Real case simulations using spectral bin cloud microphysics: Remarks on precedence research and future activity

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Collaborator

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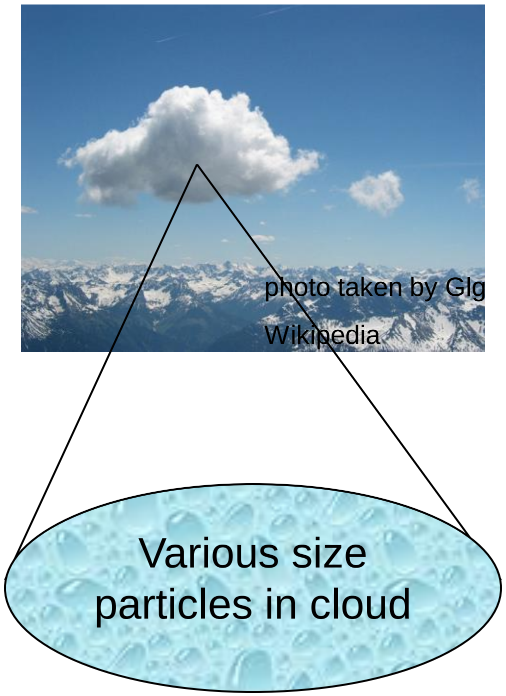
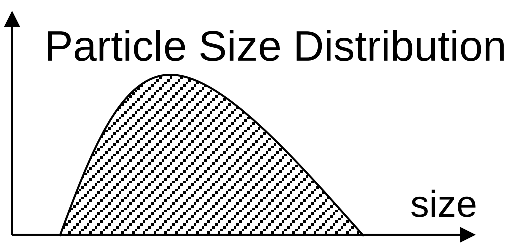
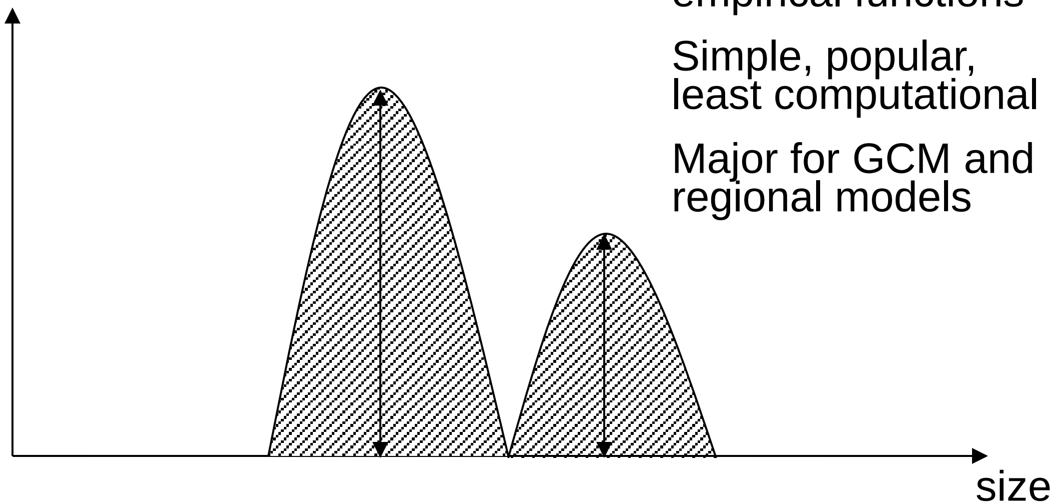
Numerical representation of cloud particle size distribution (PSD)





- Cloud microphysics
- Radiation
- Dynamics

・Bulk microphysics

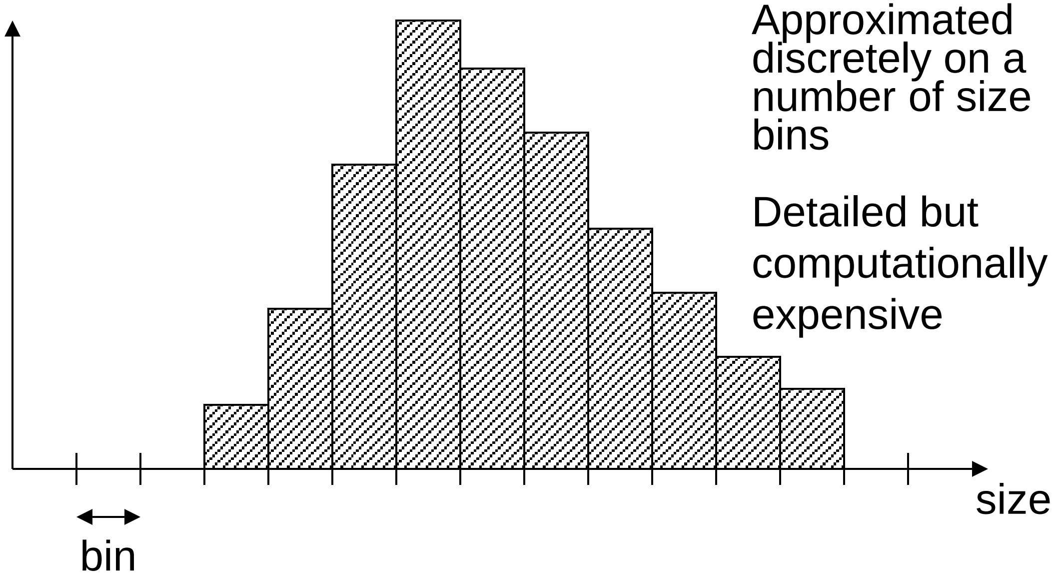


Approximated by empirical functions

Simple, popular, least computational

Major for GCM and regional models

・Spectral bin microphysics (SBM)



Approximated discretely on a number of size bins

Detailed but computationally expensive

Introduction

Spectral bin microphysics (SBM) is considered as a detailed and generally better cloud microphysical scheme than traditional bulk cloud microphysics.

SBM started to be employed in the framework of real case (real-time) simulation in the 2000s, in addition to ideal simulation framework like Large Eddy Simulation (LES).

At present, the application is on the stage of case-study usage, mostly for the research purpose of aerosol-cloud interaction on the sensitivity test basis.

Global simulation and routine weather prediction simulation (not operational) may be possible in next 10-20 years.

Starting Point

One of my case-study simulation showed that SBM simulation had worse result than bulk cloud microphysics simulation.

Analysis on the reason for this and what is needed for the further development of SBM in the framework of real case simulation.

Application of SBM real case simulations

- **Study of aerosol effect (only CCN) on clouds**

  Lynn et al. 2005ab (convective squall line over Florida)

  Iguchi et al. 2008 (stratocumulus over East China Sea)

  Khain et al. 2010 (Hurricane Katrina)

  Sato et al. 2012 (shallow stratocumulus over California off-coast)

  Fan et al. 2012 (deep convective and stratus clouds over East China)

- **Comparison with the simulations using bulk microphysics**

  Lynn et al. 2005ab, etc

- **Analysis on particular microphysical properties**

  Iguchi et al. 2012a (riming effect on snowfall over Great lakes region)

  Iguchi et al. 2012b (convective and shallow stratus modes over central US)

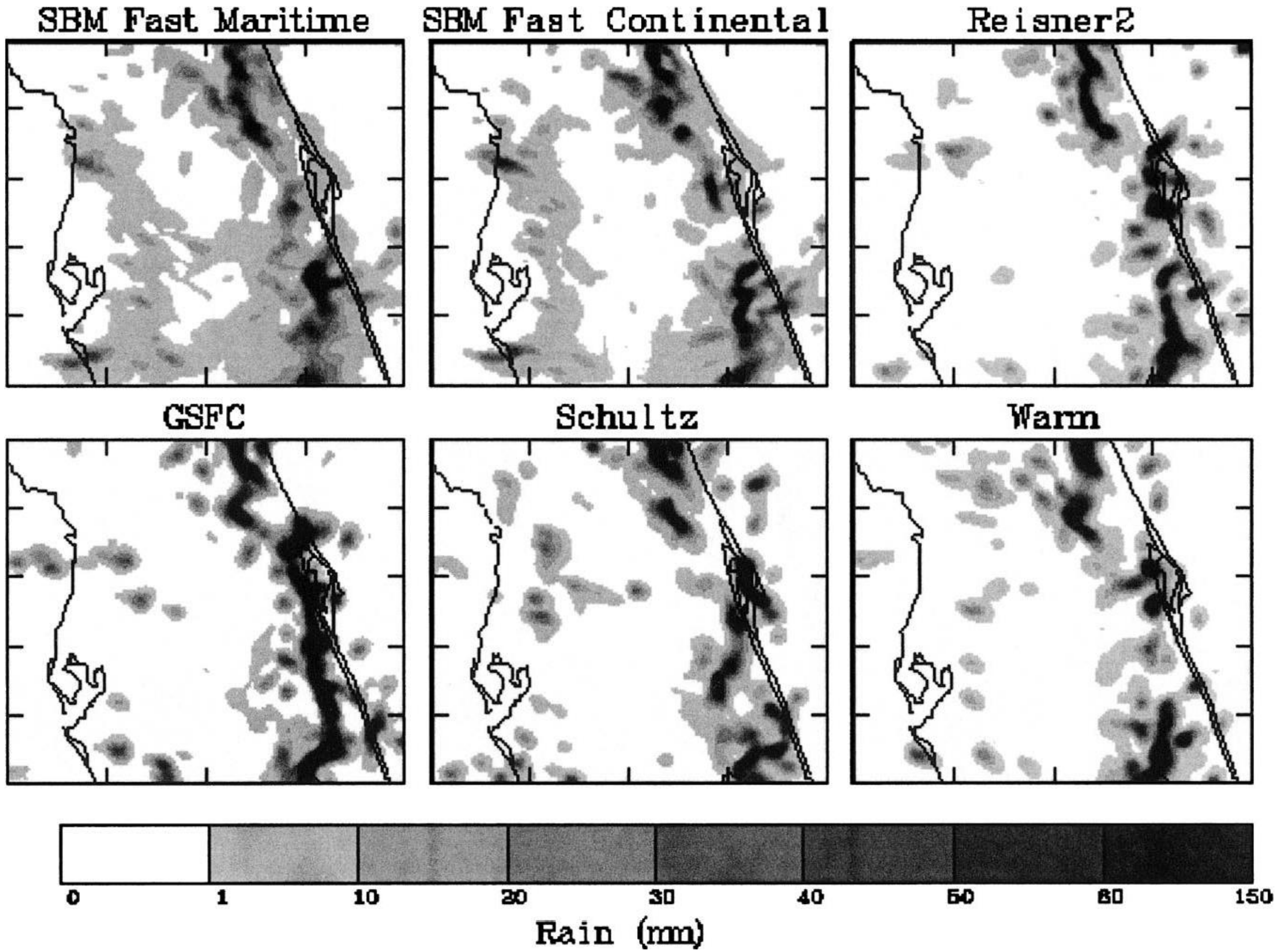
  Iguchi et al. 2014 (mixed-phase precipitation melting and bright band)

- **Supporting the development of satellite retrieval algorithm**

  Matsui et al. 2013 (GPM satellite simulator coupled with WRF-SBM)

The first study using real case simulation with SBM (MM5-SBM)

Rainfall accumulation for 3 hours over Florida



(Lynn et al., 2005b)

The first study using real case simulation with SBM (MM5-SBM)

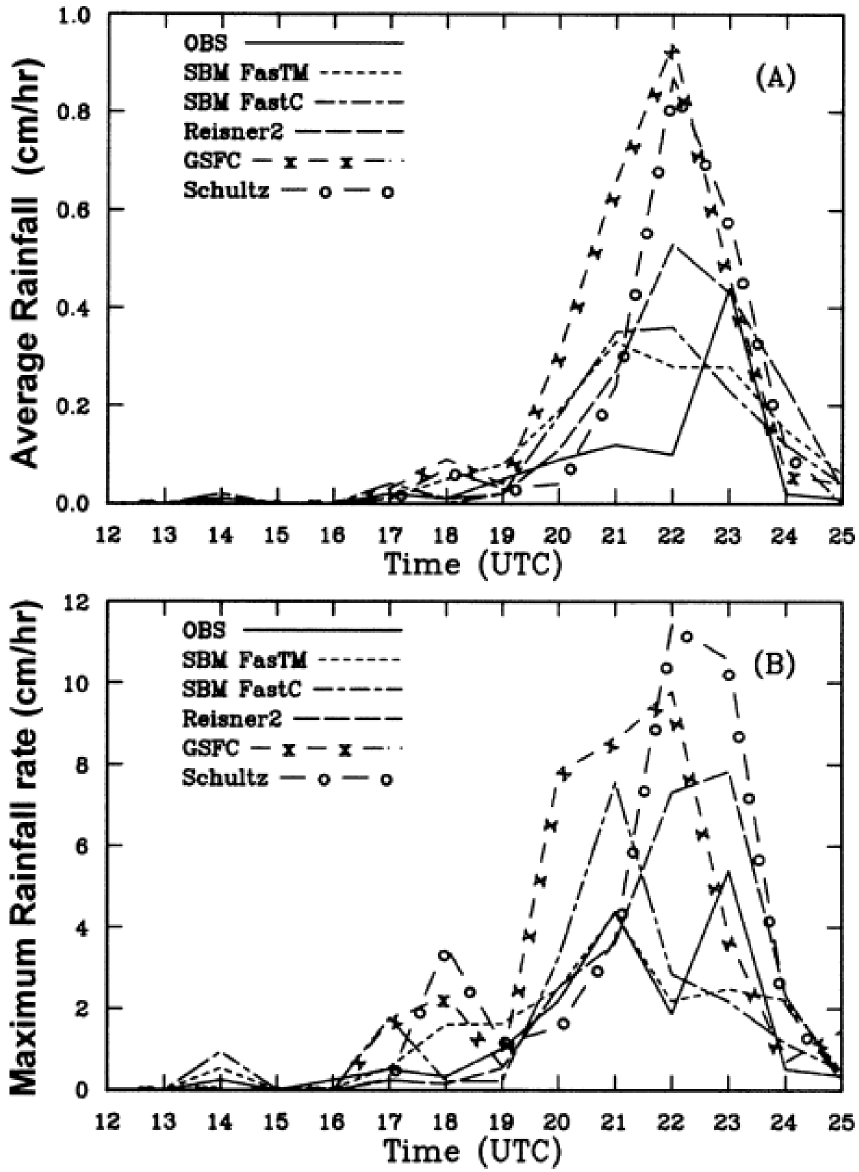


FIG. 6. Average and maximum rainfall obtained from observations and model simulations from the locations of rainfall observations shown in Fig. 3 (within the inner domain of Fig. 1).

Lynn et al. (2005b)

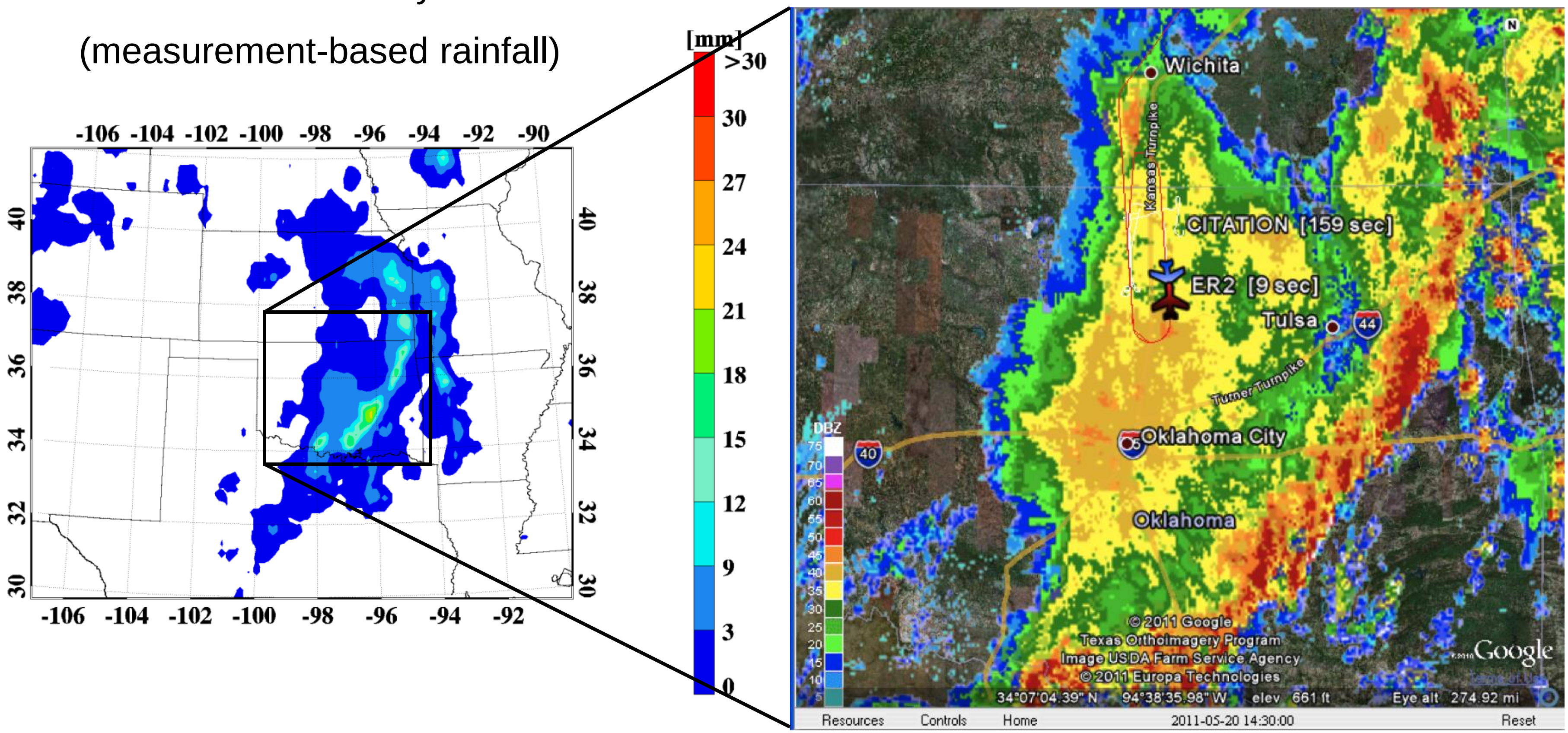
SBM is not always better than bulk cloud microphysics:

A continental squall line case over central part of US

NLDAS 1500UTC May 20 2011

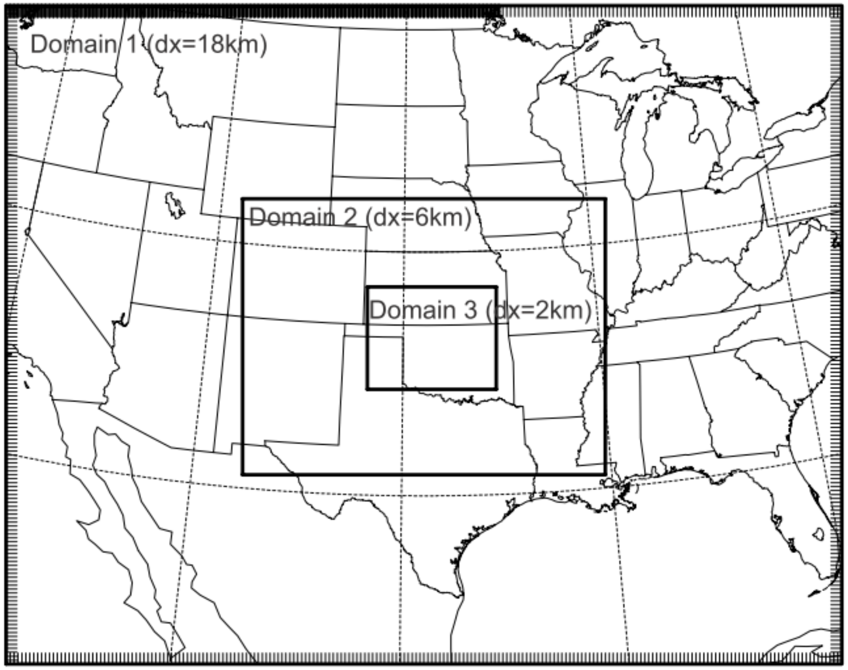
(measurement-based rainfall)

Precipitation Radar



WRF (Bulk and SBM) experiment design

48-hours integration on 20-21 May 2011



Initial and boundary conditions:

AWIP: NCEP Eta/NAM model analysis (40km)

Nesting configuration:

On-line two-way nesting the all domains

Physics options:

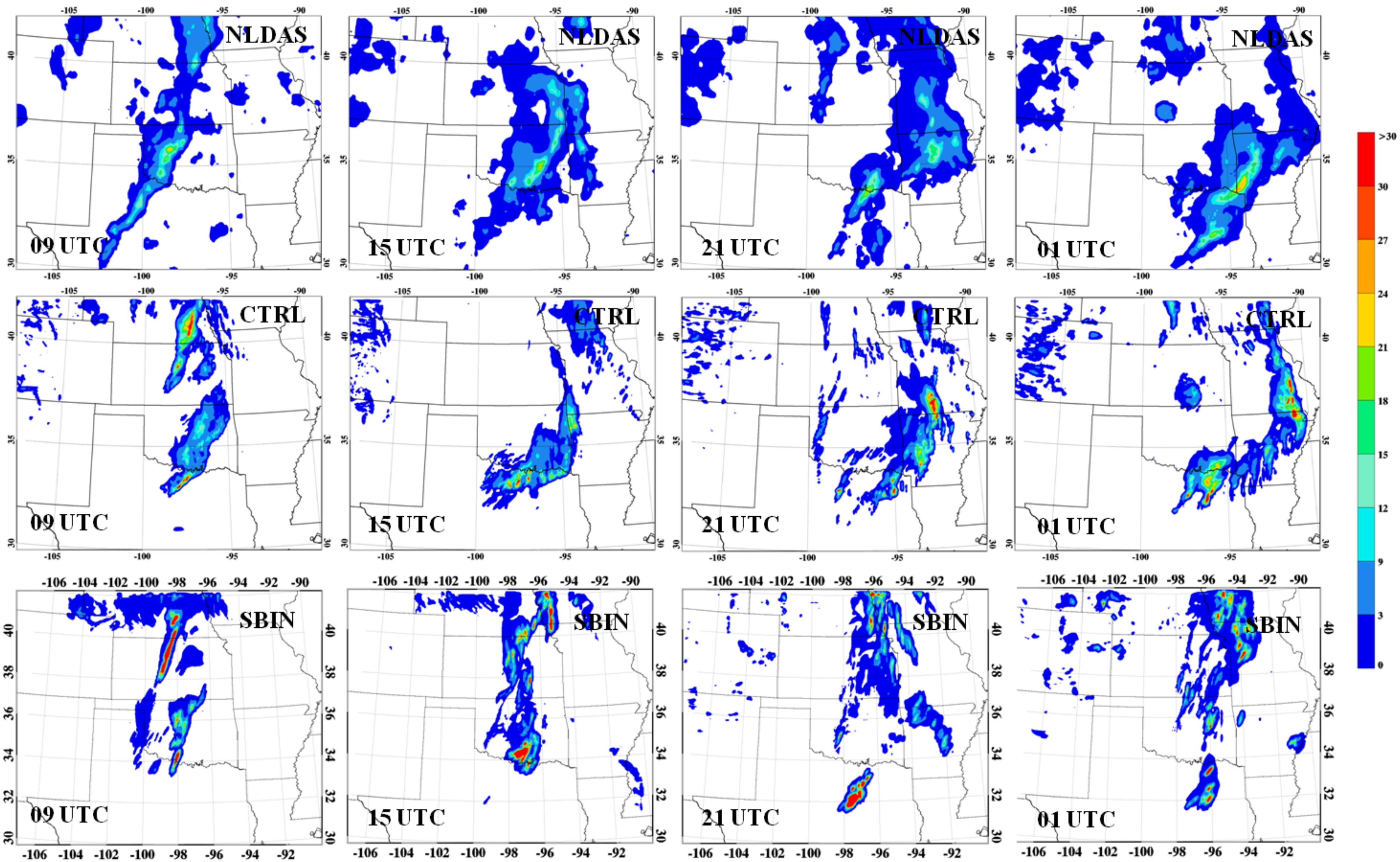
HUCM SBM / **GCE bulk cloud microphysics**

Mellar-Yamada-Janjic Level 2.5 turbulent closure model for PBL process

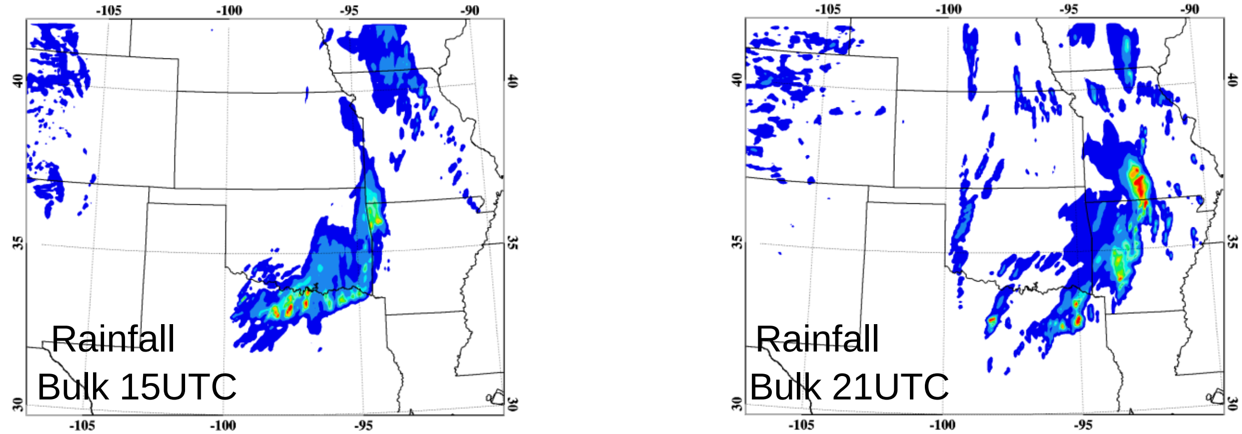
Noah land surface model with 4-layer soil structure

Goddard radiation package for both longwave and shortwave radiations

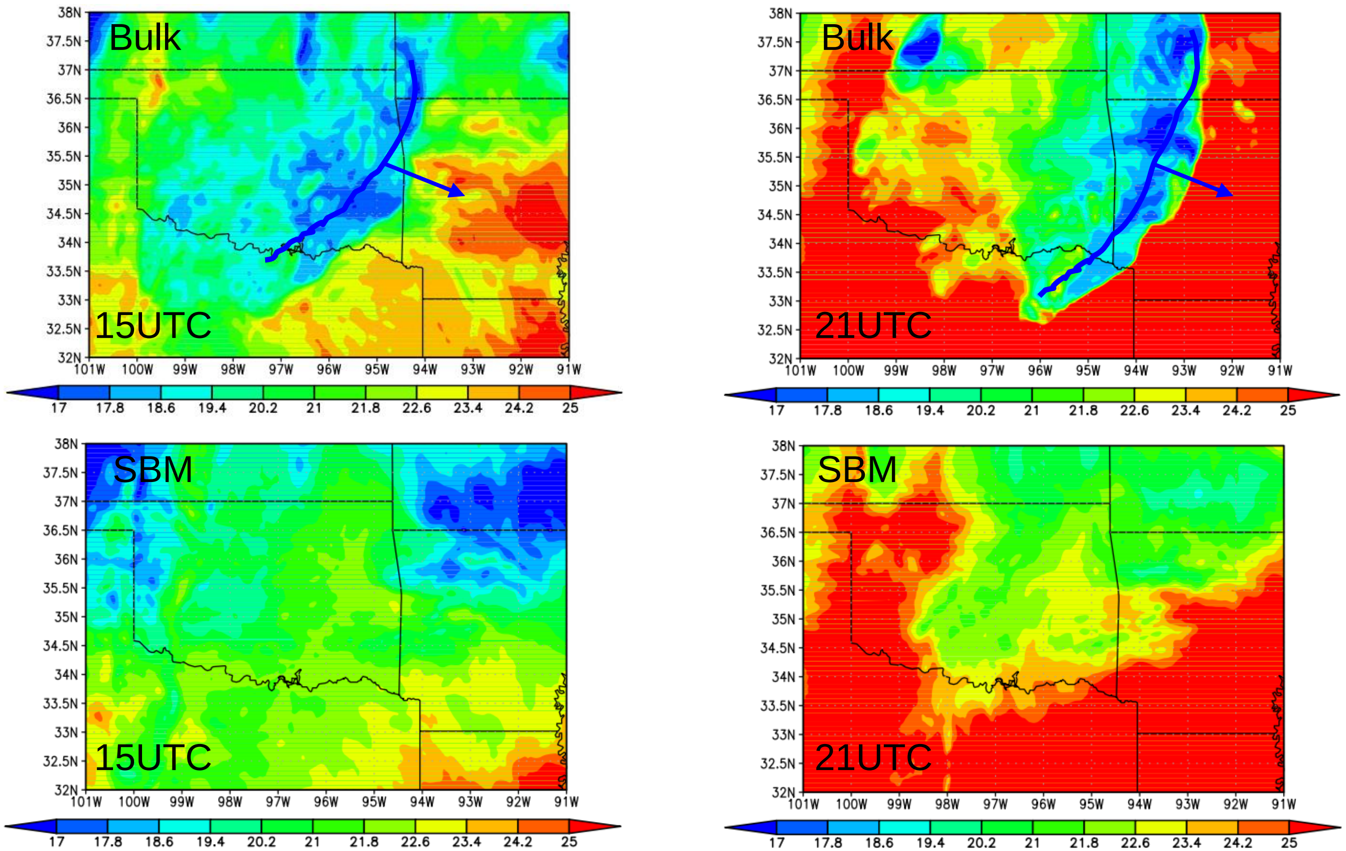
Hourly rainfall 09, 15, 21, 01UTC of NLDAS, Bulk (CTRL) and SBM



Cold pool continuously organized the squall line system



Air temperature near the surface

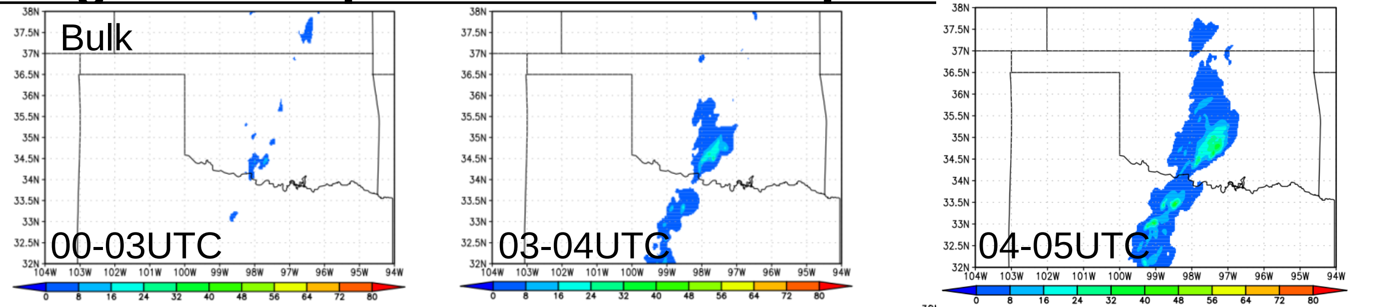


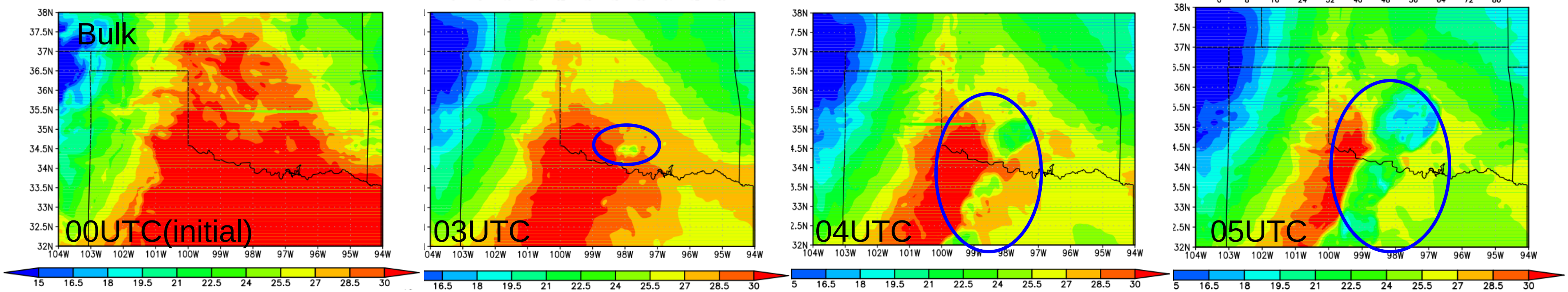
The first stage of cold pool formation in spin-up time

Bulk microphysics:

Surface rainfall (up)

Surface air temp (down)

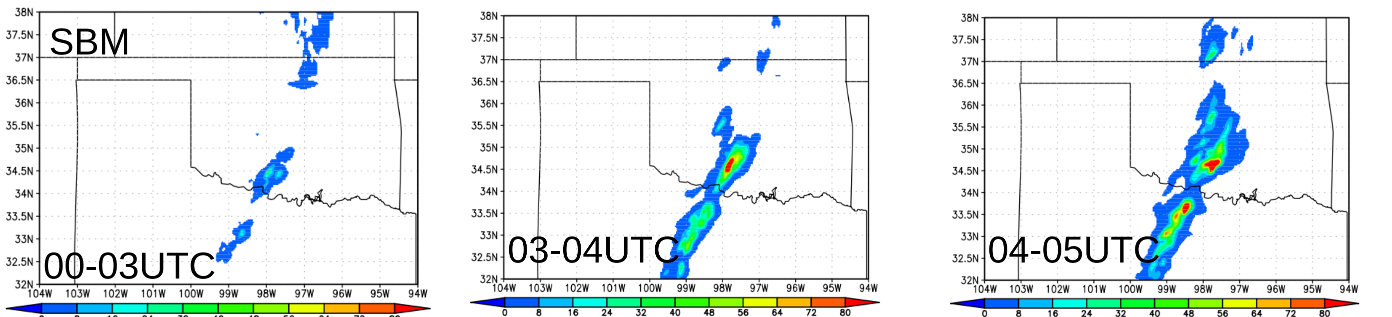


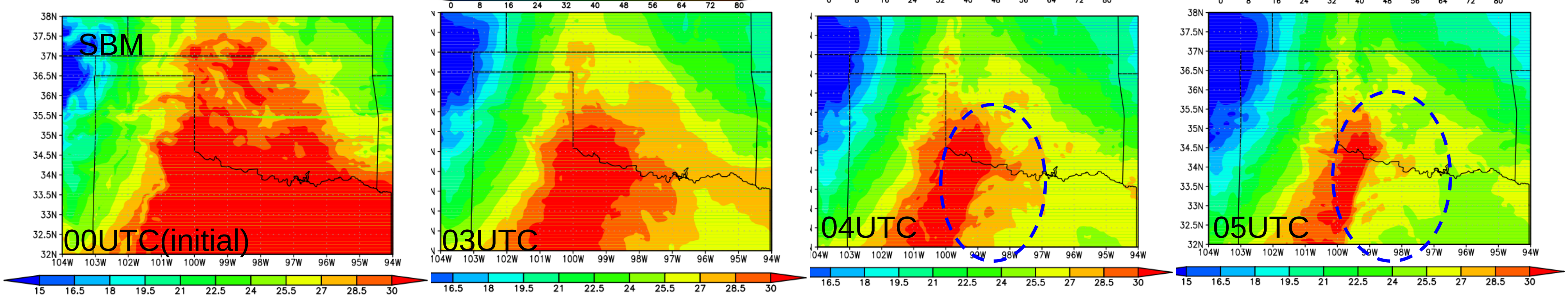


SBM:

Surface rainfall (up)

Surface air temp (down)

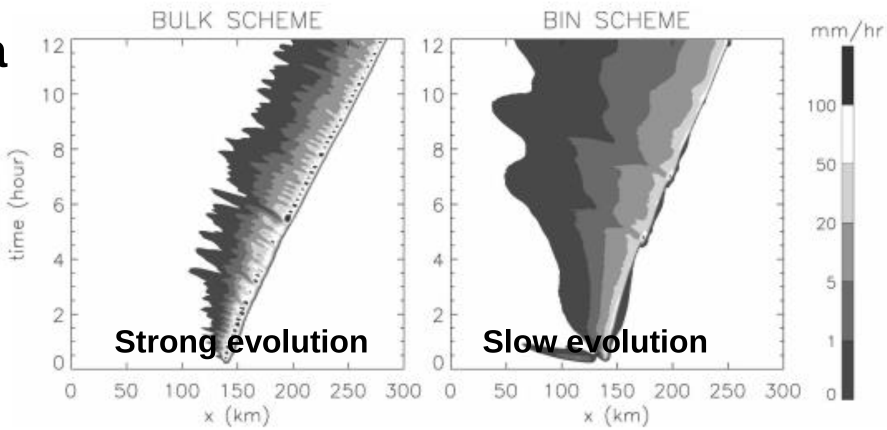




Discussion

Li et al. (2009ab): 2D ideal simulations of a squall line case using bulk and SBM

The bulk simulation produced a multicell storm with rapid and strong evolution. The bin simulation produced a unicell storm with slow and weak evolution. This distinction was caused by the difference in the rain evaporation leading to continuous cold pool formation. Note: Their bin simulation was in better agreement with the observation result in their target case.



The time-domain diagram of surface rainfall

The trends in the difference of the storm development between the bulk and bin microphysics are similar between our 3D and their 2D simulations. The difference between the bulk and SBM simulations is enlarged in our 3D simulation for large domain with no regulated initial forcing.

SBM provides either better or worse result according to factors, e.g. compatibility with the initial condition. (Ensemble forecasting approach may be effective to reduce the uncertainty)

Summary

- SBM is not always better than bulk microphysics, but an approach with better potential. Many uncertain parts still remain, especially in mixed-phase processes.

- Variation induced by difference in the types of microphysics may be much larger in deterministic real case simulations than in ideal simulations. This issue should be more concerned in sensitivity tests for aerosol-cloud interaction study.

- Routine and/or ensemble forecasting approach is the next step for the quantitative evaluation, advanced from qualitative evaluation on a case study basis. (We need more high-performance computers!)

Global Precipitation Measurement mission (GPM)

The core satellite was successfully launched last Friday!

Image Credit: NASA/Bill Ingalls

Extra Slides

Computational Cost

CPU usage report on WRF simulations on a massive Linux server:

A sample case for WRF-ARW run (US east coast winter storm of Jan 24, 2000)

Single domain configuration with 74 x 61 grids and 28 levels

12 hours integration with 3 minutes time-step intervals (240 time-steps)

Output every 1 hour

- GCE 1-moment Bulk: typical bulk (qc, qr, qi, qs, qg)
- HUCM 1-moment SBM: 500 additional tracers

	CPU time	Advection	Microphysics	Dynamics & others	Output file size
GCE Bulk	00:00:35	0%	12%	85%	12Mb
SBM	01:58:46	10 %	60 %	30 %	234Mb

SBM needs 250 times (orders of 10 or 100 times, in general) CPU time as much as bulk microphysics

<u>Microphysics</u>

- **Ice nucleation (ice nuclei) ?**
- **Density and shape of mixed-phase particle ?**

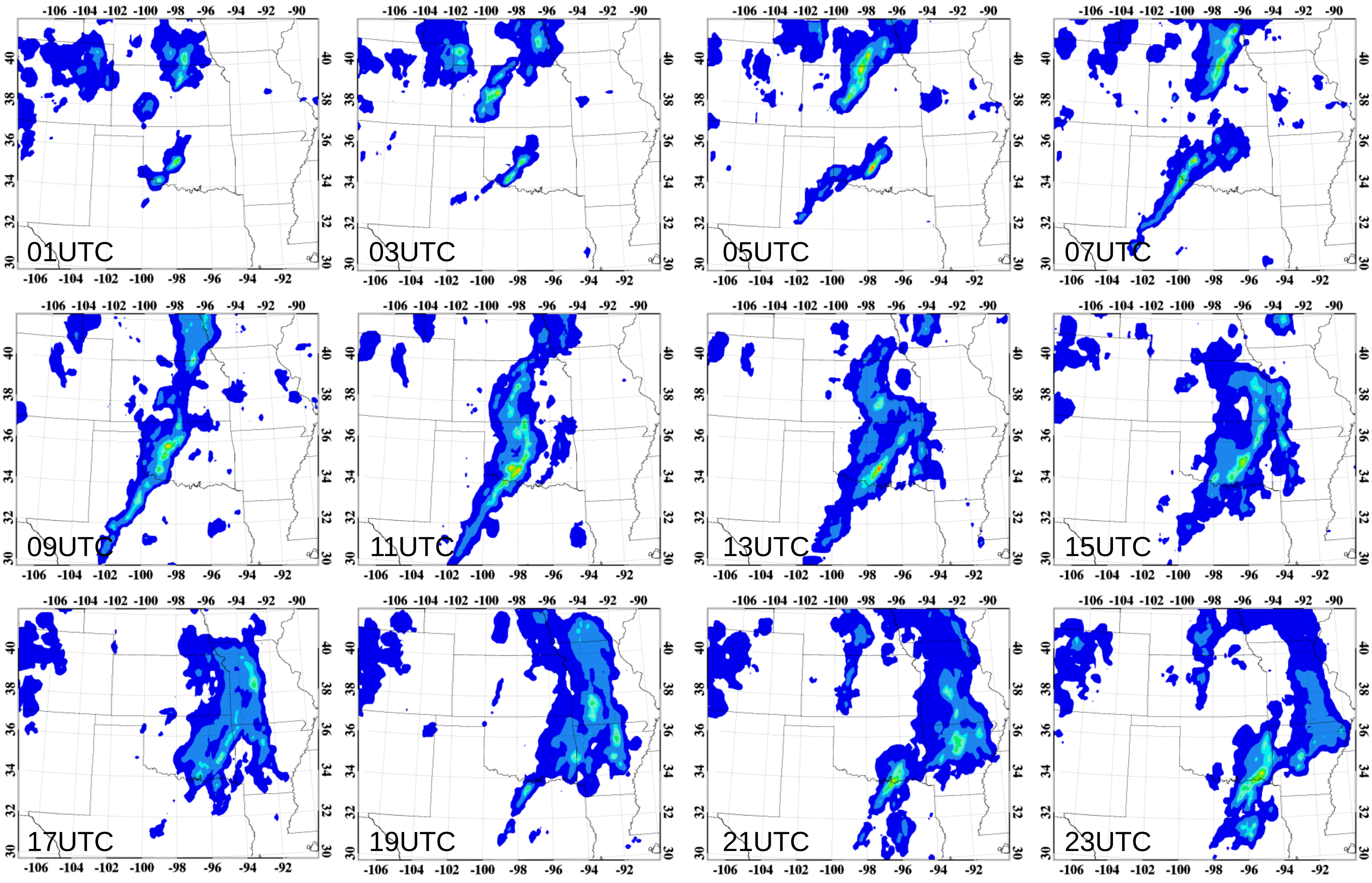
<u>Simulation</u>

- **Data assimilation ?**
- **Ensemble simulation ?**
- **Chemical model ?**
- **Isotope model ?**
- **Global model ?**
- **Regional climate model ?**

<u>Architecture</u>

- **CPU or GPU ?**

Hourly rainfall of NLDAS

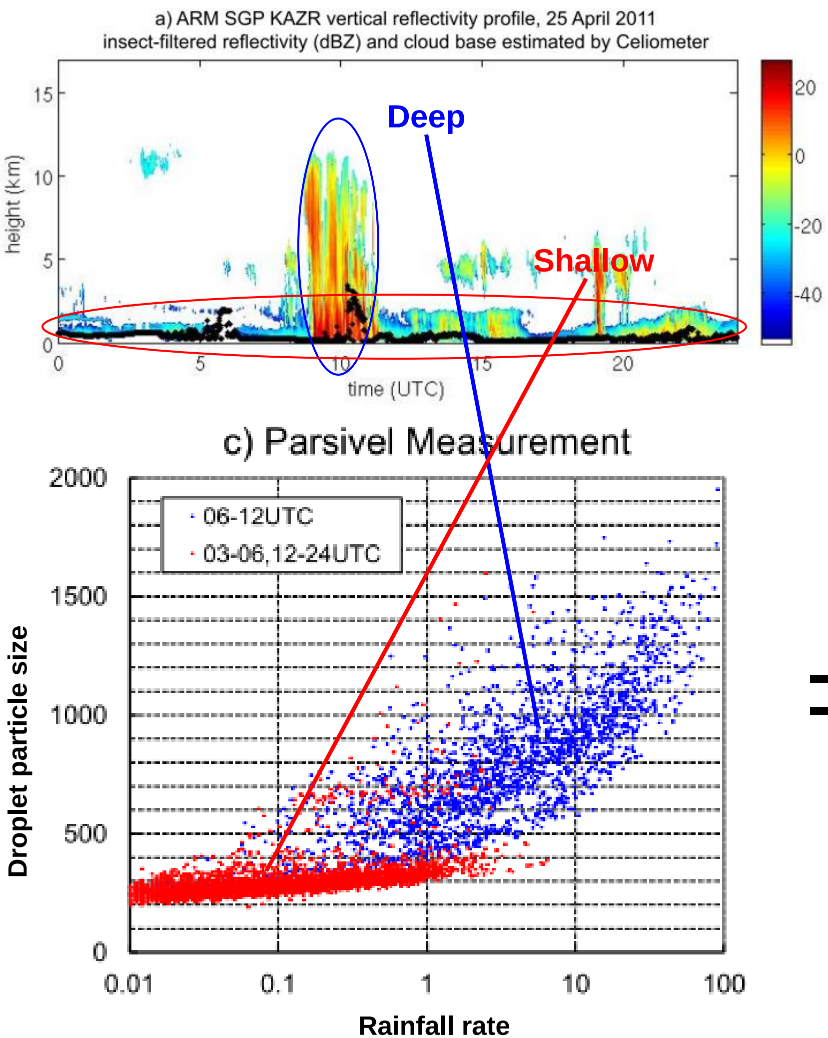


Bulk microphysics and SBM: the advantages and disadvantages

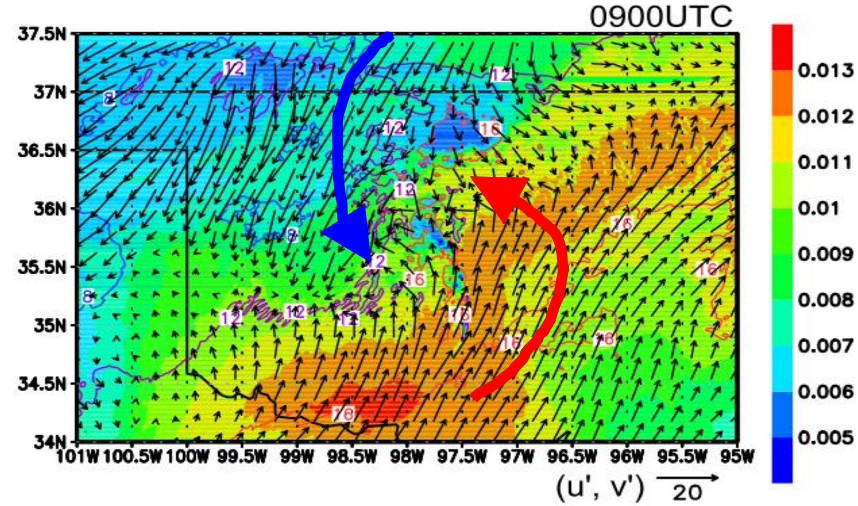
Bulk	Bin
Long history and many users	Short history and less users
More simple	More complicated
More assumptions	More straightforward
More tuning parameters	Less tuning parameters
Less CPU time	More CPU time

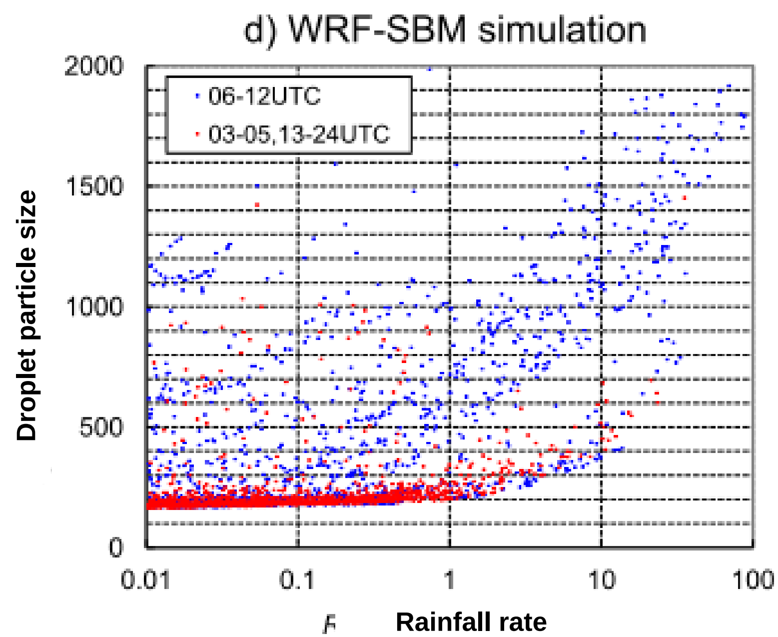
Two mode of rainfall characteristic in continental rainfall event over central US

Ka-band zenith radar and Parsivel disdrometers on ARM SGP site revealed two distinct modes of DSD in shallow and deep convective clouds in one-day rainfall.



a) Vapor (kg/kg, shaded), temperature (degree C, contour), and horizontal wind anomaly (m/s, vectors) on 850 hPa



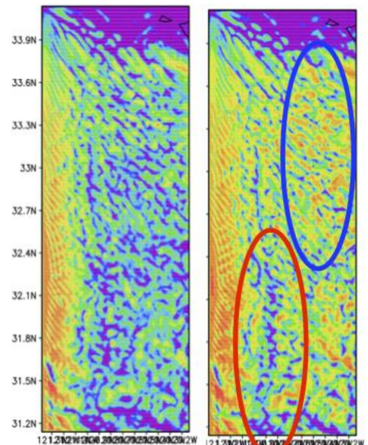


Stratus clouds case (Sato et al. 2012 and p.c.)

Bulk model is good even not considering any explicit aerosol effects. SBM needs perfect treatment (aerosol regeneration process) to simulate the observed clouds.

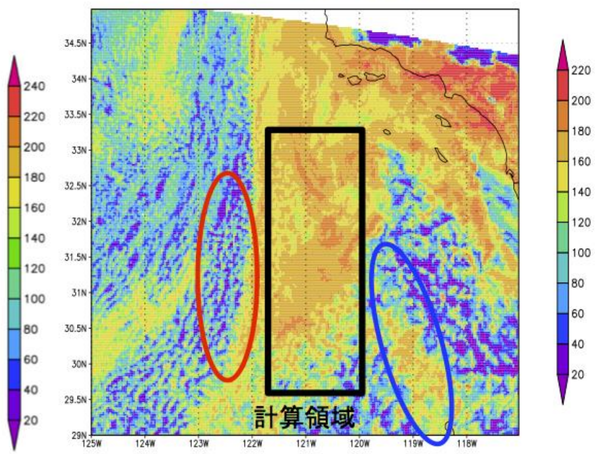
モデルの妥当性評価（衛星との比較(Radiance λ=0.62μm)）

モデル＋J-simulator



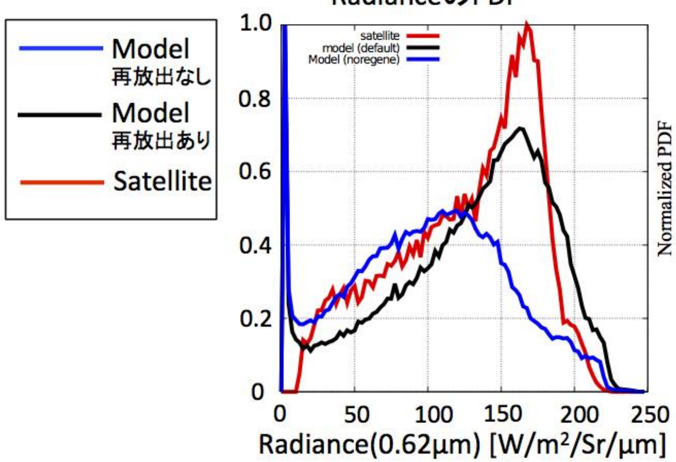
再放出なし　再放出あり

衛星の観測結果

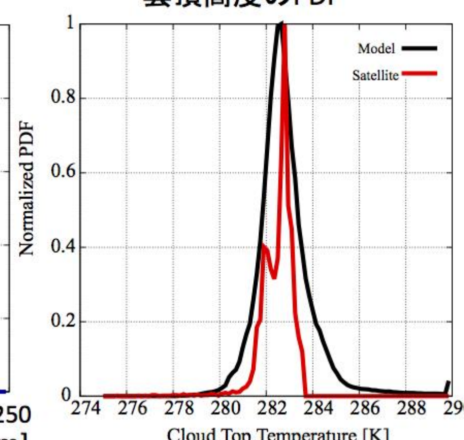


- regeneration過程がないと雲が厚くならないためradianceも過小評価になっている
- 再放出を入れると当該領域の雲の構造を完全に再現できてはいないが、セル構造のでているところに関しては比較的良く再現できている。
- また相関パターンも再現できている

RadianceのPDF



雲頂高度のPDF



エアゾロル鉛直積算数密度 [10^4 cm^{-2}]	
再放出あり	6.73
再放出なし	5.85

数密度にして14%程度が再放出で生成されている

WRF coupled with spectral bin microphysics (WRF-SBM)

WRF

WRF model

- 3-D mesoscale model
- Real domain and condition
- Basic physical processes
- Bulk cloud microphysics

SBM

SBM from HUCM

- Detailed microphysics
- Particle size distribution
- Nucleation process from CN

WRF-SBM

GPM synthetic simulator and database for the algorithm testbed

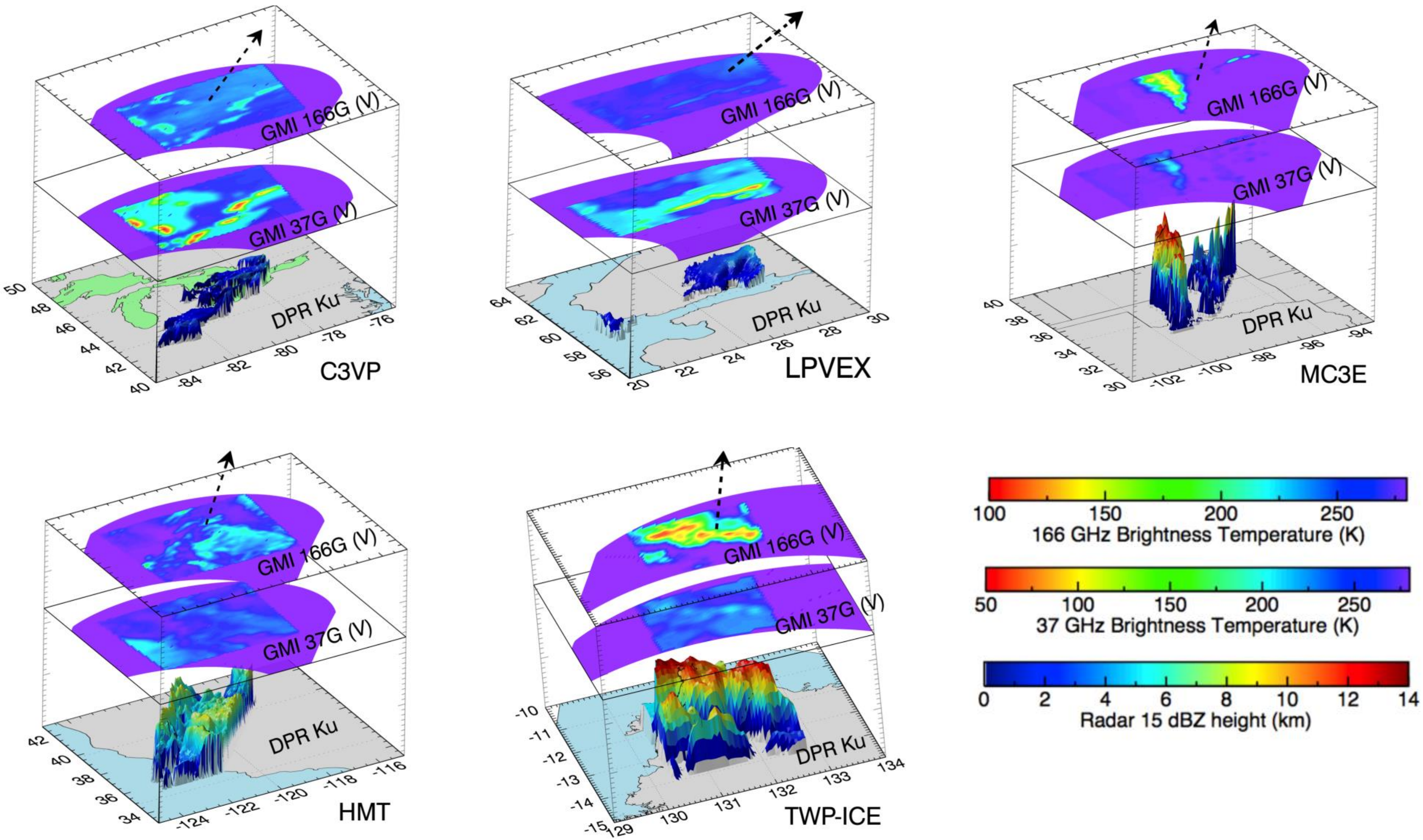
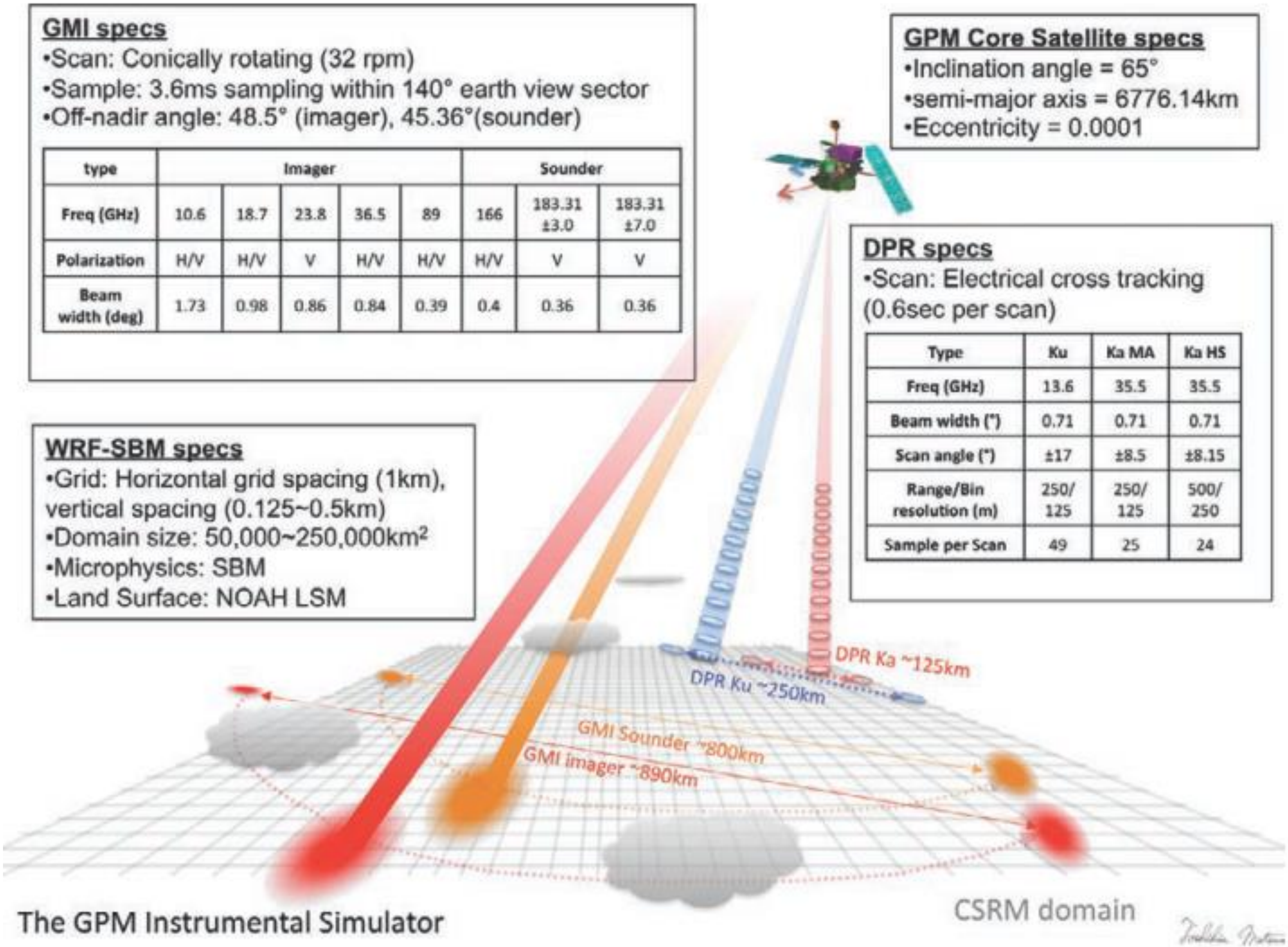


FIG. 3. Three-dimensional view of the simulated GPM orbital data over selected simulation scenes from C3VP, LPVEX, MC3E, HMT, and TWP-ICE. Color-shaded terrain represents 15 dBZ echo-top height of the DPR Ku band, and horizontal slices of color shades represent microwave brightness temperature of the GMI 37 and 166 GHz (V) channels.

Matsui et al. (2013)


GMI specs
•Scan: Conically rotating (32 rpm)
•Sample: 3.6ms sampling within 140° earth view sector
•Off-nadir angle: 48.5° (imager), 45.36°(sounder)

type	Imager					Sounder		
Freq (GHz)	10.6	18.7	23.8	36.5	89	166	183.31 ±3.0	183.31 ±7.0
Polarization	H/V	H/V	V	H/V	H/V	H/V	V	V
Beam width (deg)	1.73	0.98	0.86	0.84	0.39	0.4	0.36	0.36

GPM Core Satellite specs
•Inclination angle = 65°
•semi-major axis = 6776.14km
•Eccentricity = 0.0001

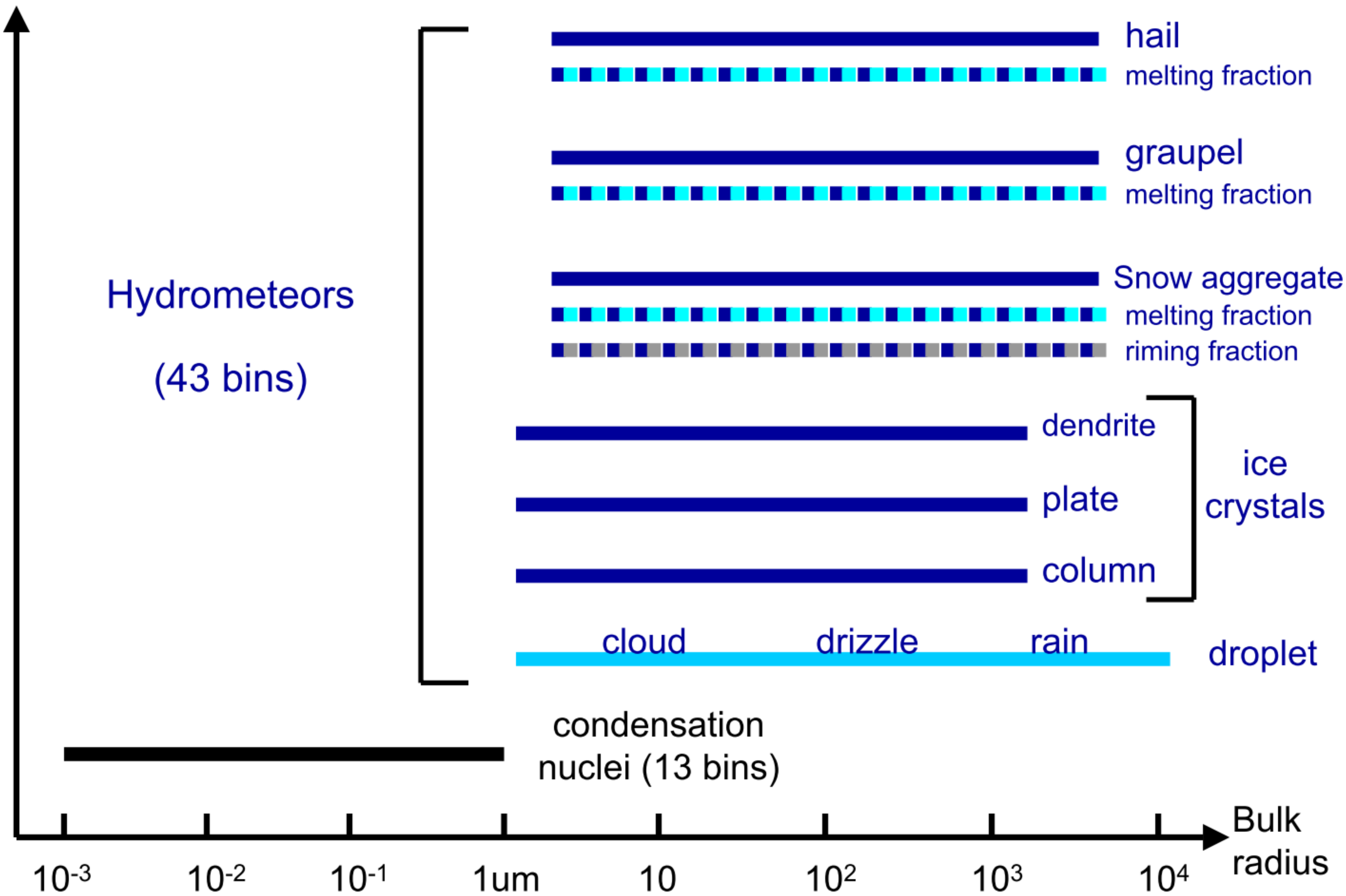
DPR specs
•Scan: Electrical cross tracking (0.6sec per scan)

Type	Ku	Ka MA	Ka HS
Freq (GHz)	13.6	35.5	35.5
Beam width (°)	0.71	0.71	0.71
Scan angle (°)	±17	±8.5	±8.15
Range/Bin resolution (m)	250/ 125	250/ 125	500/ 250
Sample per Scan	49	25	24

WRF-SBM specs
•Grid: Horizontal grid spacing (1km), vertical spacing (0.125~0.5km)
•Domain size: 50,000~250,000km²
•Microphysics: SBM
•Land Surface: NOAH LSM

DPR Ka ~125km
DPR Ku ~250km
GMI Sounder ~800km
GMI imager ~890km
The GPM Instrumental Simulator
CSRM domain

Particles categories and bins (the total number of bins is about 500!)



What study can be done by using NWP-SBM model?

- **Study of interaction between aerosol and cloud**

  Iguchi et al., 2008; Khain and Lynn, 2009; ANTISTORM project; Khain et al., 2010

- **Comparison with simulations using bulk microphysics**

  Lynn et al., 2005ab; Lynn and Khain, 2007

- **Evaluation of model by comparison with remotely sensed mea.**

  Iguchi et al., 2012ab

- **Supporting the development of satellite retrieval algorithm**

  Matsui et al., 2013

- **Data assimilation ?**
- **Ensemble simulation ?**
- **Chemical cloud model ?**
- **Regional or Global climate model ?**