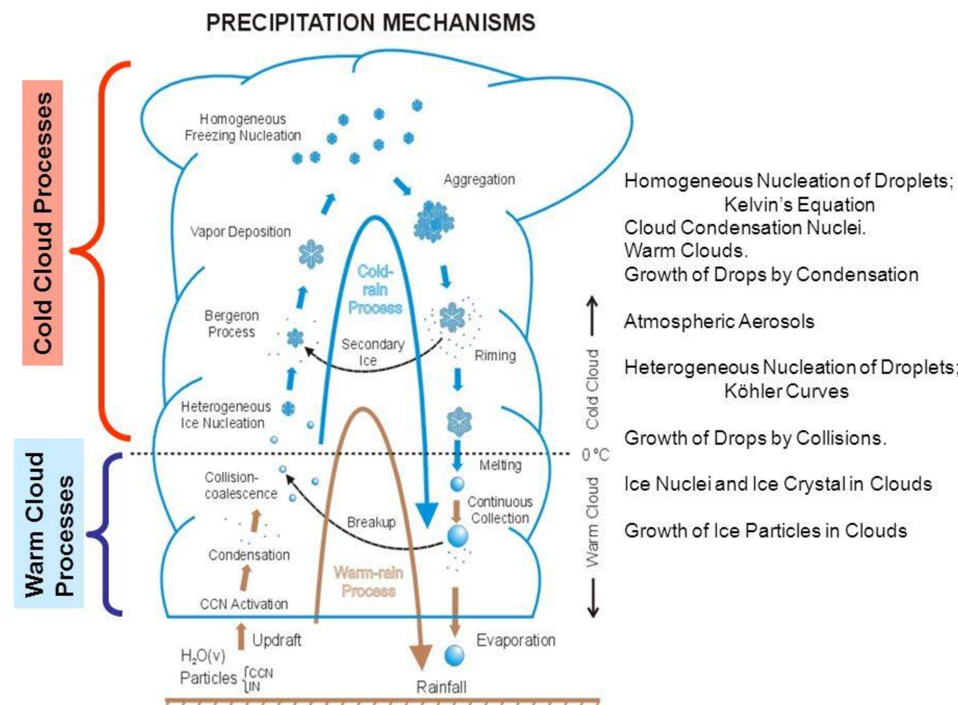
Dr Hyun-Joo Choi, Dr Sooya Bae, Dr Ji-Young Han

Background



- *Latent heat released during phase transformation process (during cloud formation) and affects the thermal and dynamical (structure of cloud and precipitation distribution and results in vertical transfer of energy (Yanai et al., 1973; Dudhia) 1989)*

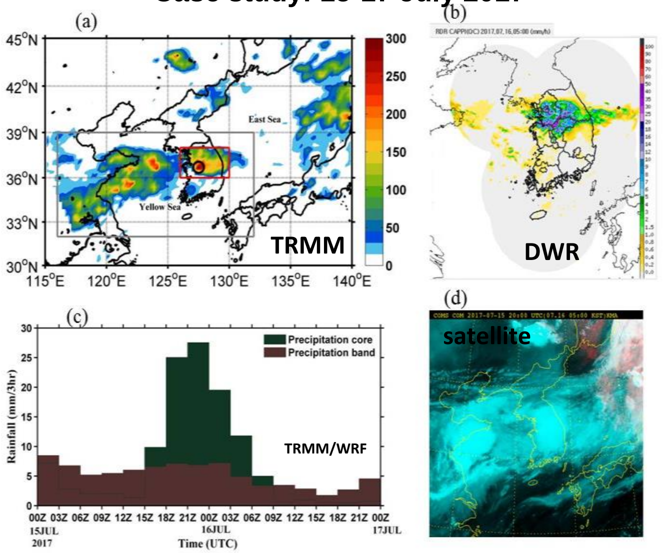
- *Cloud microphysics parameterization schemes accounts hydrometeor formation and directly impact the buoyancy through condensate loading and latent heating/cooling and affect storm-scale dynamics, precipitation accumulation ((Dudhia, 1989; Hong et al., 2004, Morrison et al 2009).*



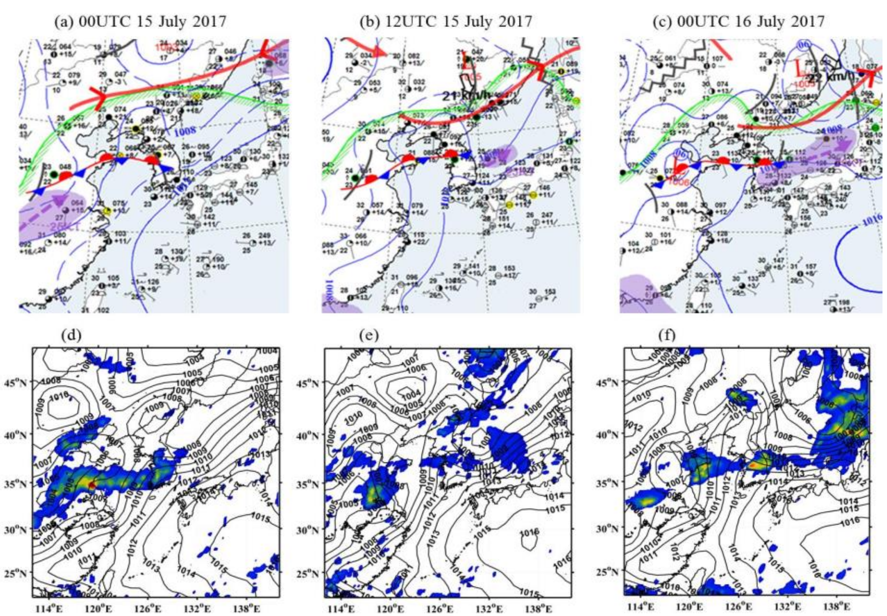
Courtesy: Steve Platnick, NASA

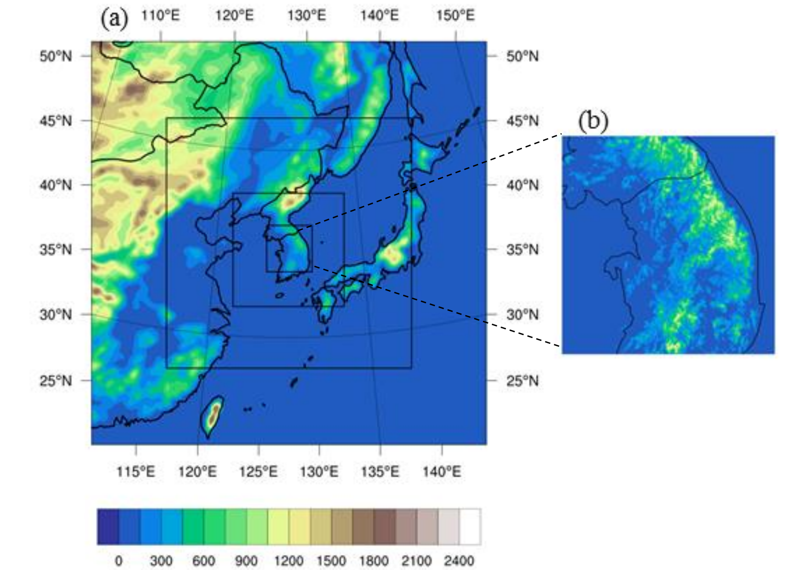
System Description and Model Configuration

Case study: 15-17 July 2017



- A Record-Breaking rainfall of 290 mm (the most in 22 years) is noticed over Cheongju region on 16 July 2017.
- Surface Weather charts (KMA), MSLP (NCEP-FNL data) shows that system has developed in association with Changma front passage.





Madhulatha et al., 2021

Model domain and Numerical setup

WRF Configuration V3.9.1	Domain 1	Domain 2	Domain 3	Domain 4
WRF Core	ARW	ARW	ARW	ARW
Horizontal Resolution	27km	9km	3km	1km
Number of grid points	132X132	244X244	331X331	406X406
Model Integration	48hrs	48hrs	48hrs	48hrs
Time step	72s	24s	8s	2s
Vertical levels	51	51	51	51
Microphysics	WDM6 (Lim and Hong, 2010)	WDM6	WDM6	WDM6
Scale Aware PBL	Shin and Hong, 2015	Shin and Hong	Shin and Hong	Shin and Hong
Korean Integrated Model (KIM (Hong et al., 2018)) Physics				
KIM Scale aware cumulus	KSAS (Kwon and Hong, 2017)	KSAS	KSAS	KSAS
Radiation	RRTMK (Baek, 2017)	RRTMK	RRTMK	RRTMK
Nesting Methods	Two-way, One-way Concurrent, One-way Sequential			

Latent heating rate computation from Microphysical Process

- ❑ Latent heating rate: f(microphysical process, latent heat constant, specific heat capacity)

(Li et al., 2017; Hjelmfelt et al., 1989; Guo et al., 1999).

- ❑ lf=3.34*10^5; ls=2.5*10^6; lv=2.25*10^6; cpd=1005.7; cpv=1870;

$$q_{\mathrm{con}} = L_{\mathrm{v}} \times \left(P_{\mathrm{con}} + P_{\mathrm{rcond}} + P_{\mathrm{cact}}\right)/C_{\mathrm{pm}}, \quad (1)$$

$$q_{\mathrm{revp}} = L_{\mathrm{v}} \times \left(P_{\mathrm{evap}} + P_{\mathrm{revp}} + P_{\mathrm{gevp}} + P_{\mathrm{sevp}}\right)/C_{\mathrm{pm}}, \quad (2)$$

$$q_{\mathrm{frz}} = L_{\mathrm{f}} \times \left(P_{\mathrm{ihmf}} + P_{\mathrm{ihtf}} + P_{\mathrm{gfrz}} + P_{\mathrm{iacr}} + P_{\mathrm{gacr}} + P_{\mathrm{sacr}} + 2 \times P_{\mathrm{aacw}}\right)/C_{\mathrm{pm}}, \quad (3)$$

$$q_{\mathrm{mlt}} = L_{\mathrm{f}} \times \left(P_{\mathrm{smlt}} + P_{\mathrm{gmlt}} + P_{\mathrm{imlt}} + P_{\mathrm{seml}} + P_{\mathrm{geml}}\right)/C_{\mathrm{pm}}, \quad (4)$$

$$q_{\mathrm{dep}} = L_{\mathrm{s}} \times \left(P_{\mathrm{idep}} + P_{\mathrm{sdep}} + P_{\mathrm{gdep}} + P_{\mathrm{igen}}\right)/C_{\mathrm{pm}}, \quad (5)$$

$$q_{\mathrm{sub}} = L_{\mathrm{s}} \times \left(P_{\mathrm{isub}} + P_{\mathrm{ssub}} + P_{\mathrm{gsub}}\right)/C_{\mathrm{pm}}, \quad (6)$$

$$q_{\mathrm{total}} = q_{\mathrm{con}} + q_{\mathrm{evp}} + q_{\mathrm{frz}} + q_{\mathrm{mlt}} + q_{\mathrm{dep}} + q_{\mathrm{sub}}, \quad (7)$$

- ❑ Six main transformation processes due to phase change (warm and cold Microphysical processes, WDM6).

- ❑ qcond=f(cond,rcond,cact)
- ❑ qrevp=f(evap,revp,gevp,sevp)
- ❑ qfrz=f(ihmf,ihtf,gfrz,iacr,gacr,sacr,aacw)
- ❑ qmlt=f(smlt,gmlt,seml,geml)
- ❑ qdep=f(idep,sdep,gdep,igen)
- ❑ qsub=f(isub,ssub,gsub)

Description of various Microphysical process

cond	condensation/evaporation of cloud water
raut	autoconversion of cloud water into rain
saut	autoconversion of cloud ice into snow
gaut	autoconversion of snow into graupel
revp	evaporation-condensation rate of rain
sevp	evaporation of melting snow
gevp	evaporation of melting graupel
idep	deposition-sublimation rate of ice
sdep	deposition-sublimation rate of snow
gdep	deposition/sublimation rate of graupel
imlt	instantaneous melting of cloud ice
smlt	melting of snow
gmlt	melting of graupel
seml	enhanced melting of snow
geml	enhanced melting rate of graupel
racw	accretion of cloud water by rain
sacw	accretion of cloud water by snow
gacw	accretion of cloud water by graupel
gacr	accretion of rain by graupel
sacr	accretion of rain by snow
iacr	accretion of rain by cloud ice
racs	accretion of snow by rain
gacs	accretion of cloud ice by graupel
raci	accretion of cloud ice by rain
gaci	accretion of cloud ice by graupel
saci	accretion of cloud ice by snow
igen	generation (nucleation) of ice from vapor

(Lim and Hong, 2010)

WDM6

- Computation of latent heating terms
- Warming/cooling processes due to latent heat release/absorption
- Condensation, freezing, deposition
- Evaporation, melting and sublimation.

MAY 2010 LIM AND HONG

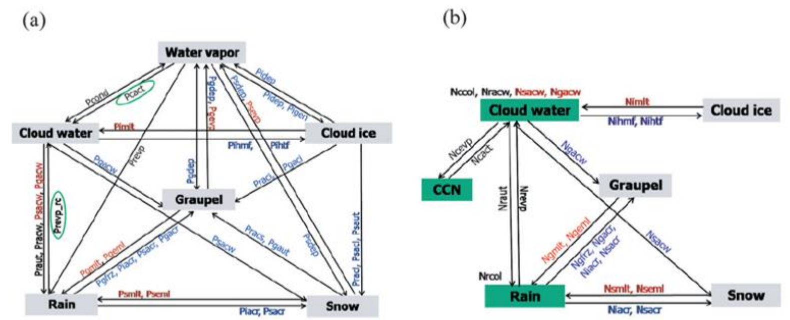


FIG. 1. Flowchart of the microphysics processes for the prediction of (a) the mixing ratios and (b) the number concentrations in the WDM6 scheme. The terms with red (blue) colors are activated when the temperature is above (below) 0°C, whereas the terms with black color are in the entire regime of temperature. The added term compared with the WSM6 scheme is circled in green in (a). Number concentrations of the species in the green box in (b) are only predicted in the current scheme.

```
float PSEML_OUT(Time, bottom_top, south_north, west_east) ;
        PSEML_OUT:FieldType = 104 ;
        PSEML_OUT:MemoryOrder = "XYZ" ;
        PSEML_OUT:description = "Enhanced melting of snow by accretion of water" ;
        PSEML_OUT:units = "kg kg-1 s-1" ;
        PSEML_OUT:stagger = "" ;
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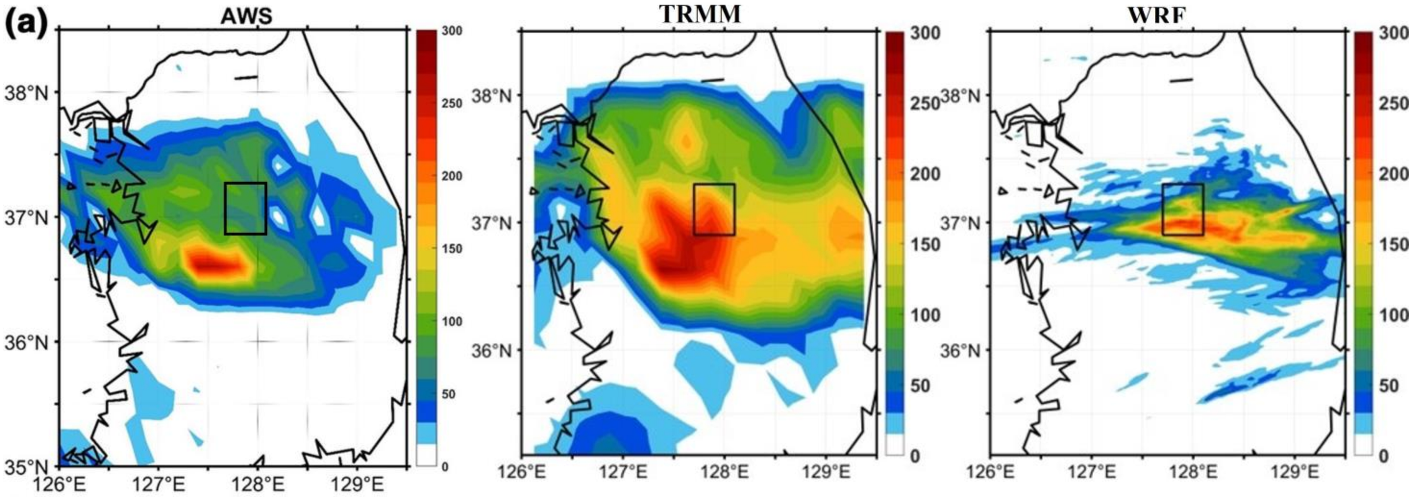
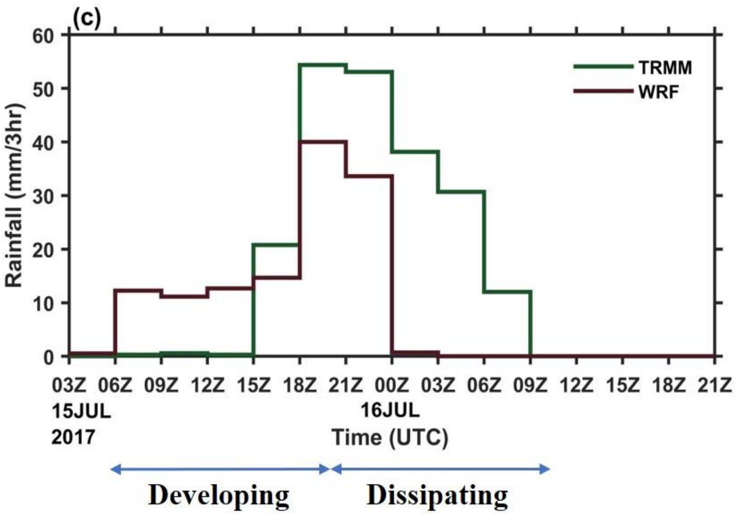
Included these Microphysics variables from module_mp_wdm6.F into WRF output

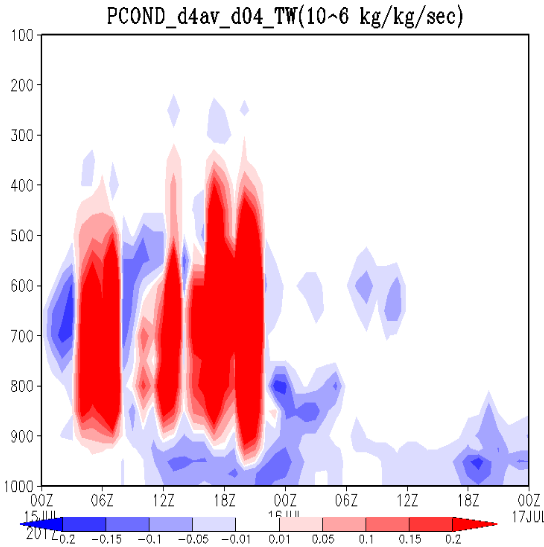
Spatial and Temporal Distribution of Rainfall

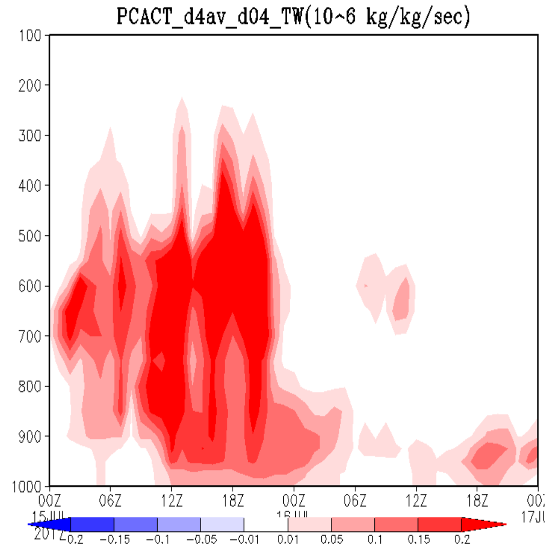


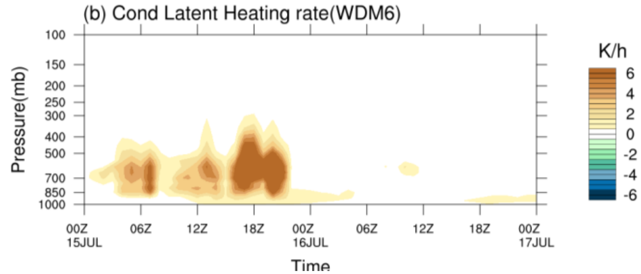


Grid box region:127.7ºE-128.1ºE and 36.9ºN-37.3ºN

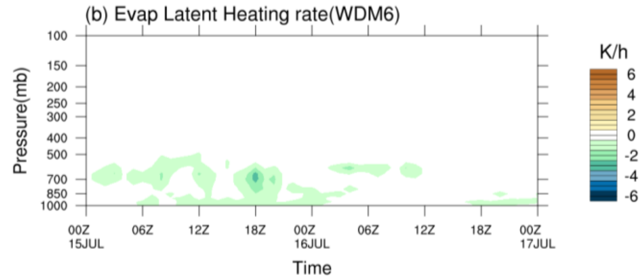
Distribution of various microphysical production rates used for LH computation



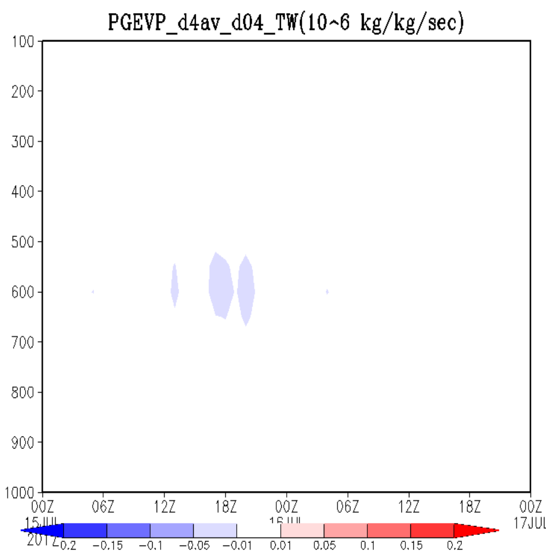


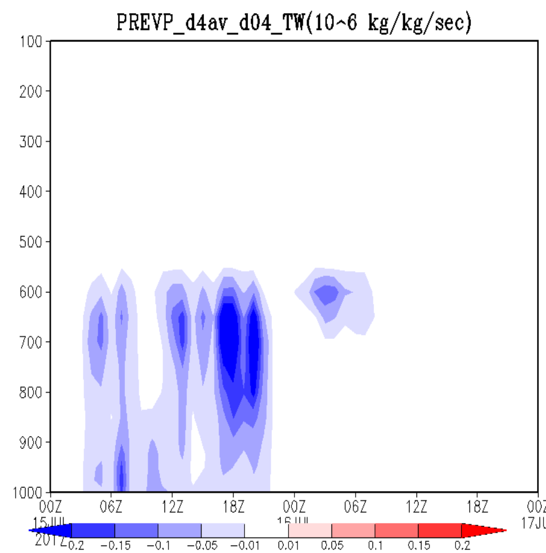


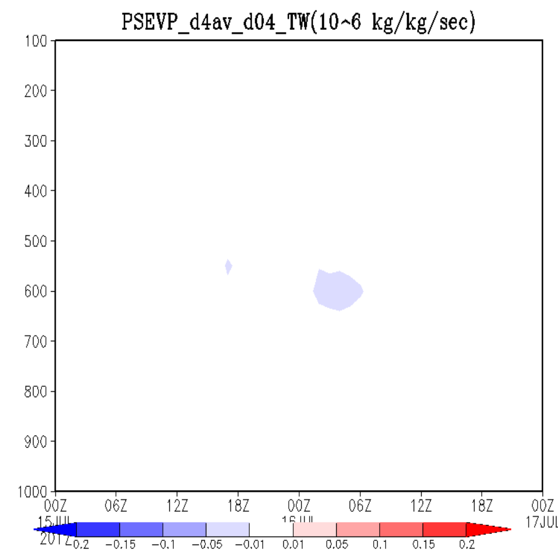
- qcond=f(pcond,prcond,pcact)
- qrevp=f(pevap,prevp,pgevp,psevp)



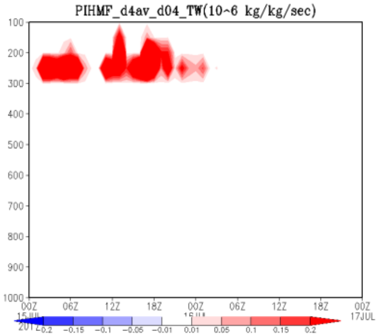
Condensation/Evaporation (over the precipitation core region)

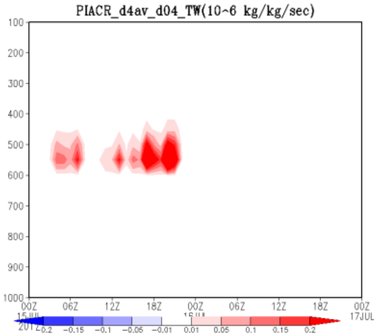


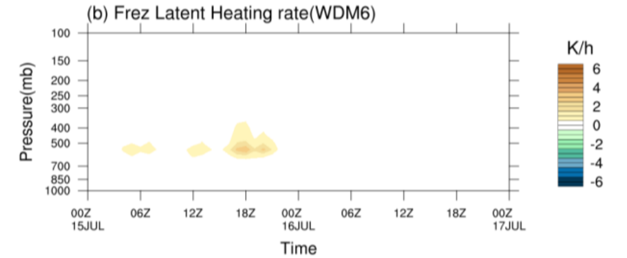




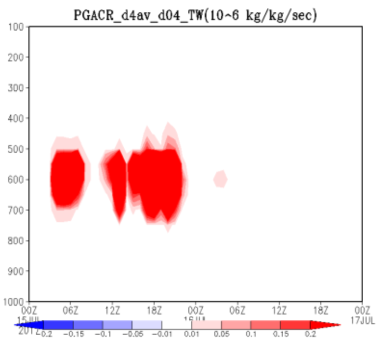
Freezing/Melting

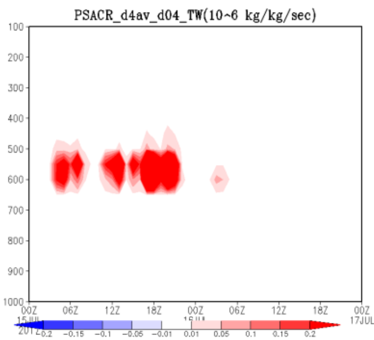


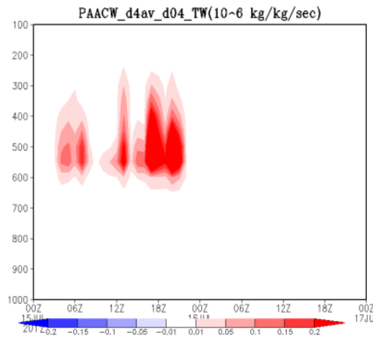


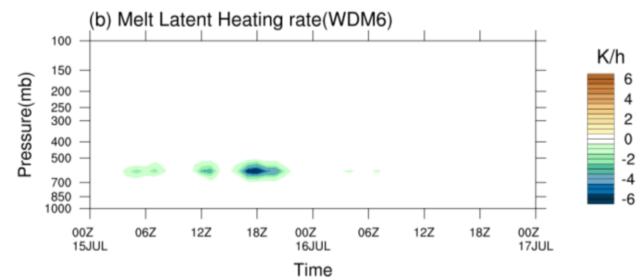


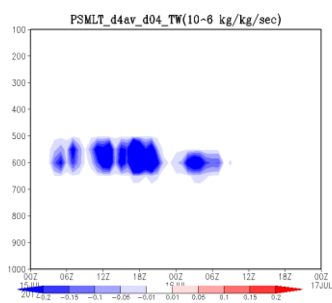
- qfrz=f(ihmf,ihtf,gfrz,iacr,gacr,sacr,aacw)
- qmlt=f(smlt,gmlt,seml,geml)

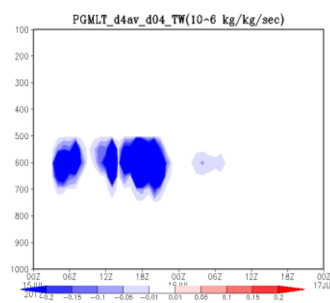


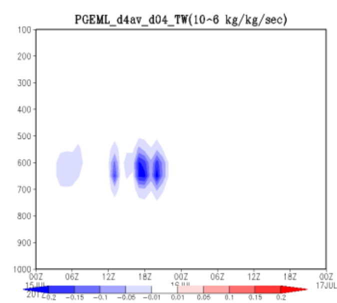


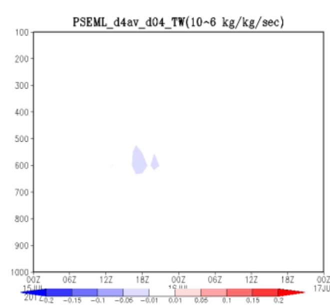




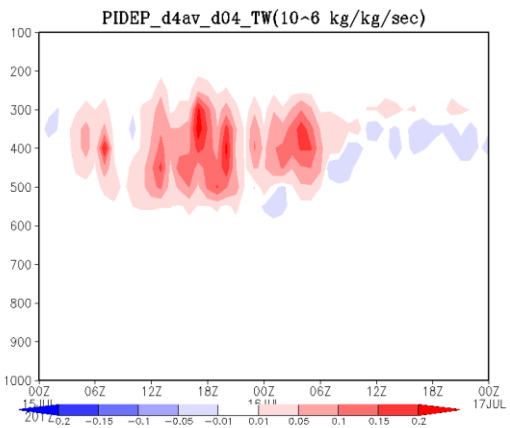


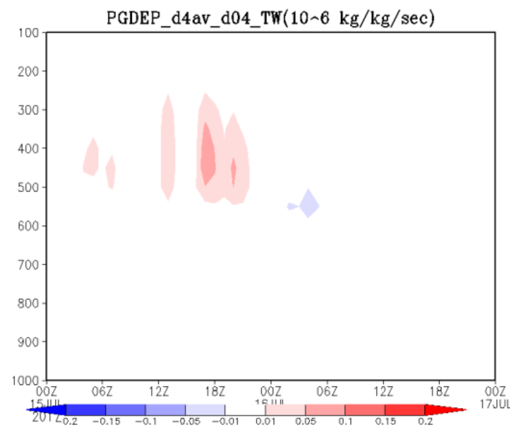


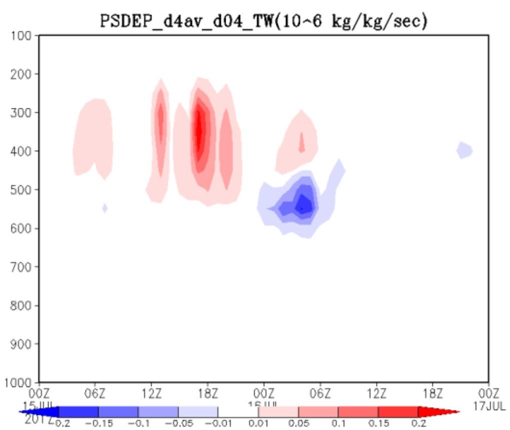


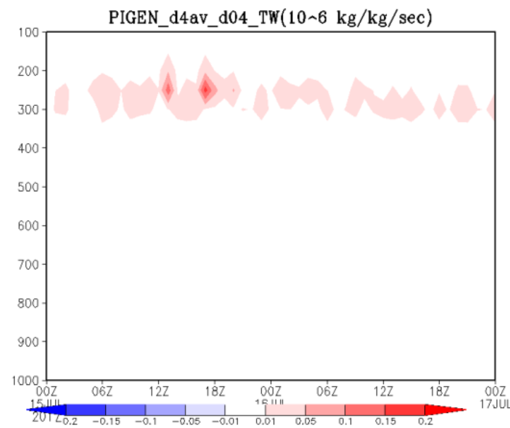


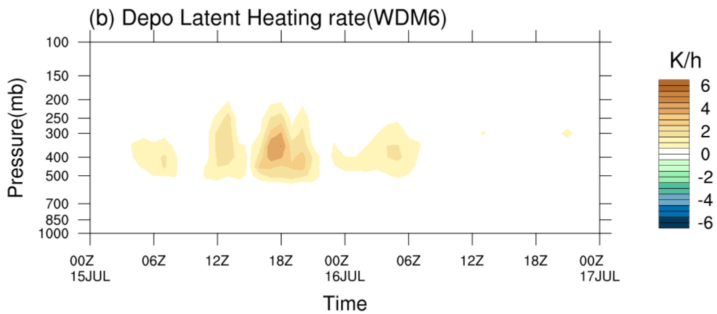
Deposition/Sublimation



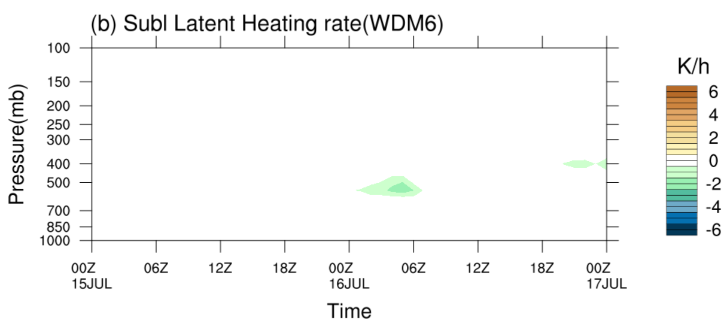




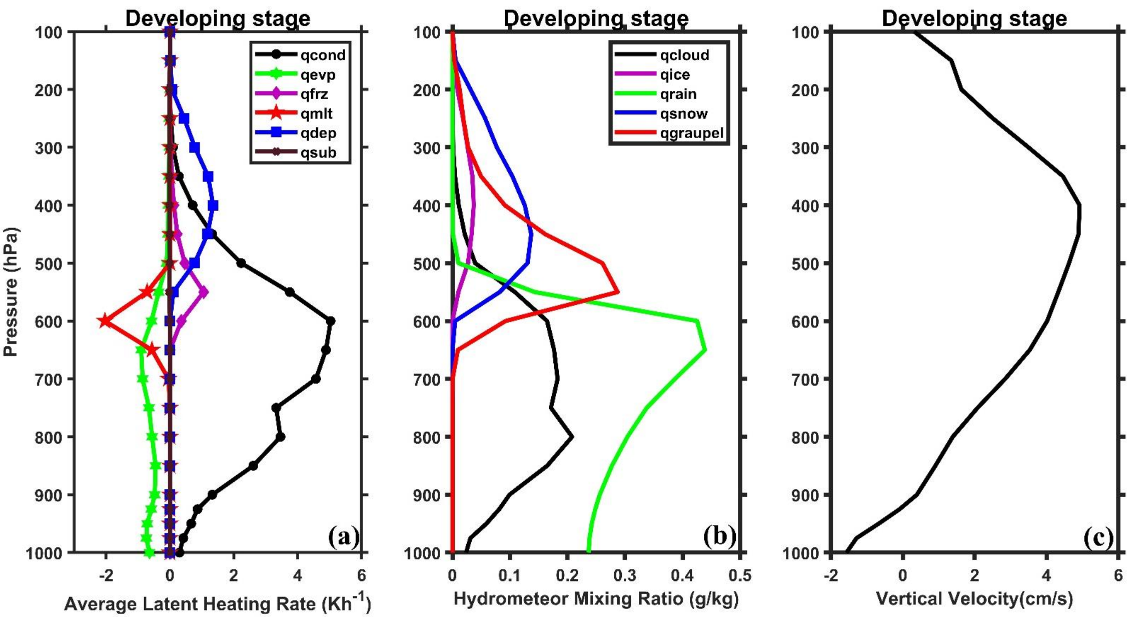




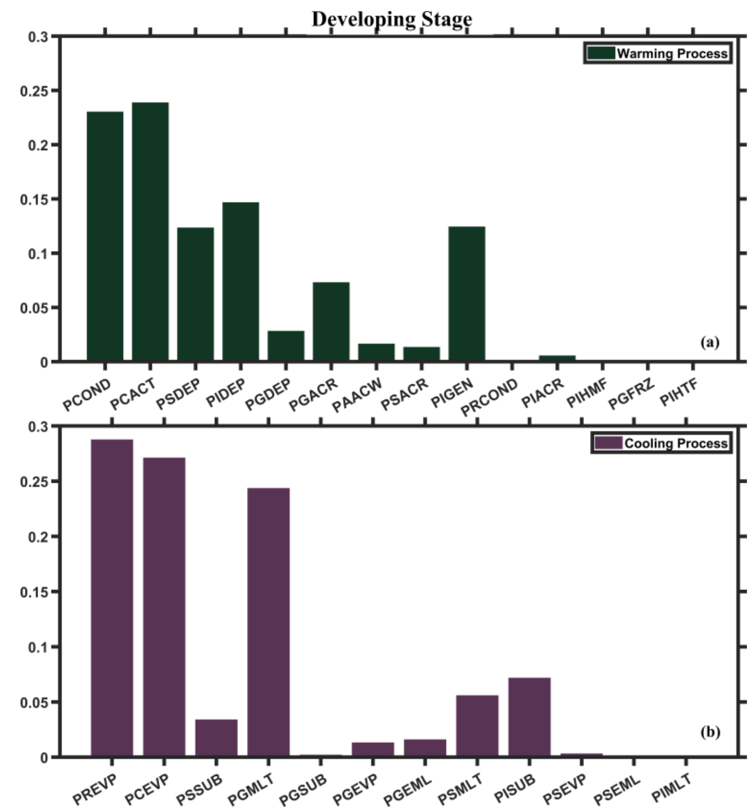
- qdep=f(idep,sdep,gdep,igen)
- qsub=f(isub,ssub,gsub)



Vertical distribution of Average latent heating rates over precipitation core region



Developing Stage

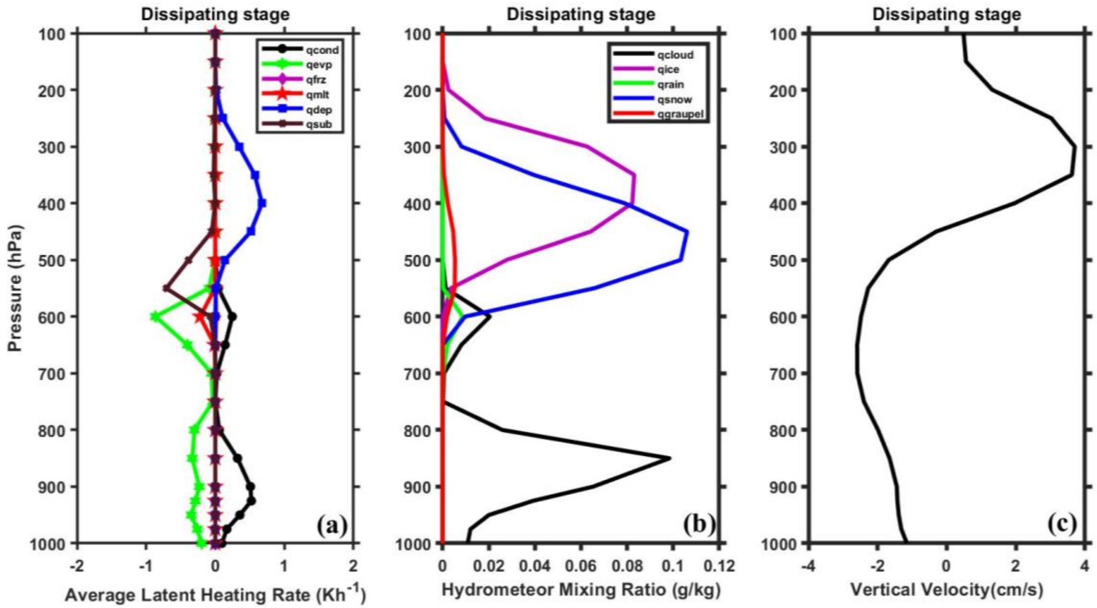


Contribution of microphysical process

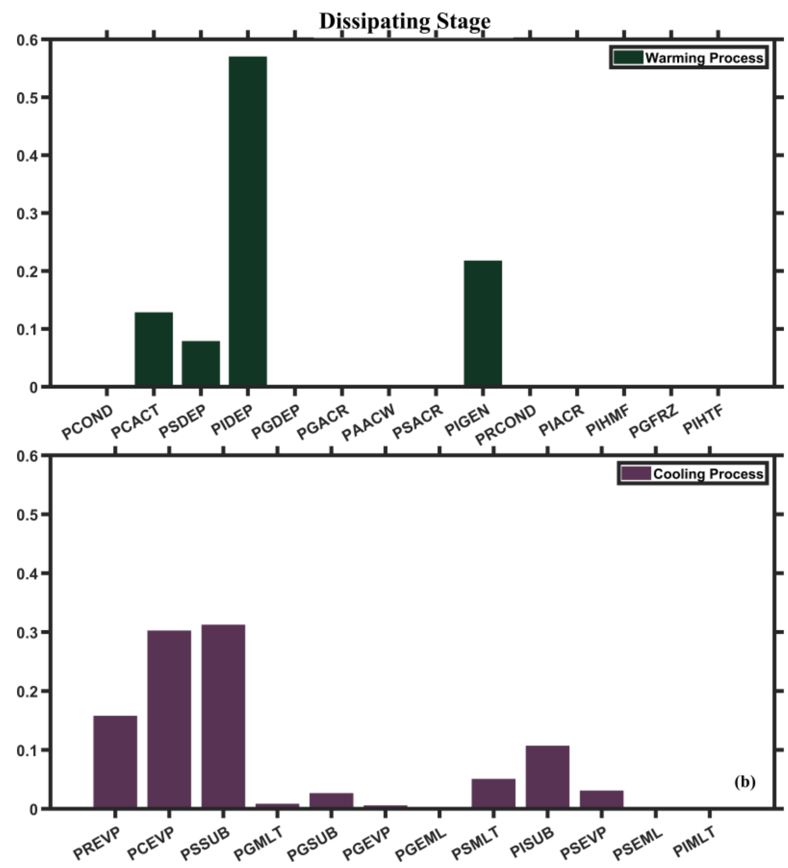
Developing stage (development/mature stage).

Top warming process
(Condensation, Accretion, Deposition)

Top cooling process (Evaporation and Melting)
Major updraft motion.



Dissipating Stage



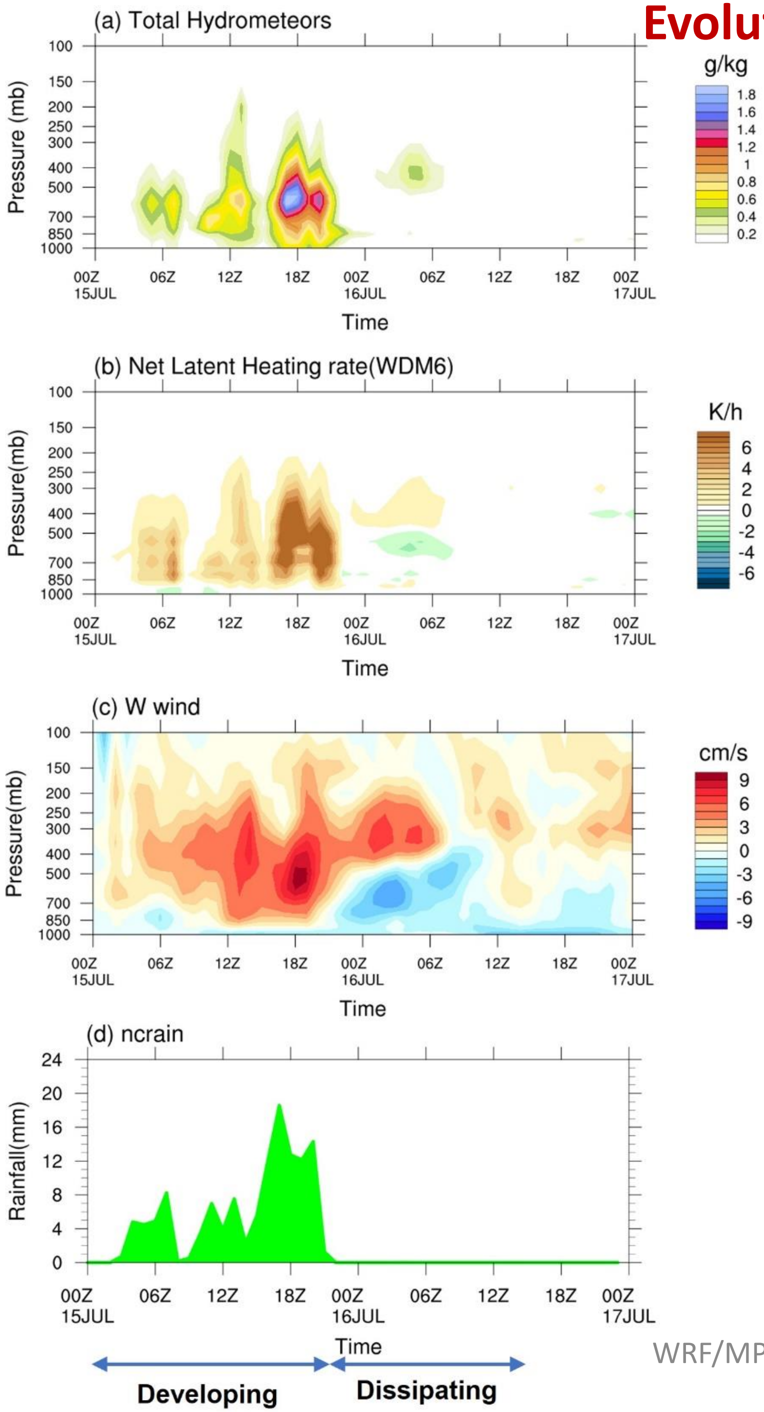
Contribution of microphysical process

Dominant cooling processes: evaporation, sublimation and melting.

Dominant warming by ice deposition

Dominant downdraft motion.

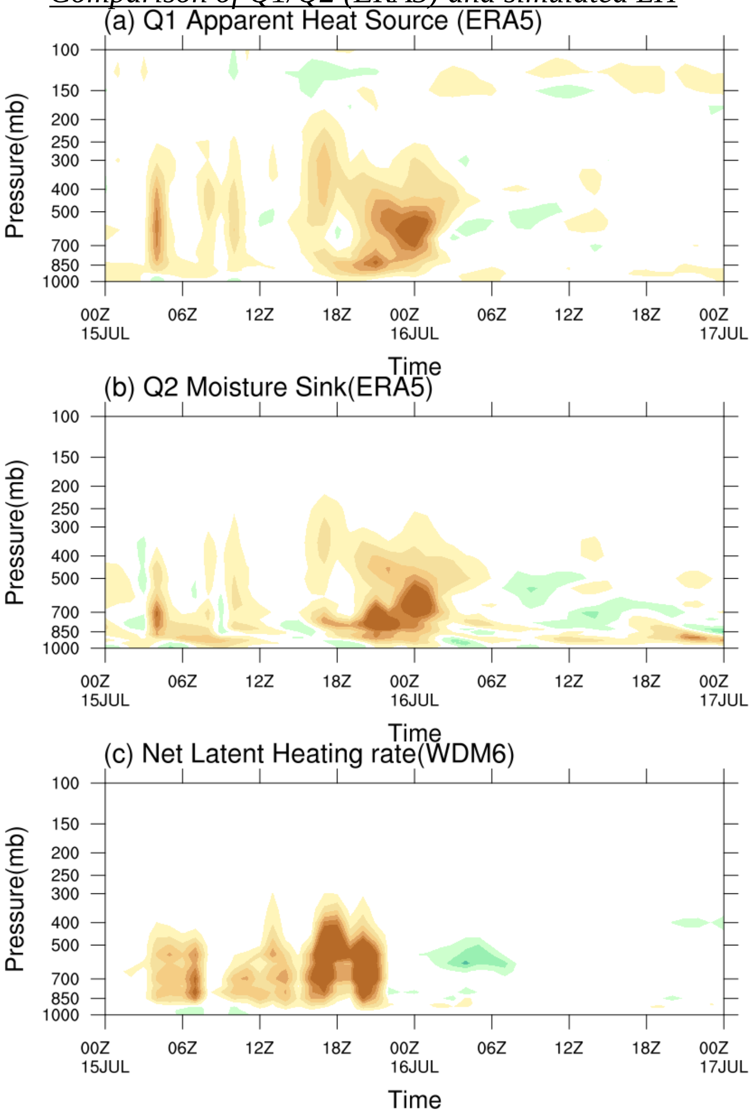
Evolution of parameters: Storm environment

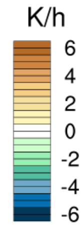


- ✓ Dominant positive (negative) total latent heating provided (restrained) energy for convection.
- ✓ Ascent of air parcel from surface to upper levels and latent heat release associated with transformation of air parcel.
- ✓ Representation of microphysical process affect- Hydrometeor distribution-latent heating rates- Vertical motion and subsequent rainfall.
- ✓ Consistency between different process.
- ✓ Therefore, proper choice of microphysics play vital role in simulation of severe convective systems

Inference

Comparison of Q1/Q2 (ERA5) and simulated LH

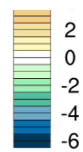


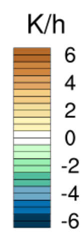


(Yanai et al., 1973)

$$Q_1 = c_p \frac{\partial T}{\partial t} - c_p(\omega\sigma - \mathbf{V}\cdot\nabla T),$$

$$Q_2 = -L\frac{\partial q}{\partial t} - L\mathbf{V}\cdot\nabla q - L\omega\frac{\partial q}{\partial p},$$





- Quantifying and understanding the temporal evolution of latent heating profiles can be useful
- To understand the uncertainties in microphysical terms and further improvement.
- Proxy to test the sensitivity of different microphysical schemes.
- Comparing Q1,Q2 distributions helpful to discriminate specific heating processes in atmosphere
- To develop parameterizations of organized convection for large scale models that do not explicitly represent cloud processes.

A.Madhulatha, Jimy Dudhia, Rae-Seol Park, M. Rajeevan (2022)"Simulation of latent heating rate from the microphysical process associated with Mesoscale Convective System over Korean Peninsula" (Manuscript under review)

Thank you all