The sensitivity of passive microwave responses to the hydrometeor properties simulated by a cloud resolving model in real rainfall systems associated with Baiu front

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Motivations

- **Cloud Resolving Models (CRMs) with complicated cloud microphysical parameterization can forecast various hydrometeors with high resolution in time and space.**
- **CRMs serve as a valuable tool to be used in satellite remote sensing of precipitation such as TRMM and GPM for inferring information about clouds that cannot be directly observed.**
- **It is indispensable that CRM’s outputs are verified with observational data to ensure the information being inferred from them is of the highest possible quality.**
- **Several observational data should be used fully to improve CRMs by estimating biases within the models and conducting needed adjustments to their physics and parameters to reduce those biases.**

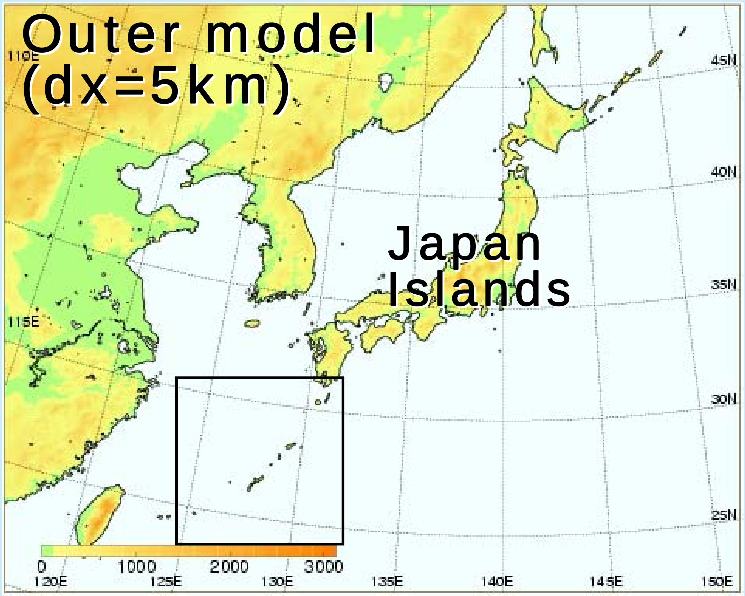
Objectives

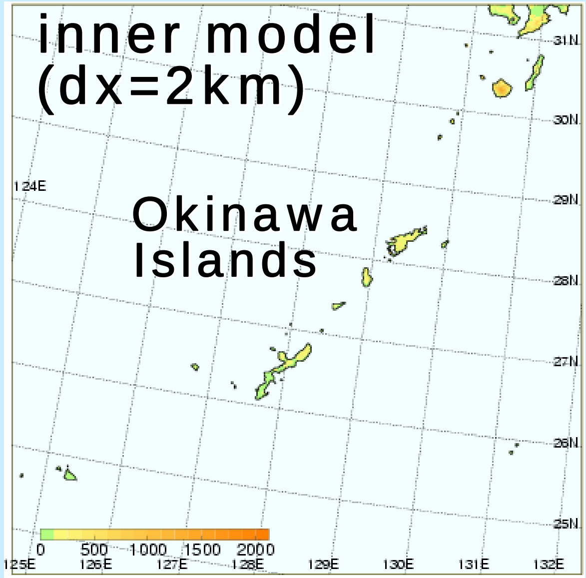
- **This study investigates the sensitivity of microwave brightness temperatures (TBs) simulated by a radiative transfer model to the hydrometeor properties simulated by CRM for the cloud microphysical validation of CRM.**
- **The sensitivity of simulated equivalent radar reflectivity (Ze) is also analyzed.**
- **TBs and Ze simulations are conducted for real rainfall systems associated with Baiu front around Okinawa Islands, Japan on 8 June 2004, which are compared to the timely corresponding satellite radiometer and grand-based radar observations, respectively**
- **Special attention will be given to the characteristics and sensitivities of CRM's ice hydrometeors forecasting.**

Cloud resolving model

JMA-NHM (Saito *et al*., 2006)

- **JMA-NHM is an operational nonhydrostatic mesoscale model developed by Japan Meteorological Agency (JMA).**
- **Rainfall systems focused in this study has been simulated with double nested models, with a horizontal grid size of 5 and 2 km.**
- **The inner model covers 800 x 800 km. The vertical grid has 50 levels with a grid size of 40 m close to the surface to 904 m at high altitude.**
- **In the inner model, explicit cloud microphysics scheme is only used as precipitation process.**





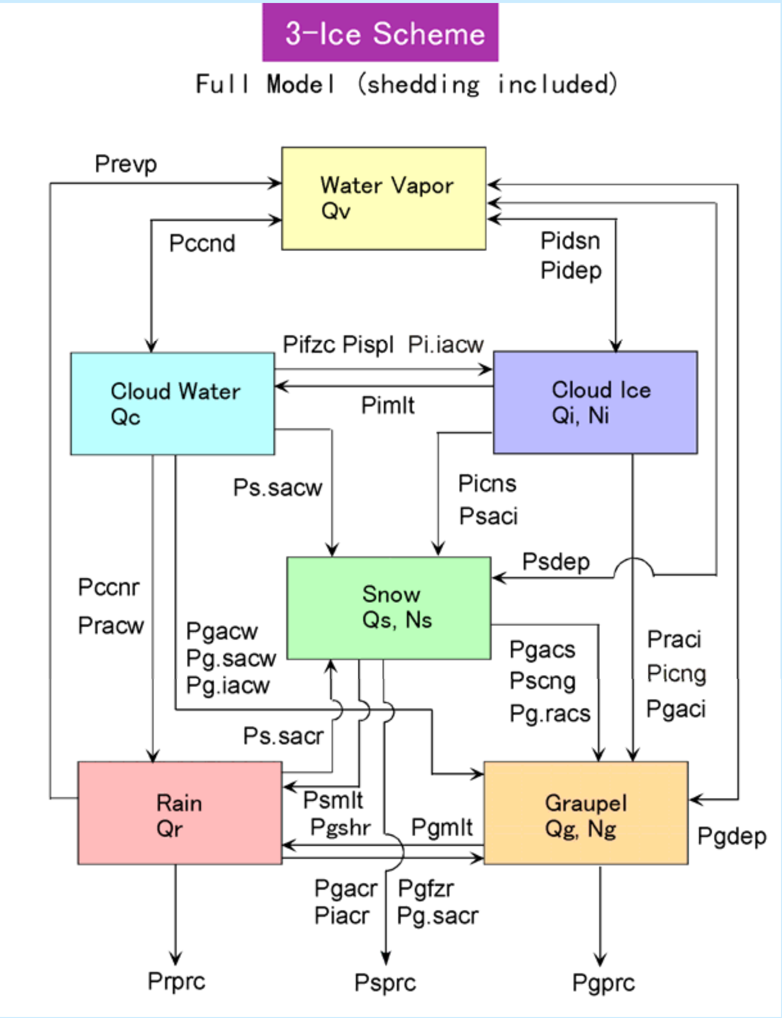
Cloud Microphysics in JMA-NHM

- **Explicit cloud microphysics scheme based on bulk method**
- **The hydrometeors are categorized into 6 water species**
- **Simple power lows are taken for the mass-size ($M_x=\rho_x D_x^3$) and for the velocity size ($V_x=a_x D_x^{bx}$) relationships**
- **The size distributions for each hydrometeors are represented by exponential functions.**

$$N_x(D_x) = N_{0x}\exp(-\lambda_x D_x)$$

- **Mixing ratios (Q_x) and number concentrations (N_x) are predicted for each ice particles, the slope (λ_x) and intercept (N_{0x}) of a given particle distribution are calculated, respectively**

$$N_{0x} = N_x\left(\pi\frac{\rho_x}{\rho}\frac{N_x}{Q_x}\right)^{\frac{1}{3}}, \lambda_x = \left(\pi\frac{\rho_x}{\rho}\frac{N_x}{Q_x}\right)^{\frac{1}{3}}.$$



Radiative Transfer Code

Liu (1998)

- **One-dimensional model (Plane-parallel)**
- **Mie Scattering (Sphere)**
- **4 stream approximation**
- **TBs are calculated for output from the JMA-NHM model simulations, compared to the timely corresponding AMSR-E observations on board Aqua.**

$$\mu \frac{dTB(\tau,\mu,\varphi)}{d\tau} = TB - (1-\omega_0)T(\tau) -$$

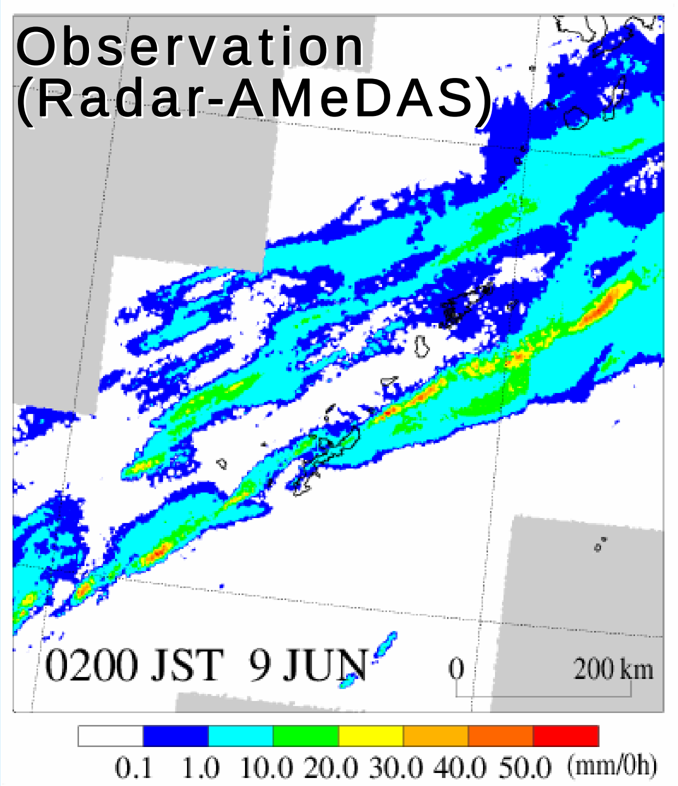
$$\frac{\omega_0}{4\pi}\iint P(\tau,\mu,\varphi,\mu',\varphi')TB(\tau,\mu',\varphi')d\mu' d\varphi'$$

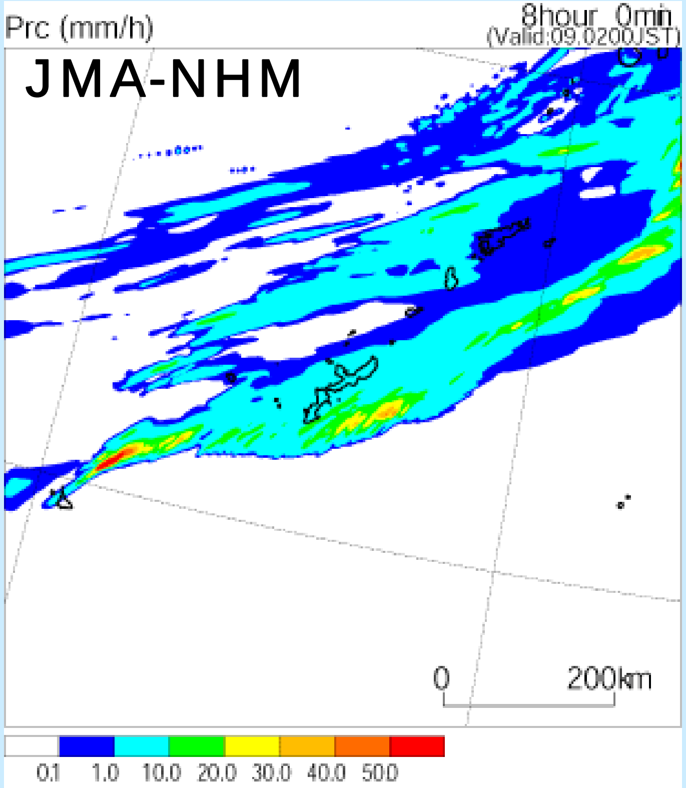
$$where\ \mu = \cos\theta, \tau = \int K_{ab} + K_{sc} dz, \omega_0 = K_{sc}/(K_{ab} + K_{sc}),$$

P is phase function

JMA-NHM simulation for observed rainfall systems

1-h precipitation 17UTC 08 JUN 2004

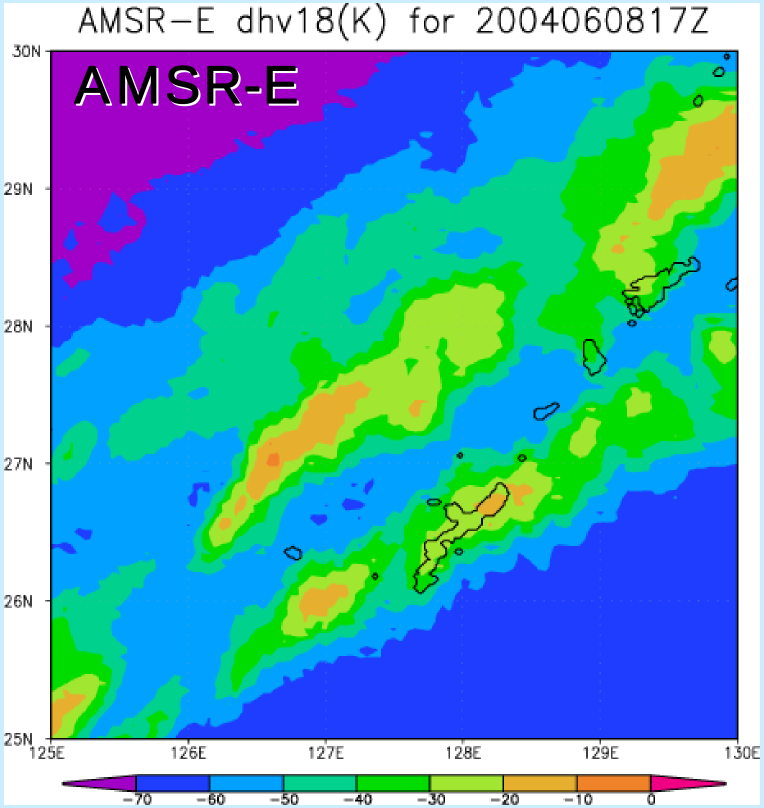


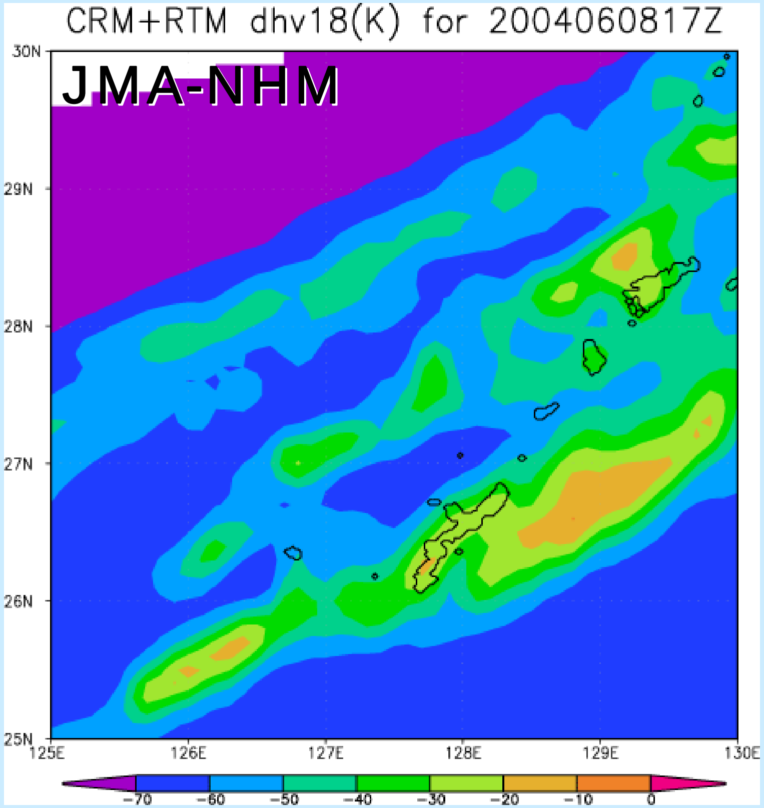


- Line-shaped precipitation associated with Baiu front were observed.
- The model well simulates the location and intensity of observed precipitation.

Comparison with AMSR-E observation

18GHz TB Absorption index 17UTC 08 JUN 2004

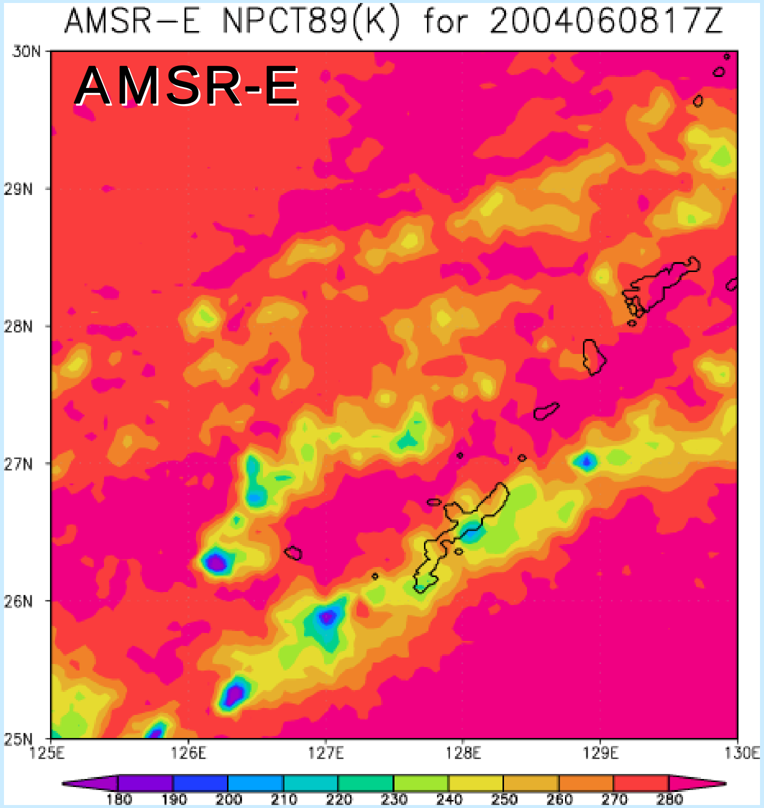


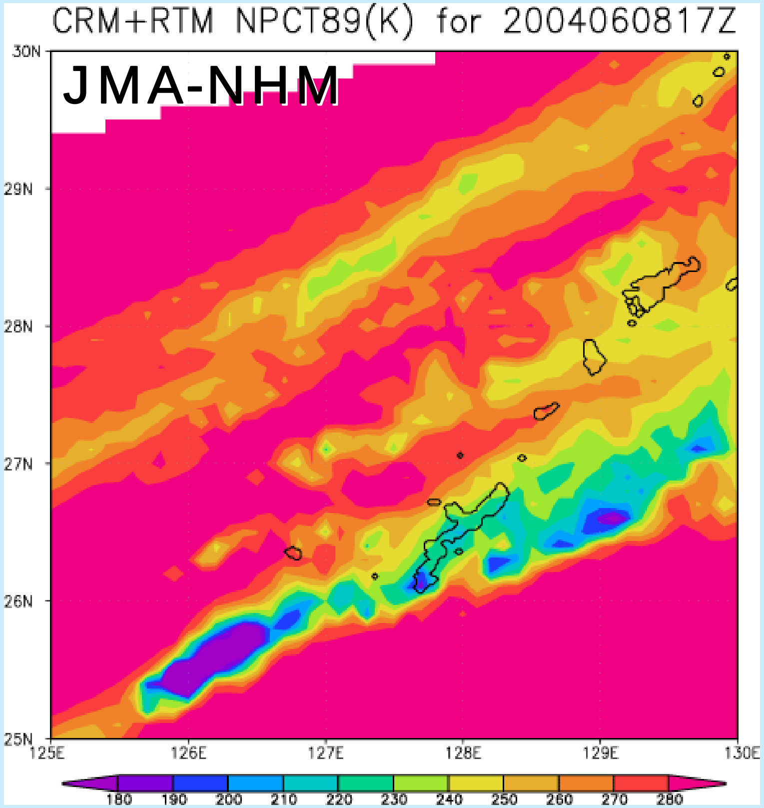


- The magnitude of simulated absorption index is in almost agreement with the observation, indicating that JMA-NHM well simulates the particle characteristics in liquid phase.

Comparison with AMSR-E observation

89GHz TB Scattering index 17UTC 08 JUN 2004

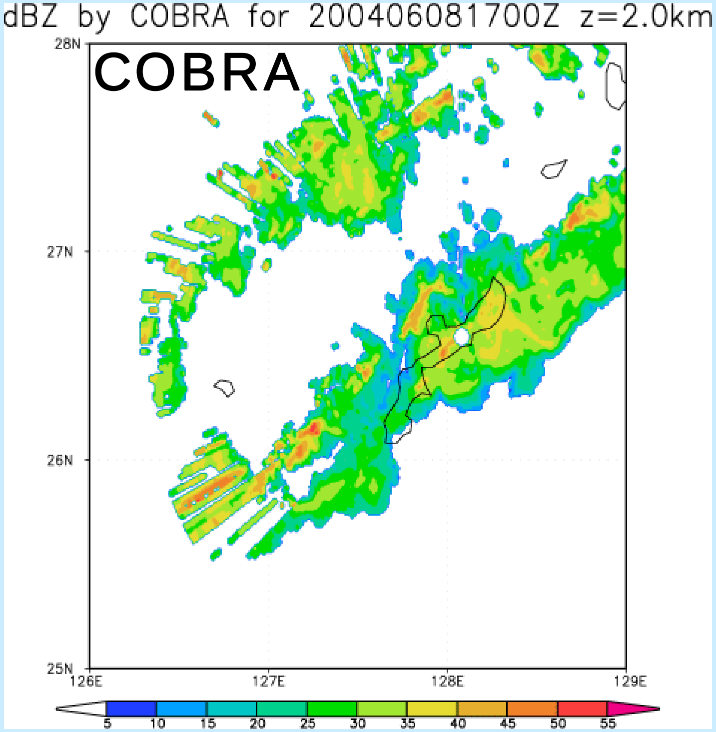


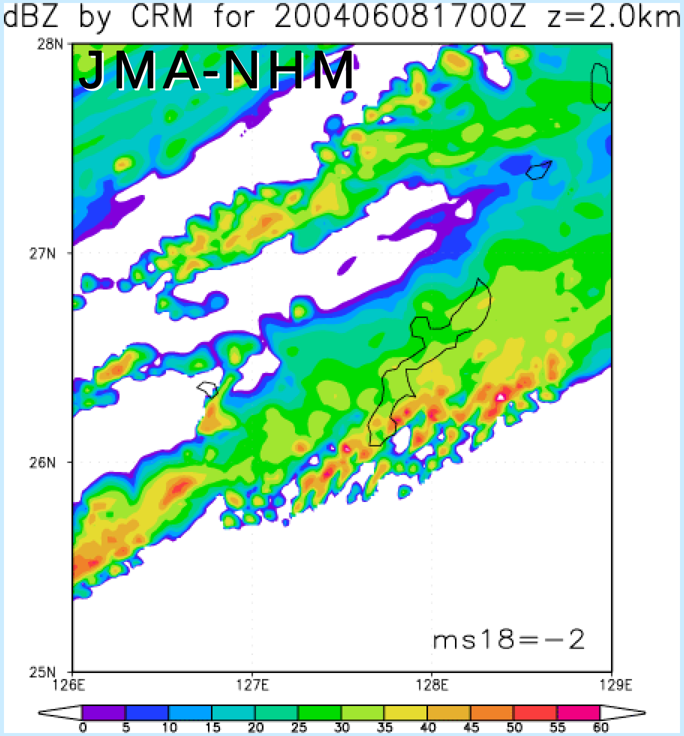


- JMA-NHM well simulates a location of the area with large scattering index.
- The simulated scattering index is larger, indicating that JMA-NHM overestimates an amount of frozen precipitation particles.

Comparison with radar observation

Radar Reflectivity (dBZ) z=2.0 km 17UTC 08 JUN 2004

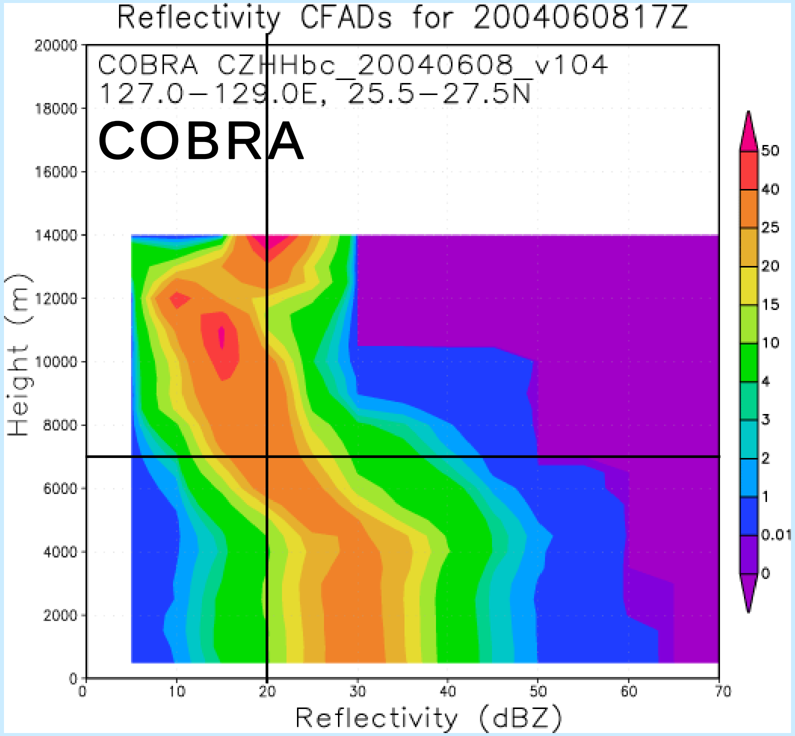


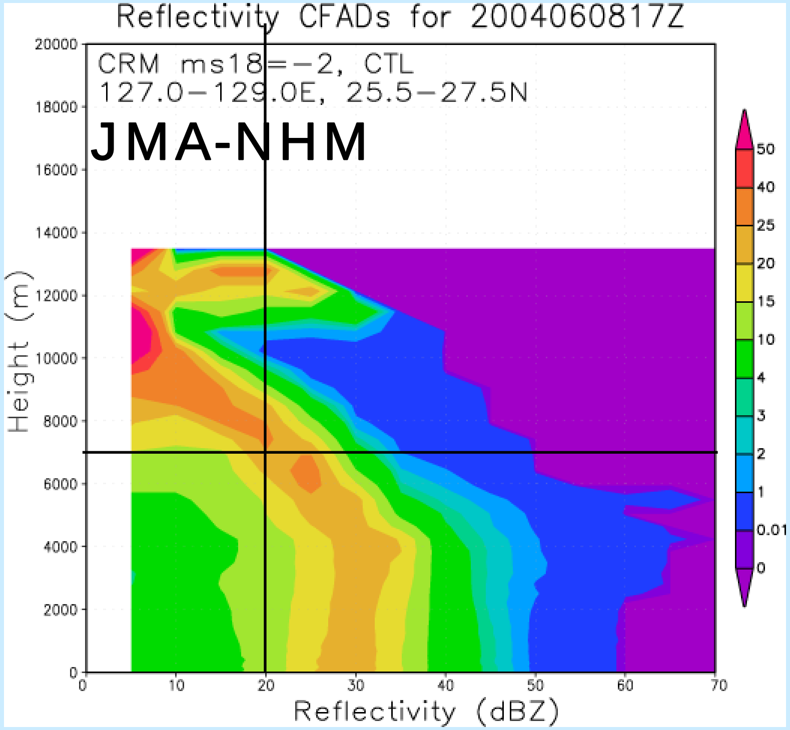


- ●NICT Okinawa Bistatic Polarimetric Radar (COBRA) captures line-shaped rainfall systems.
- ●These rainbands are mainly coverd with moderate echos of ~30 dBZ. Several intense convective cells, with reflectivities exceeding 40 dBZ, are also observed in the rainbands.
- ●JMA-NHM accurately captures the features of observed rainbands.

Comparison with radar observation

Reflectivity CFAD 17UTC 08 JUN 2004



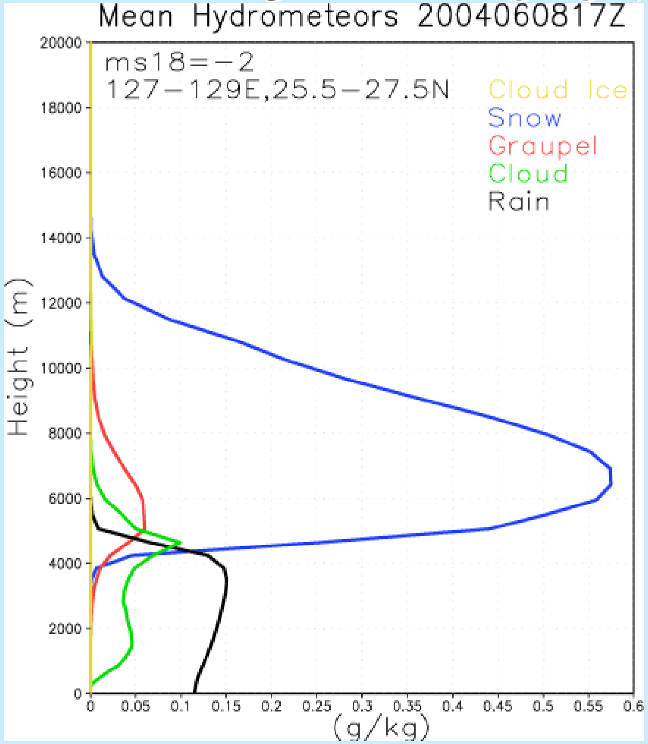


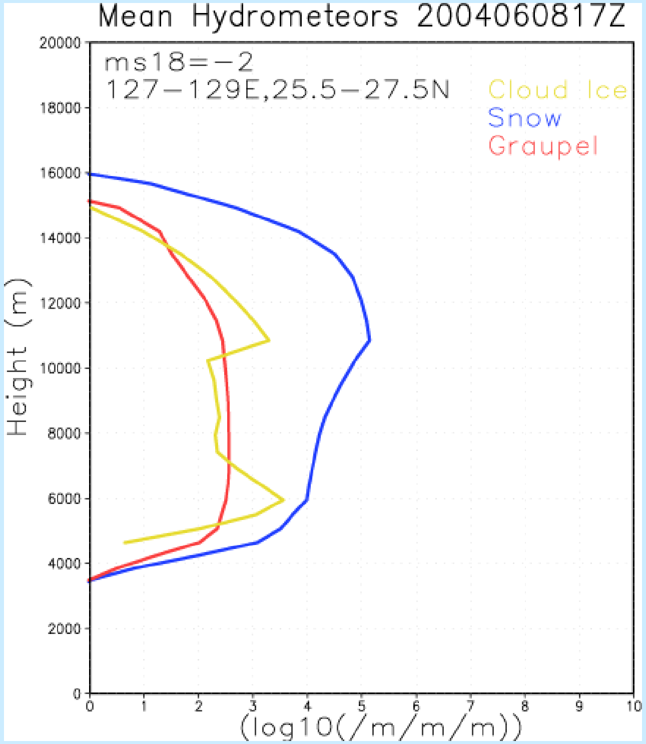
- The observed reflectivity CFAD shows that the highest probabilities follow a coherent pattern with the peak density steadily decreasing with height from between 25 and 35 dBZ near the melting level to between 10 and 20 dBZ near the strom top around 13 km.
- The simulated reflectivity CFAD shows that there is an almost good agreement between the observation and the simulation, especially below the melting level. However, maximum reflectivities are over 60 dBZ around the melting level. peak probabilities are shifted high between 4 km and 8 km, while low above 8km.

Hydrometeor profiles in JMA-NHM

17UTC 08 JUN 2004

Mixing ratios ($g\ kg^{-1}$) Number concentrations (m^{-3})





- The dominant form of ice in this simulation is snow with much smaller amount of graupel and cloud ice.
- It is reasonable that the dominant form of precipitation ice is snow in this case, because the areas with strong convection are limited and area-averaged graupel amount is probably small. However, based on the reflectivity CFAD comparison with radar data, these snow contents are too high.
- The overprediction of snow contents result in the overestimate of snow size, scattering index and radar reflectivity.

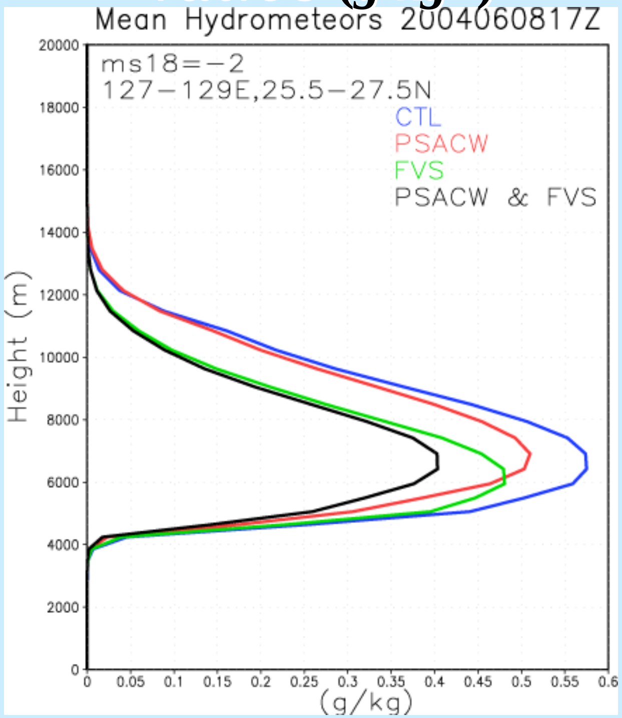
Improvements in JMA-NHM simulations

- **Comparison with radiometer and radar observation suggests that the model slightly overestimates snow size.**
- **Needed improvements of the model for reduction of snow size:**
  - **higher resolution**
  - **ice microphysical process adjustments**
  - **more detailed microphysical scheme**
- **Sensitivity experiments are conducted that involved adjustments to the ice microphysical parameters that are important to snow growth.**
  - **larger snowfall speed (FVS)**
  - **reduced riming threshold for snow to graupel conversion (PSACW)**

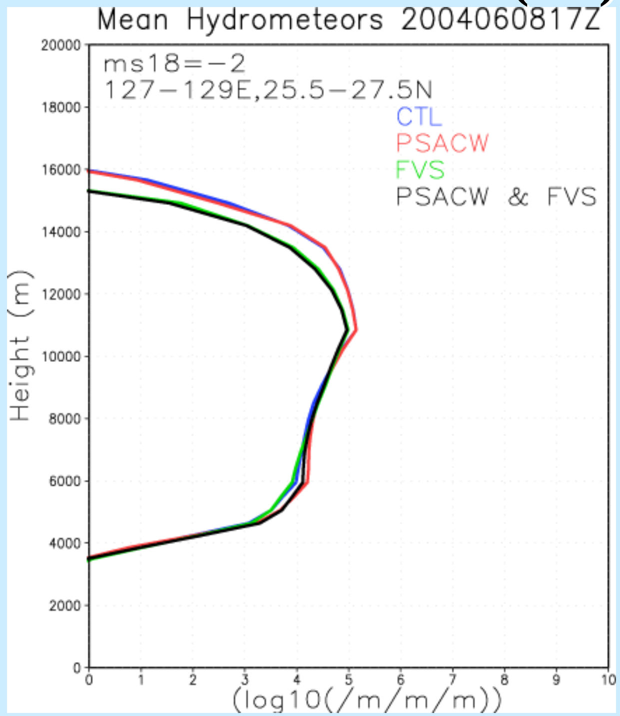
Improvements in JMA-NHM simulations

17UTC 08 JUN 2004

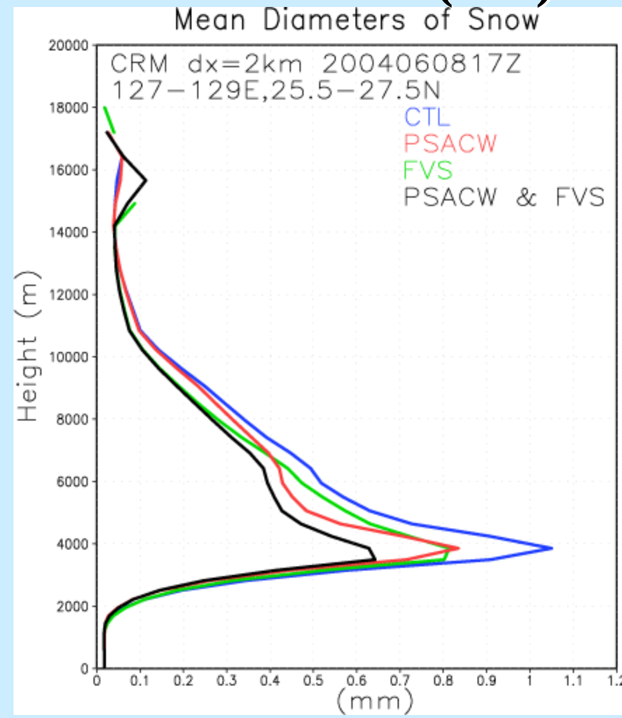
Snow mixing ratios (*g kg*$^{-1}$)



Snow number concentrations (*m*$^{-3}$)



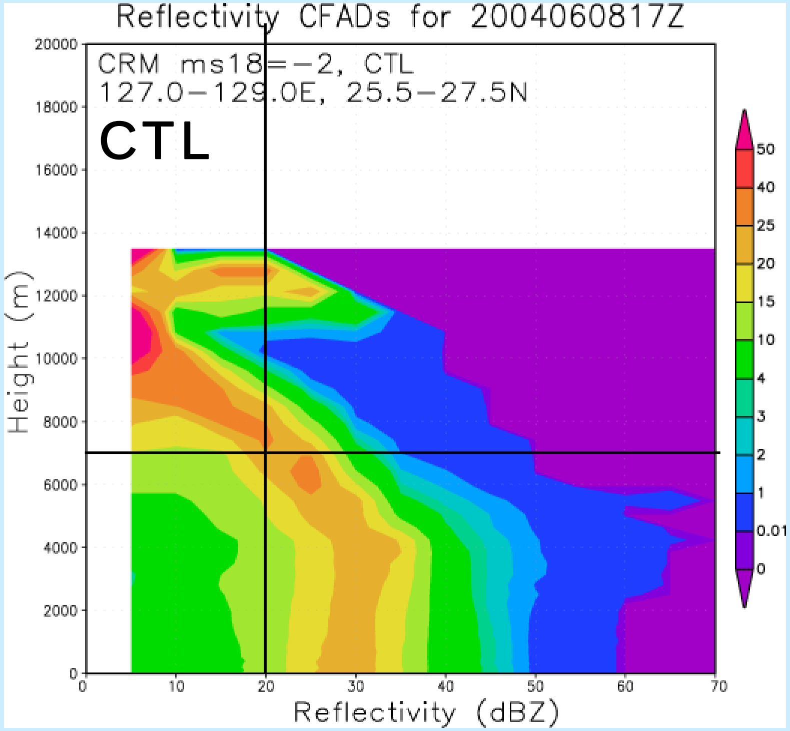
Snow mean diameters (*mm*)

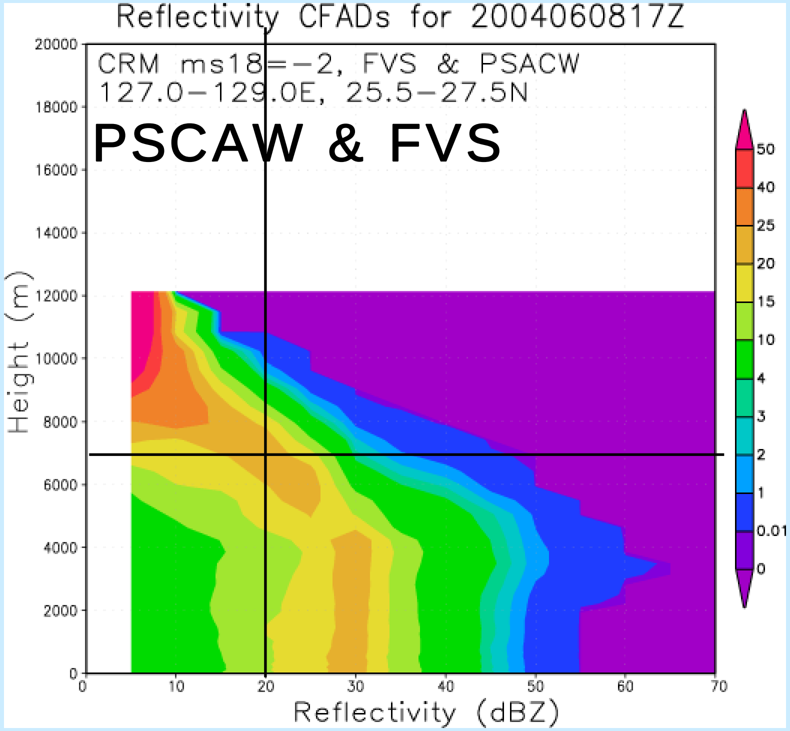


- Snow contents are reduced in both sensitivity experiments, indicating the both adjustments have a positive impact for reduction of snow content.
- Overestimate of snow size is reduced in the sensitivity experiments

Improvements in JMA-NHM simulations

Reflectivity CFAD 17UTC 08 JUN 2004

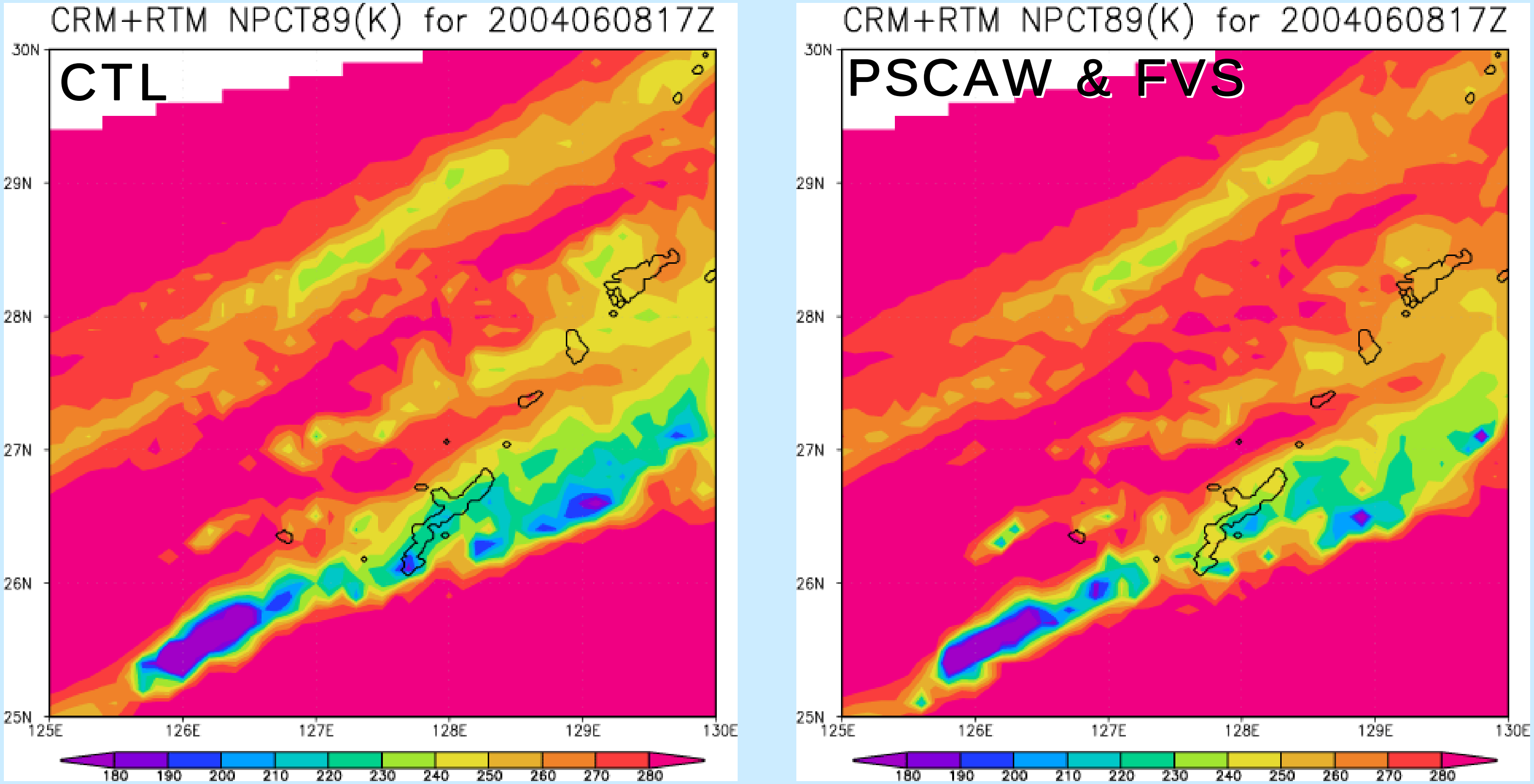




- The CFAD for sensitivity experiment shows some improvements over the control experiment.
- The improvement is the shift of probability from stronger echo to weaker echo between 4 km and 8 km above the melting level.
- Maximum reflectivities are also reduced around the melting level.

Improvements in JMA-NHM simulations

89GHz TB Scattering index 17UTC 08 JUN 2004



- The overestimate of the scattering index is reduced in the sensitivity experiment, reflecting the reduction of simulated snow diameters.
- The simulated scattering index is still slightly higher than observation, despite the improvements of the sensitivity experiment.

Summary

- TBs and Ze simulations were conducted for real rainfall systems associated with Baiu front around Okinawa Islands, Japan, which were compared to the timely corresponding AMSR-E and COBRA radar observations, respectively.
- An almost good agreement is obtained between the simulated and observed TBs and Ze; however, JMA-NHM slightly overestimated a diameter of ice hydrometeors, especially a diameter of snow particles.
- The overestimation of snow diameters were reduced by some ice microphysical process adjustments of JMA-NHM such as larger snowfall speed and reduced riming threshold for snow to graupel conversion.
- Additional cases will be analyzed to verify microphysical sensitivities of the model presented in this case and to improve the CRM and RTM by estimating biases within the models and conducting needed adjustments to their physics and parameters to reduce those biases.

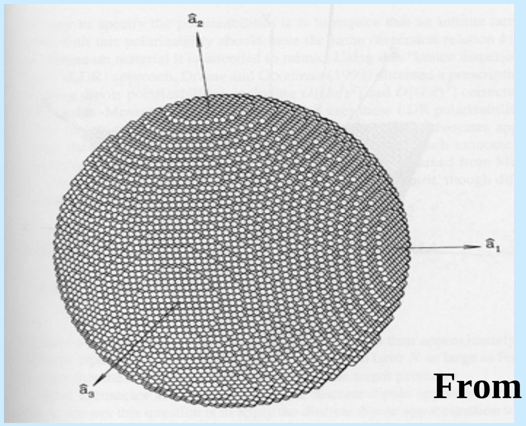
Cloud microphysics in CRM

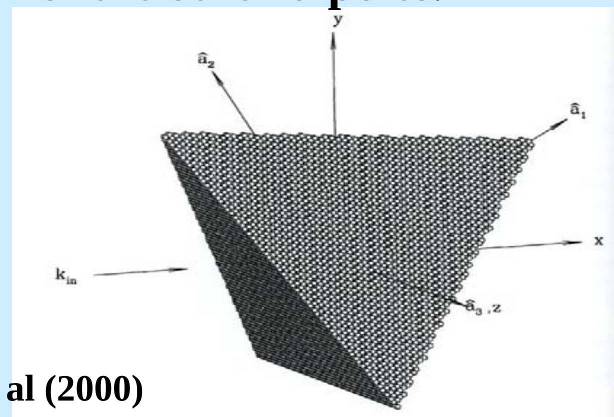
- **Shape:** sphere
- **Size distribution:** mono-dispersive distribution (*cloud water*, *cloud ice*), exponential functions (*rain*, *snow and graupel*)
- **Fall velocity:** simple power lows for their particle sizes
- **Density:** constant in each category

	Rain	Snow	Graupel	Cloud water	Cloud ice
Variable	q_r (kg kg^{-1}) N_r (m^{-3})	q_s (kg kg^{-1}) N_s (m^{-3})	q_g (kg kg^{-1}) N_g (m^{-3})	q_c (kg kg^{-1}) N_c (m^{-3})	q_i (kg kg^{-1}) N_i (m^{-3})
Size distribution	$N_r(D_r) = N_{r0}\exp(-\lambda_r D_r)$	$N_s(D_s) = N_{s0}\exp(-\lambda_s D_s)$	$N_g(D_g) = N_{g0}\exp(-\lambda_{gs} D_g)$	$\overline{D_c} = \left[\frac{6 q_c \rho}{\Pi N_c \rho_c}\right]$	$\overline{D_i} = \left[\frac{6 q_i \rho}{\Pi N_i \rho_i}\right]$
Fall velocity	$U_x(D_x) = \alpha_{ux} D_x^{\beta_{ux}} \left[\frac{\rho_0}{\overline{\rho}}\right]^{\gamma_{ux}}$				
	$\alpha_{ur} = 842$ $\beta_{ur} = 0.8$ $\gamma_{ur} = 0.5$	$\alpha_{us} = 17$ $\beta_{us} = 0.5$ $\gamma_{us} = 0.5$	$\alpha_{ug} = 124$ $\beta_{ug} = 0.64$ $\gamma_{ug} = 0.5$	$\alpha_{uc} = 2.98 \times 10^7$ $\beta_{uc} = 2.0$ $\gamma_{uc} = 1.0$	$\alpha_{ui} = 700$ $\beta_{ui} = 1.0$ $\gamma_{ui} = 0.33$
Density	$\rho_w = 1.0 \times 10^3$	$\rho_s = 8.4 \times 10^1$	$\rho_g = 3.0 \times 10^2$	$\rho_w = 1.0 \times 10^3$	$\rho_i = 5.0 \times 10^2$

Scattering properties of non-spherical frozen particles (Liu, 2004)

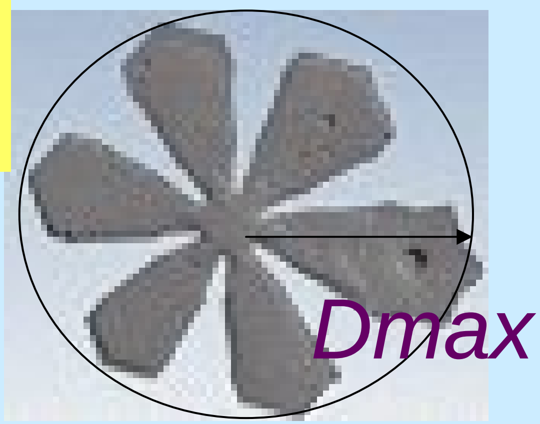
DDA :Each of the dipoles is subject to an electric field which is the sum of the incident wave and the electric fields due to all of the other dipoles.



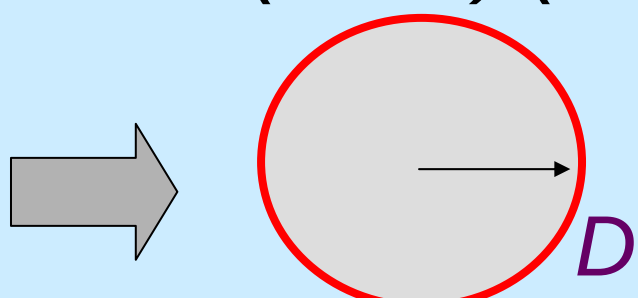


From Mishchenko et al (2000)

Non-Sphere



SP=(D-D0)/(Dmax-D0)



Sphere

- Keeping the single scattering properties

D0: diameter of solid sphere

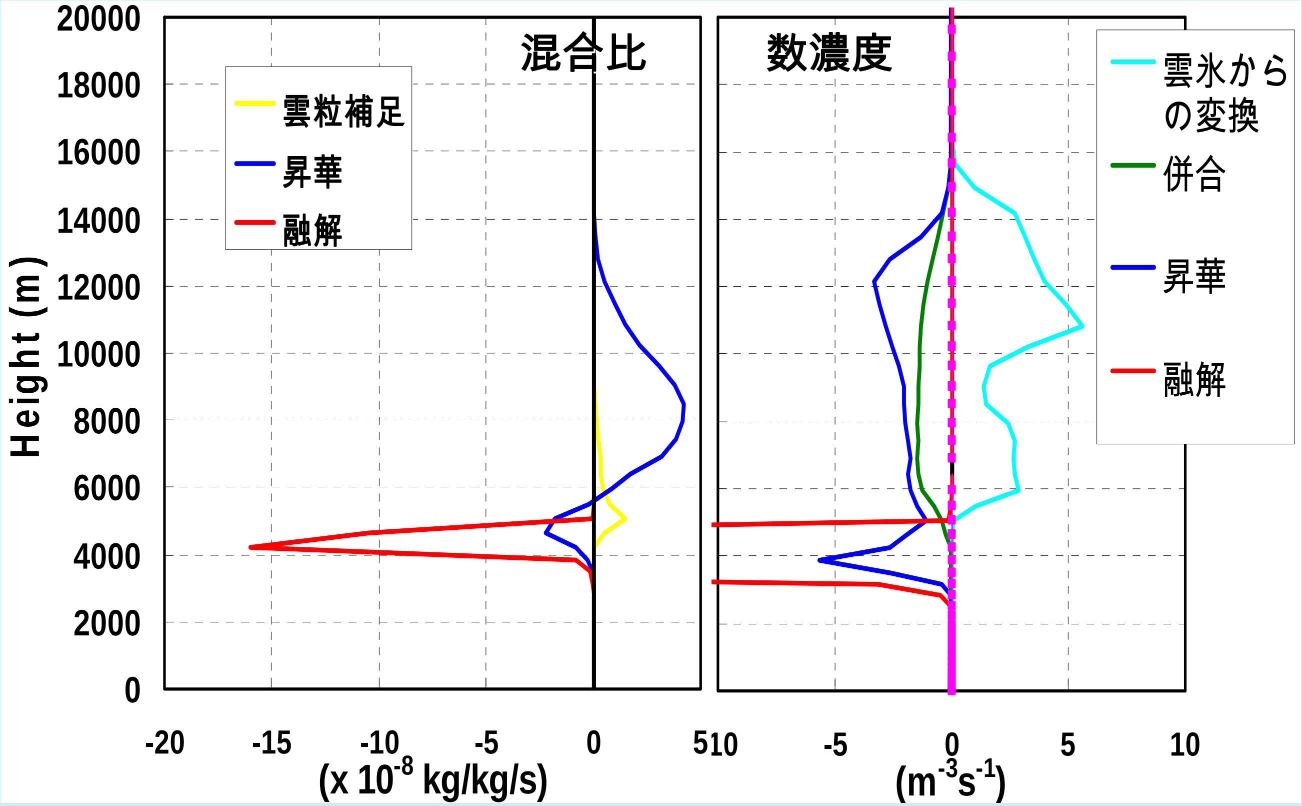
Cloud microphysical budget in CRM

17UTC 08 JUN 2004

Production terms of snow mixing ratio

Production terms of number concentrations

雪の生成項の領域平均鉛直分布



Snowfall speed sensitivity

- **Simple power laws are taken for the velocity-size relationship in the CRM.**

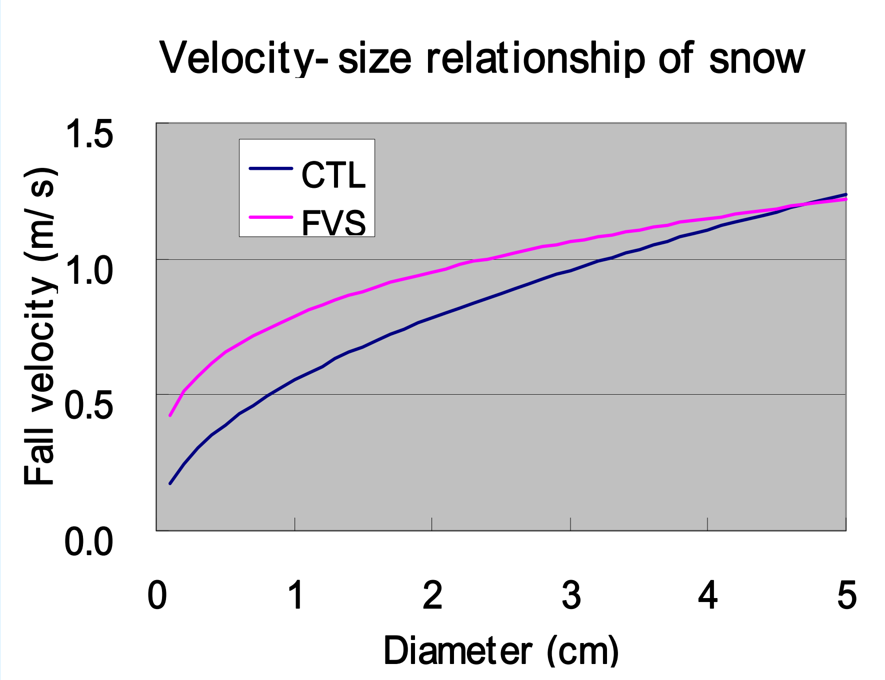
$$U_{ds}(D_s) = \alpha_s \cdot D_s^{\beta_s} \left(\frac{\rho_0}{\rho_a} \right)^{\frac{1}{2}}$$

- **The parameters for snowfall are determined referring to the observational studies.**

CTL : $\alpha_s = 17.5, \beta_s = 0.5$

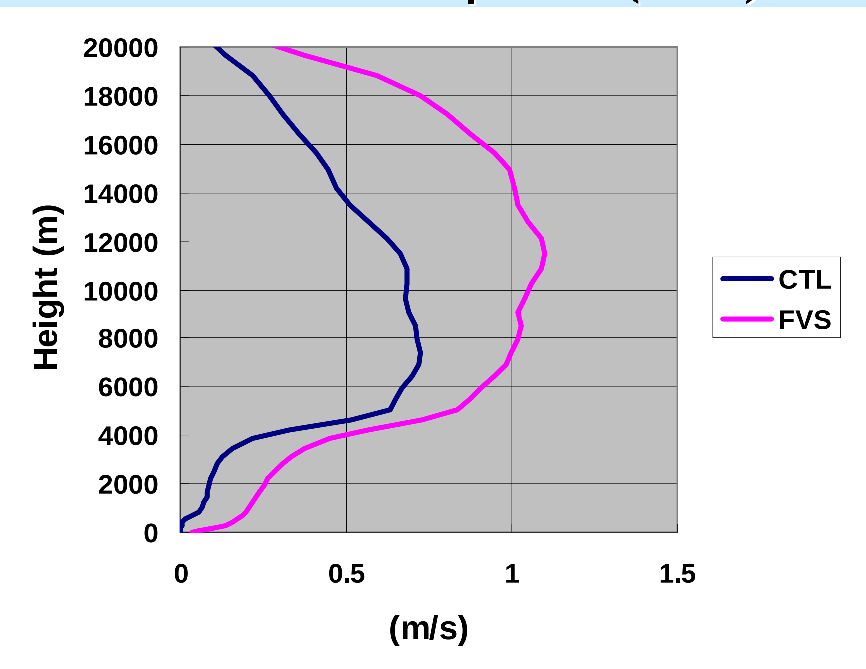
- **The sensitivity experiment is conducted using a faster snowfall speed in the smaller snow particles.**

Sensitivity run (FVS) : $\alpha_s = 5.1, \beta_s = 0.27$

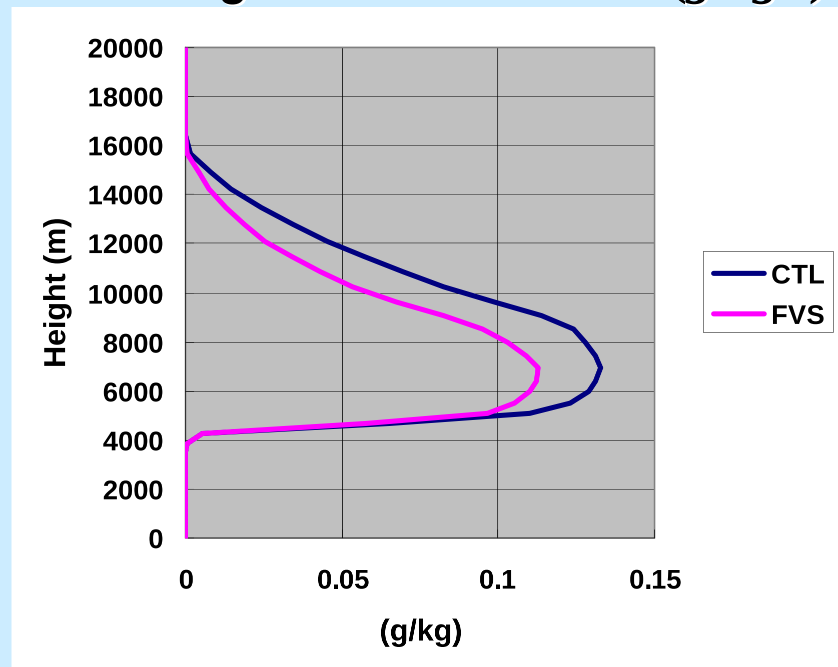


Snowfall speed sensitivity

Snowfall speed (*m s*$^{-1}$)



Mixing ratio of snow (*g kg*$^{-1}$)



- The snowfall speed in the sensitivity run (FVS) is faster than that in the CTL run at higher altitude.
- The faster snowfall speed run (FVS) results in ~15% less amount of snow as compared to the CTL.
- The changes to the microphysical budget of snow production are relatively small using the faster snowfall speed.

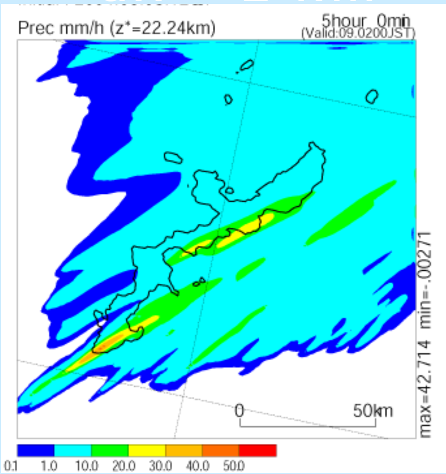
Resolution sensitivity

- **The amount of snow (and the other hydrometers) is also dependent on the model resolution.**
  - ✓ **The amplitude of vertical velocities in CRMs is strongly dependent on the model resolution; that in lower-resolution model tends to be relatively smaller.**
  - ✓ **Under smaller vertical velocities, water supersaturation is difficult to produce.**
  - ✓ **Cloud water and graupel growth are small; therefore, water vapor tends to be used for snow growth.**
- **A set of sensitivity experiments are conducted using different horizontal resolution (dx=1km, 0.5km, 0.25km and 0.125km) to quantify the sensitivities.**

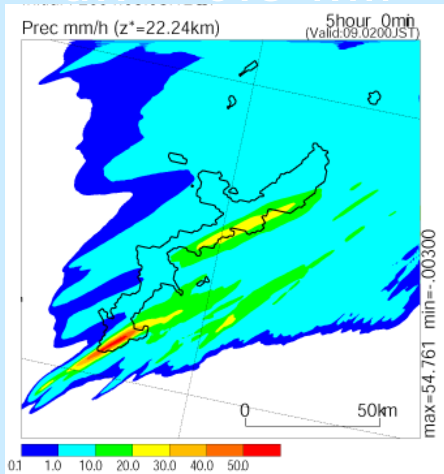
Resolution sensitivity

1-h precipitation (mm/h; FT=04-05)

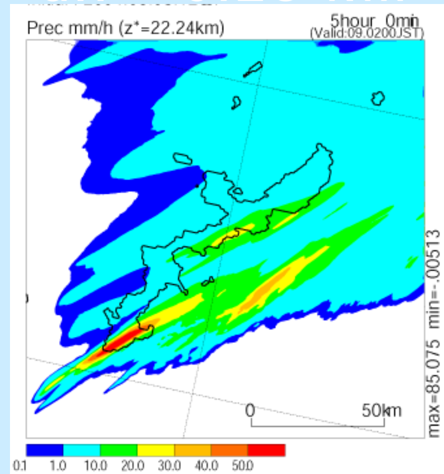
dx = 1 km



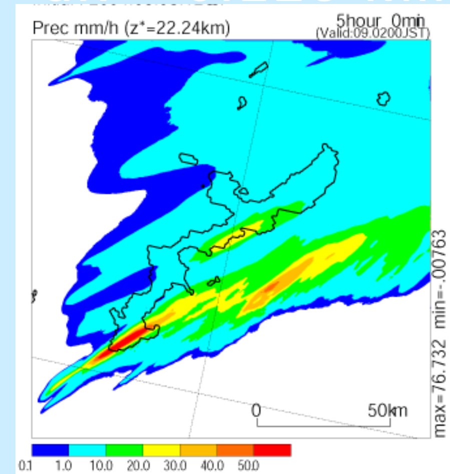
dx = 0.5 km



dx = 0.25 km



dx = 0.125 km

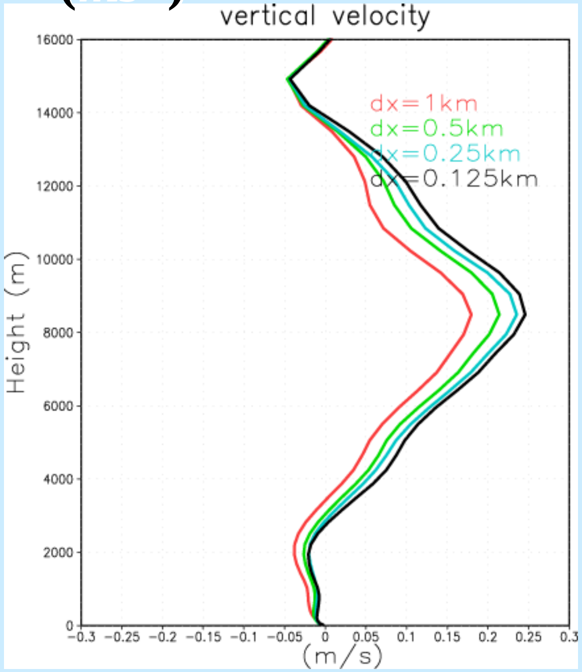


- The higher resolution run tends to have larger area of intense precipitation.

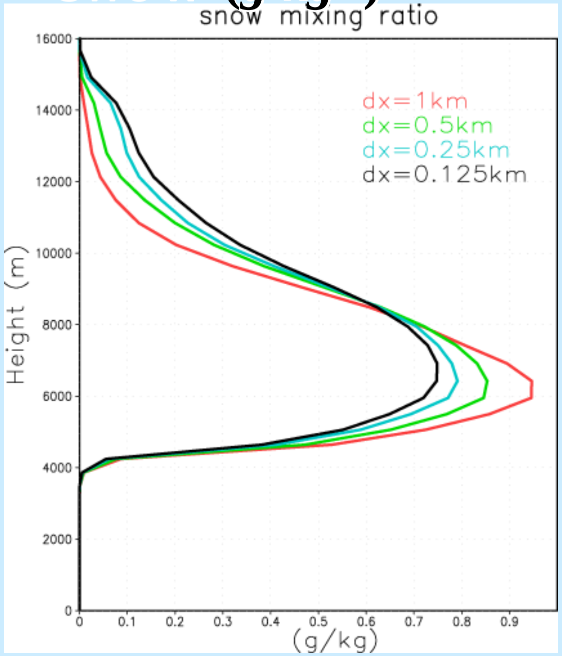
Resolution sensitivity

FT = 5 h area-average (127.5-128.5E, 26-27N)

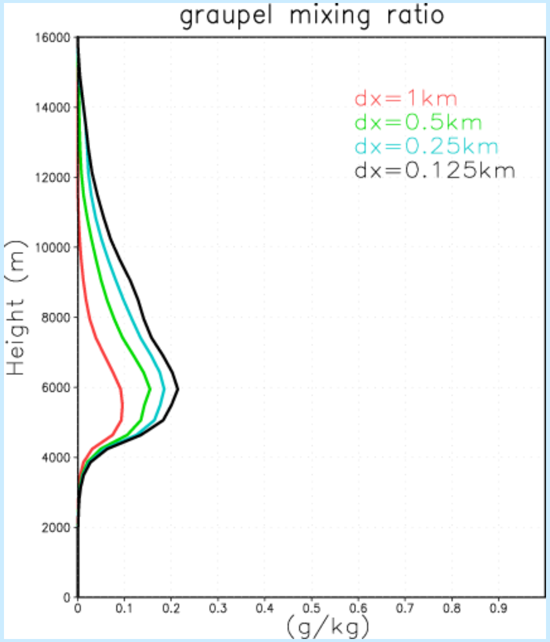
Vertical velocity (ms^{-1})



Mixing ratio of snow ($g\ kg^{-1}$)



Mixing ratio of graupel ($g\ kg^{-1}$)



- The amplitude of vertical velocity with higher resolution runs are relatively larger than that with lower resolution runs.
- The highest resolution (dx=0.125km) run results in ~ 25% less amount of snow as compared to the lowest resolution (dx=1km) experiment.
- Results of higher resolution run are close to convergence.