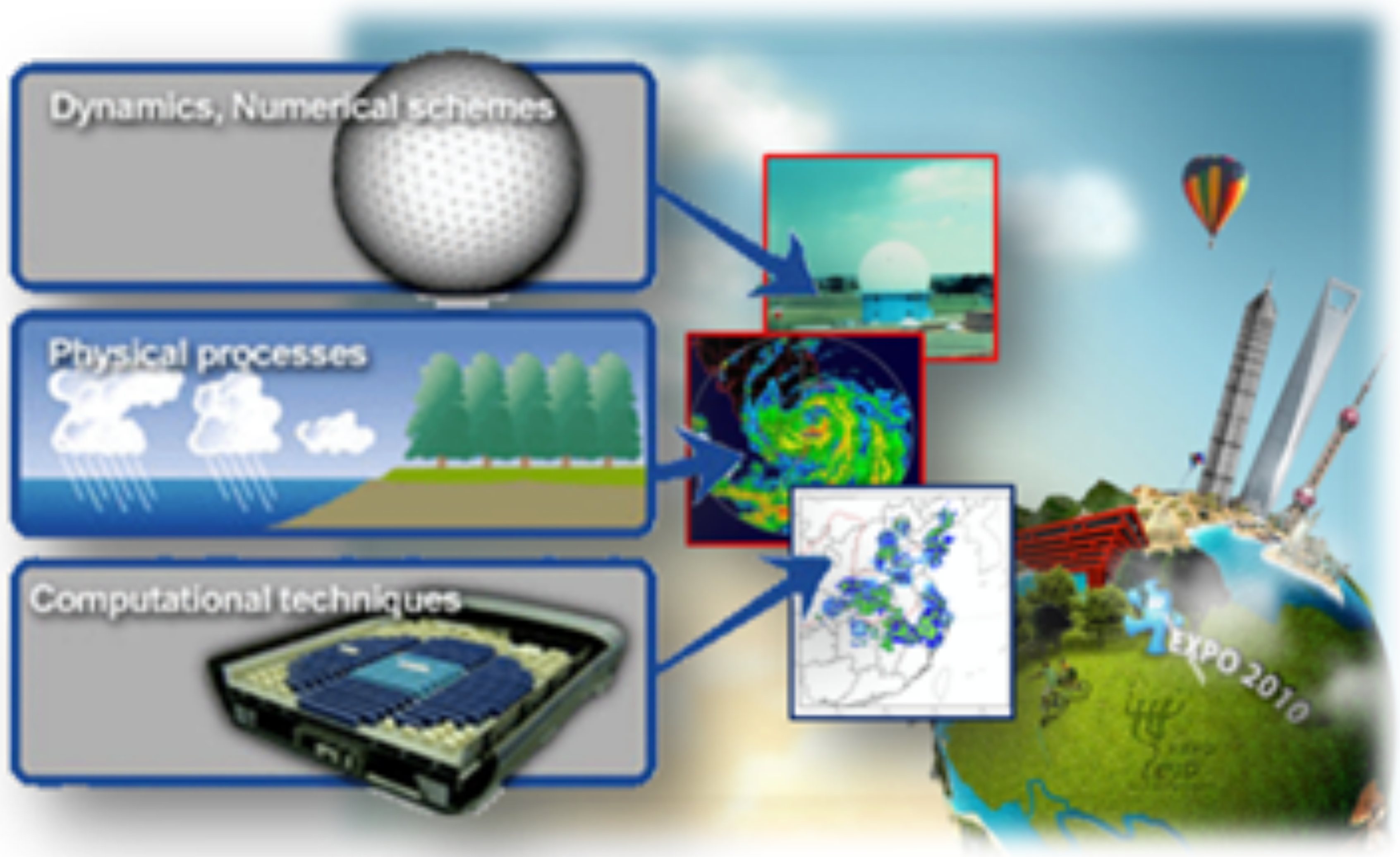
数值模式微物理过程的冰雹模拟和参数化



吴宛真

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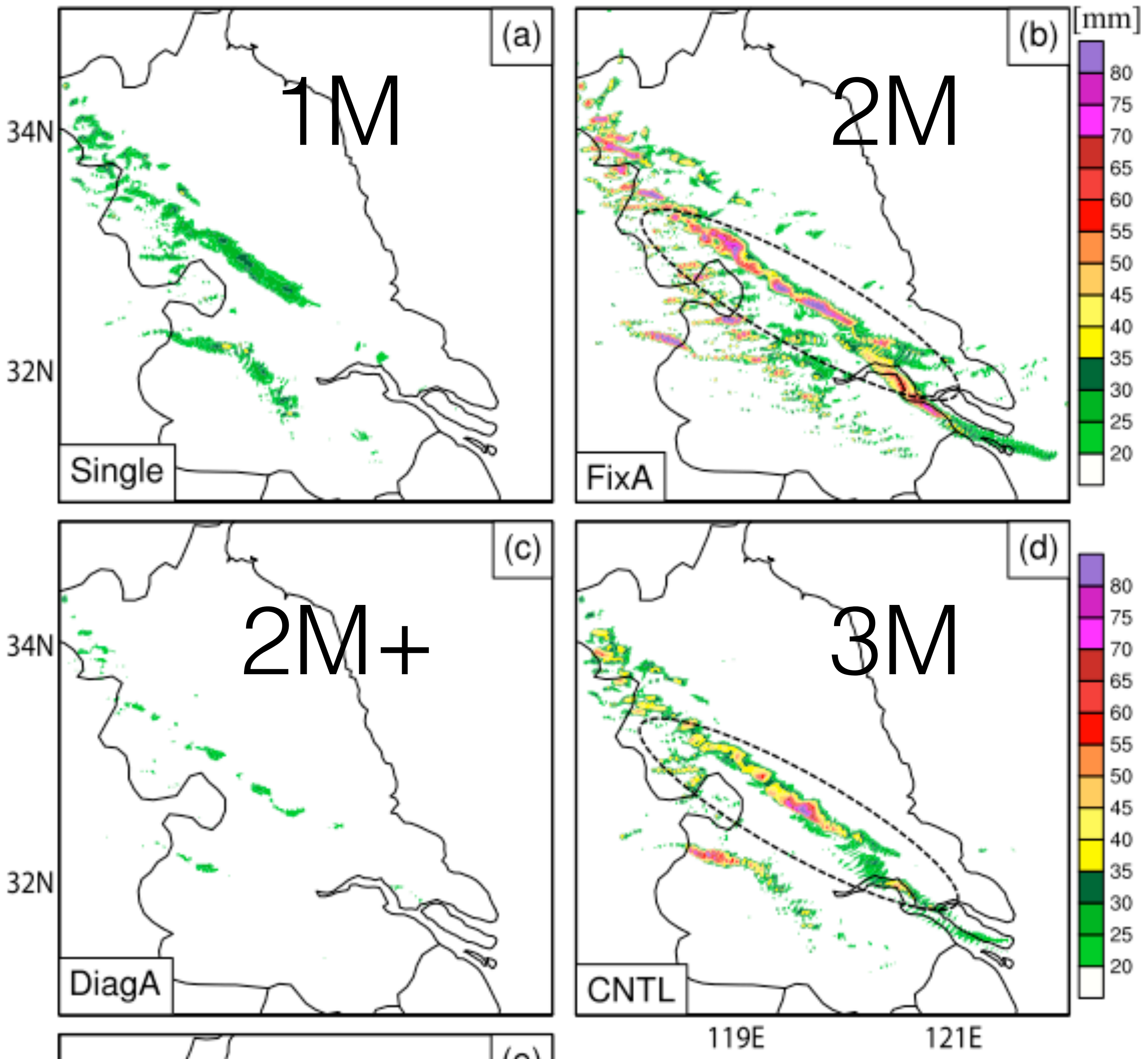
2023.08.11

极端天气之一: 冰雹

冰雹(最大)尺度: Maximum estimated hail size (MEHS)

预报常见的误差



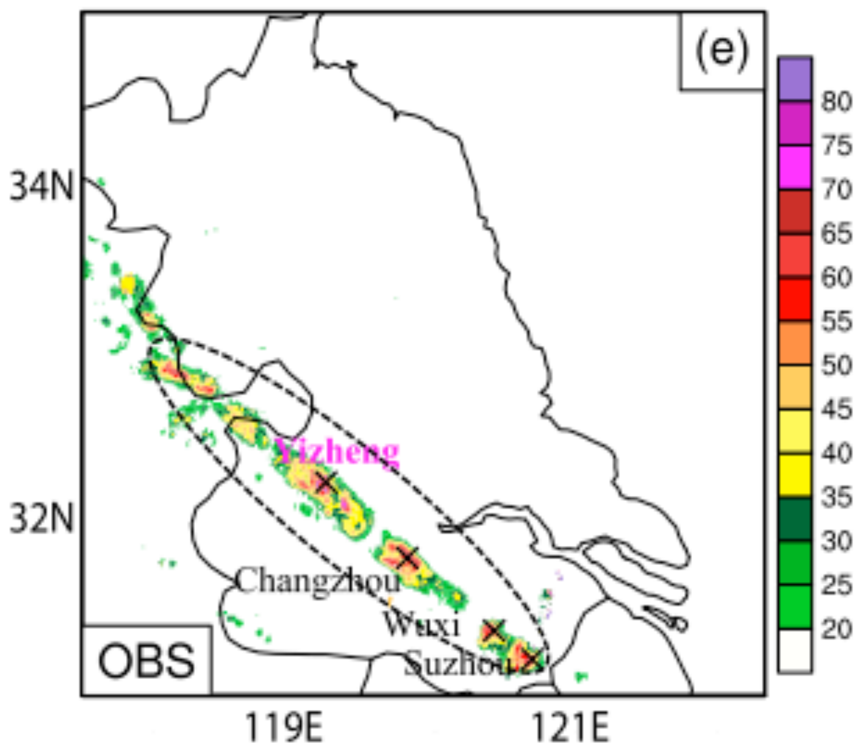


FIG. 8. Simulated MESH with one-, two-, and three-moment microphysics schemes: (a) Single, (b) FixA, (c) DiagA, (d) CNTL, and (e) observed MESH derived from Weather Surveillance Radar-1998 Doppler (WSR-98D) observations. The MESH fields are created as a composite from observed and simulated data between 0600 and 1600 UTC at 5-min intervals. Locations of the cities of Changzhou, Wuxi, and Suzhou, where hail was reported, are indicated (black ×). The city of Yizheng is labeled in magenta, where maximum hail size is registered at around 10 cm.

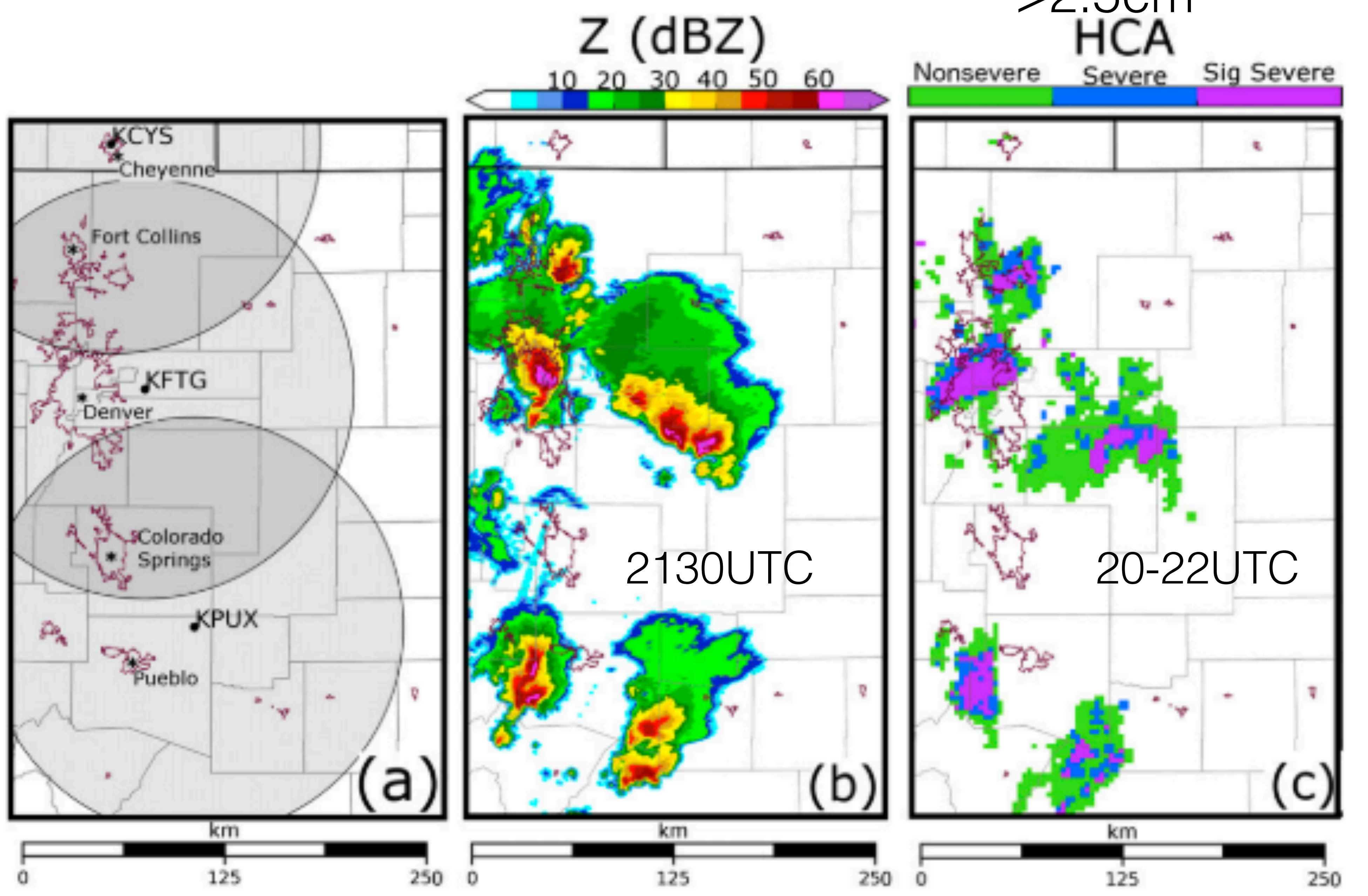
Luo et al. 2018

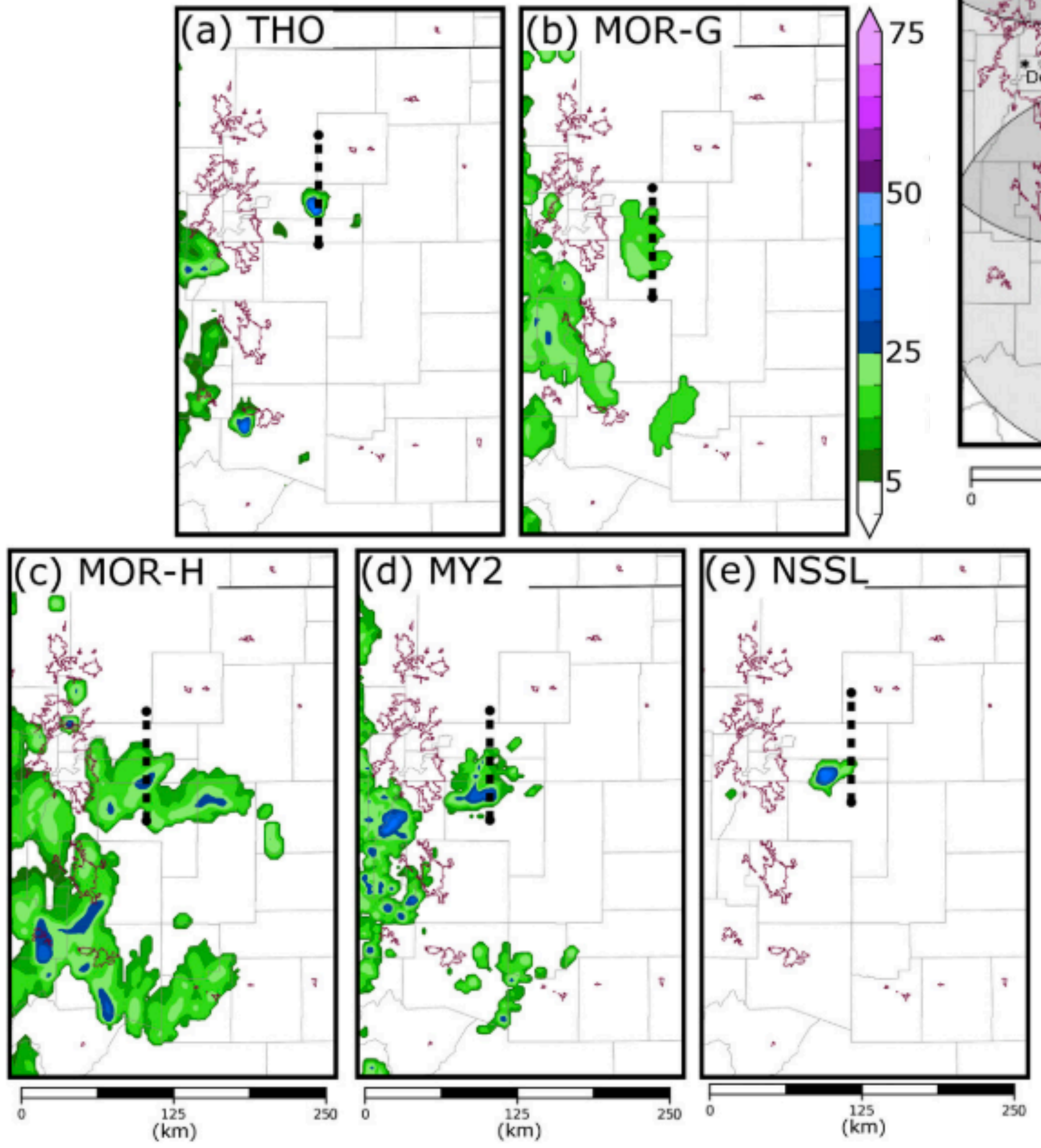
2017/5/8 00-24UTC Denver

>5mm

>5cm

>2.5cm





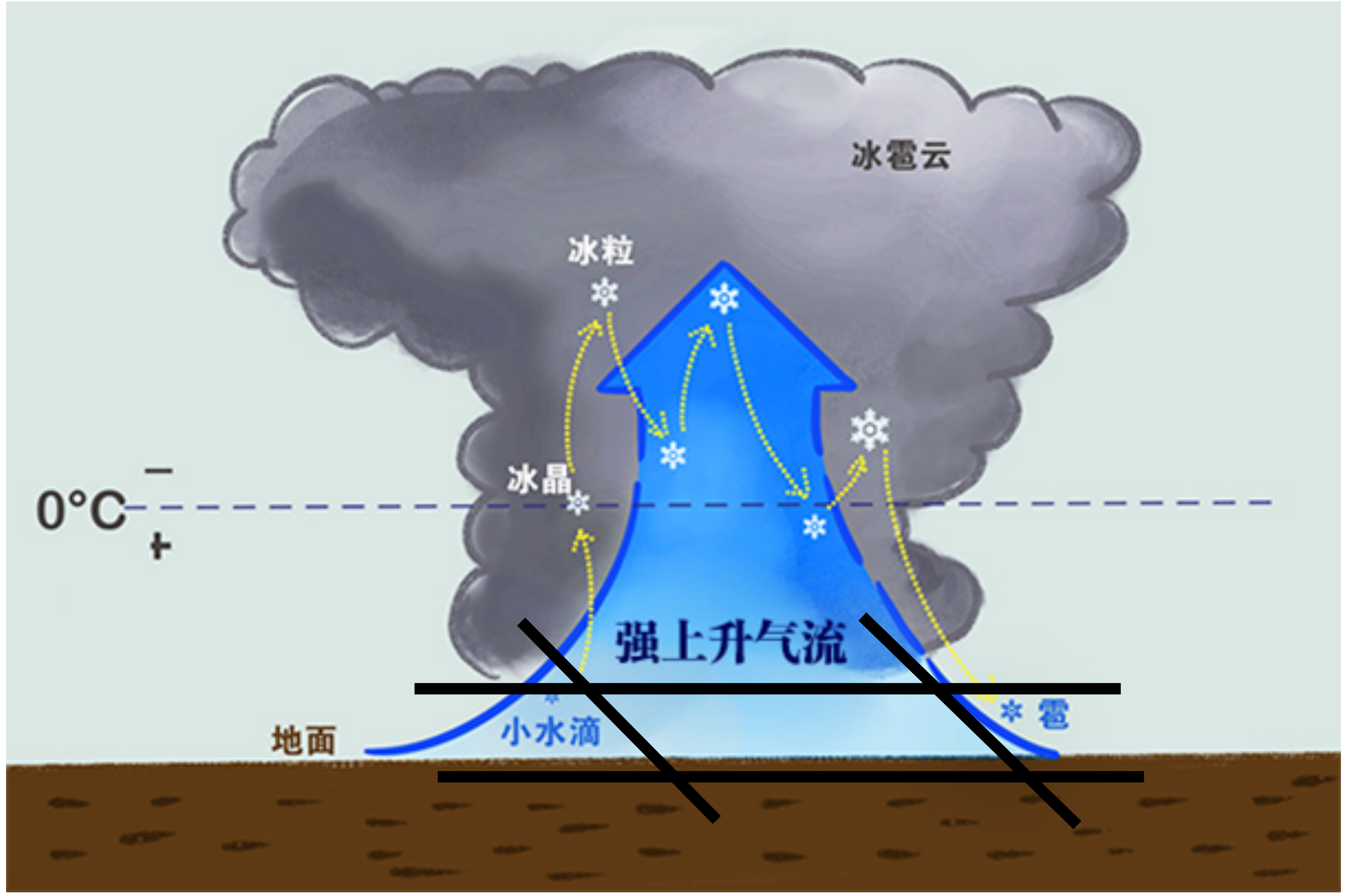
Labriola et al. 2019

推论：

数值模式模拟强对流天气的困难不一定在微物理参数化方案，但模拟冰雹遇到的瓶颈，和微物理脱不了关系。

Hail microphysics

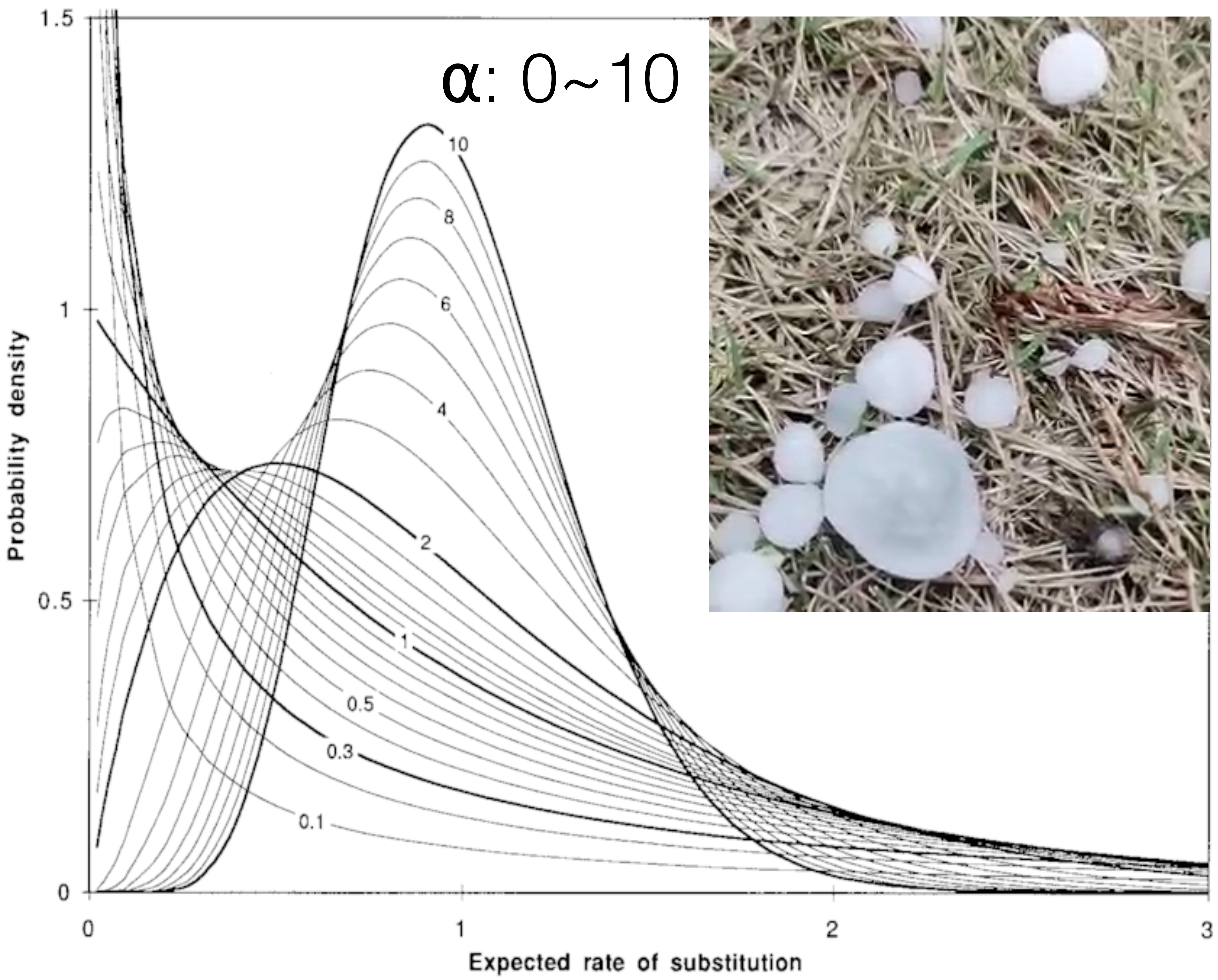
- **Intense updraft**
  - condensation and frozen mass
  - collision and coalescence
  - shed rainwater as hail embryo
  - wet growth
- Future work!



http://www.news.cn/science/2021-11/05/c_1310297564.htm

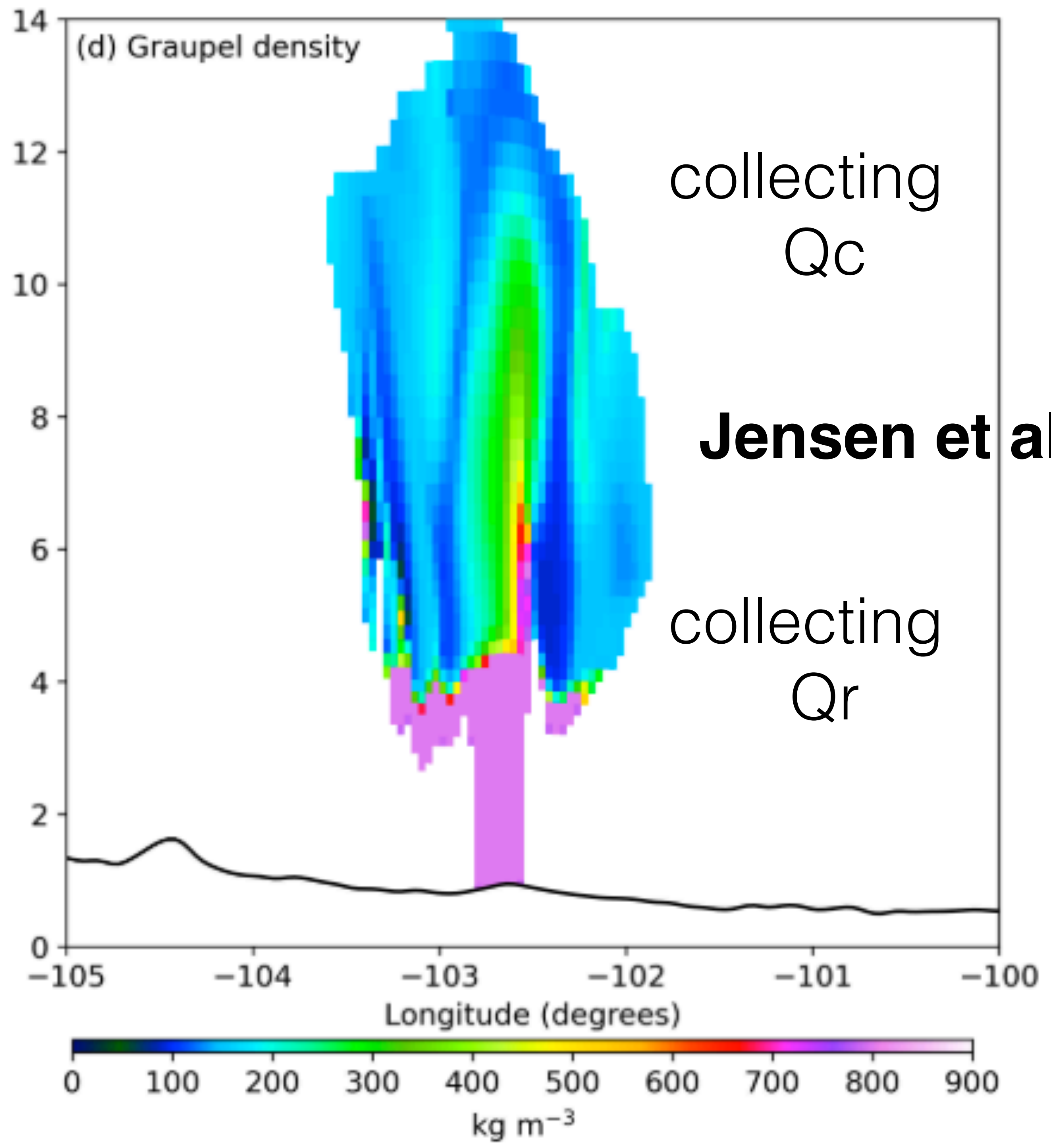
冰雹物理特征

- **Particle size distribution**
  - MEHS ~ severity
  - exp vs gamma
  - shape parameter (α)

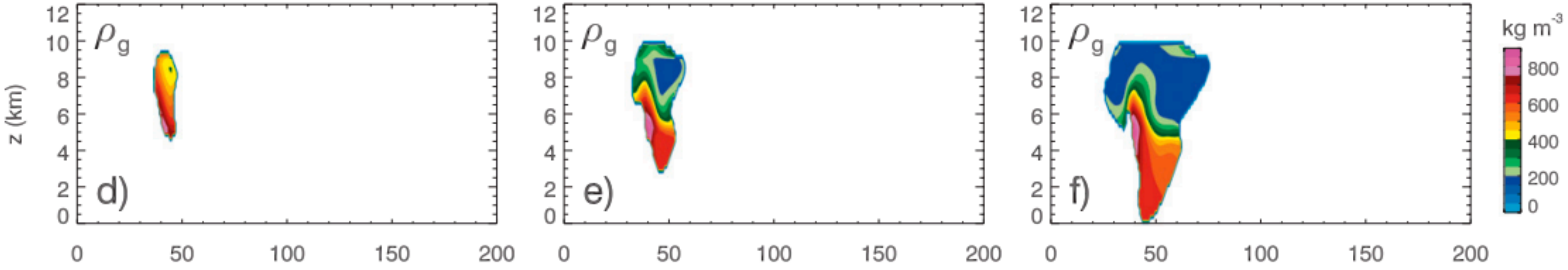


冰雹物理特征

- Modeling:
  - low density graupel
  - high density hail
  - predicted density (Jensen 2023)



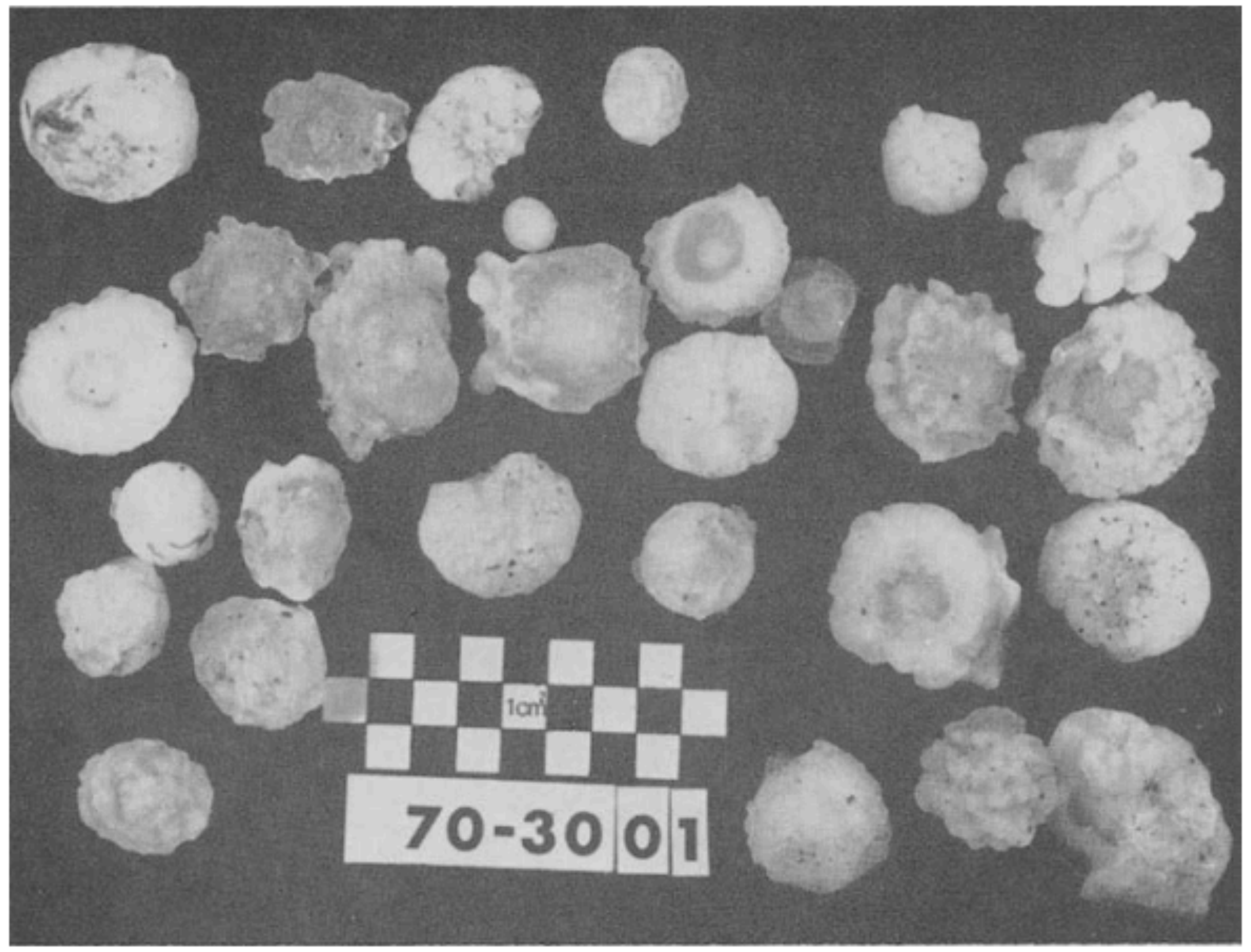
Jensen et al. (2023)

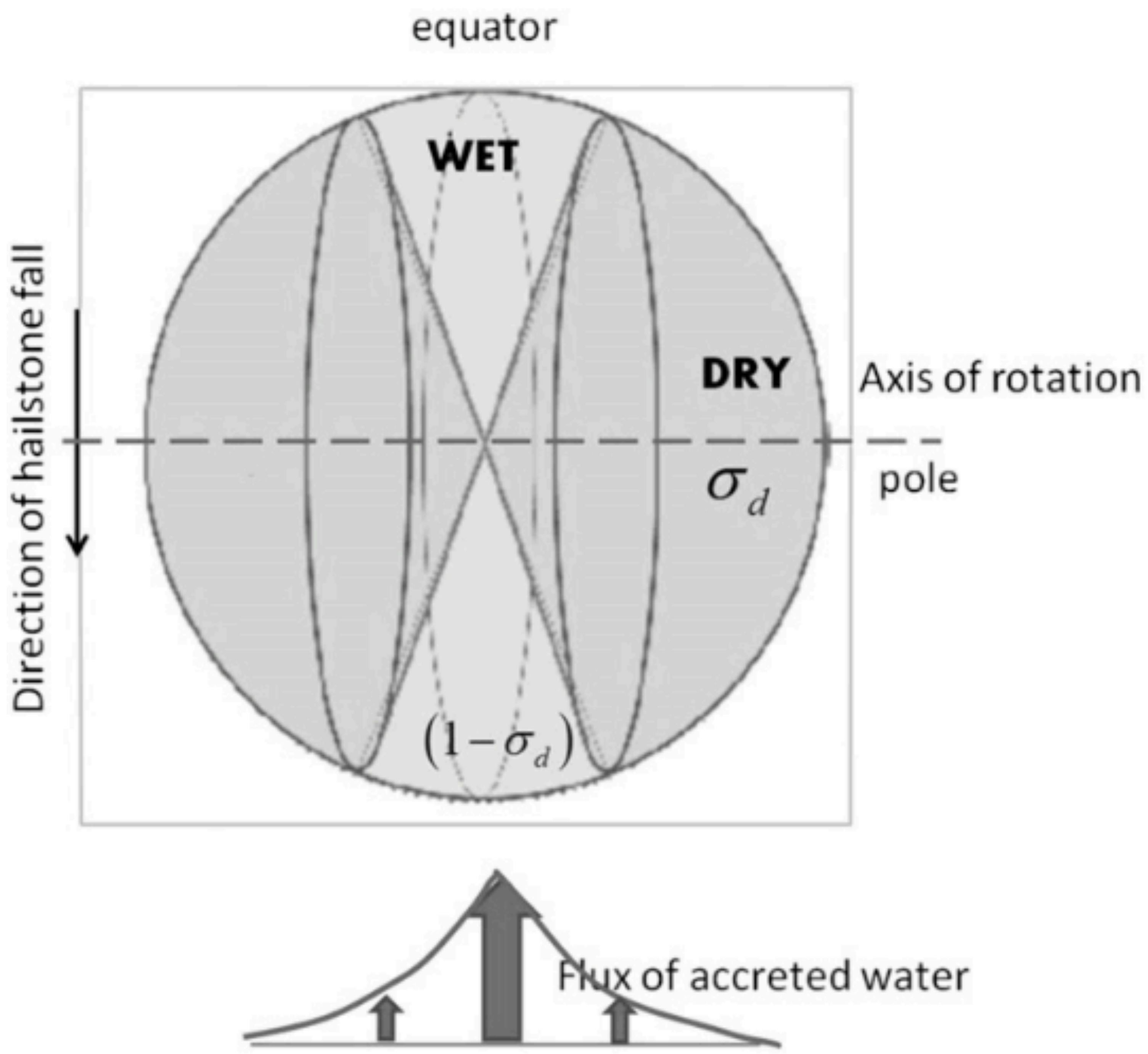


Milbrandt and Morrison (2013)

冰雹物理特征

- Irregular shape
- Wet and dry parts
- Surface temperature

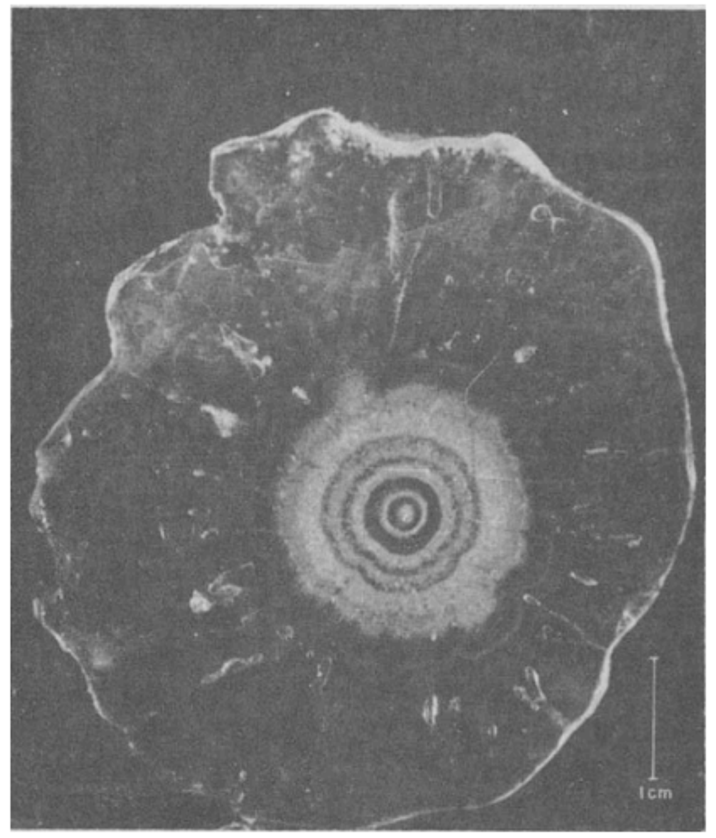




Phillips et al. (2014)

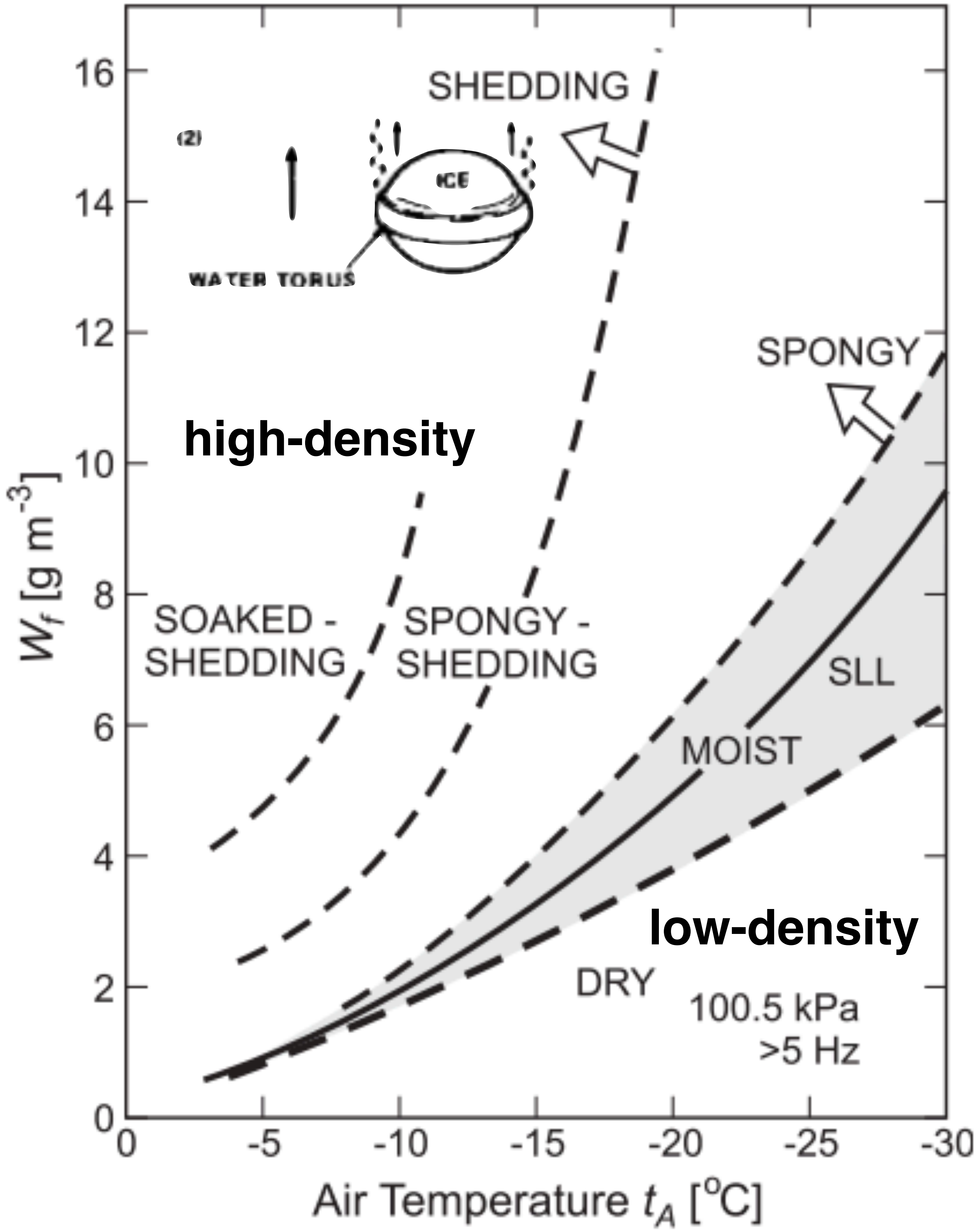
冰雹增长理论

- Growth theory for a single hailstone
- Schumann–Ludlam Limit (SLL)
  - Dry growth (riming)
  - Wet growth and shedding
- Supercooled water vs ice aggregates



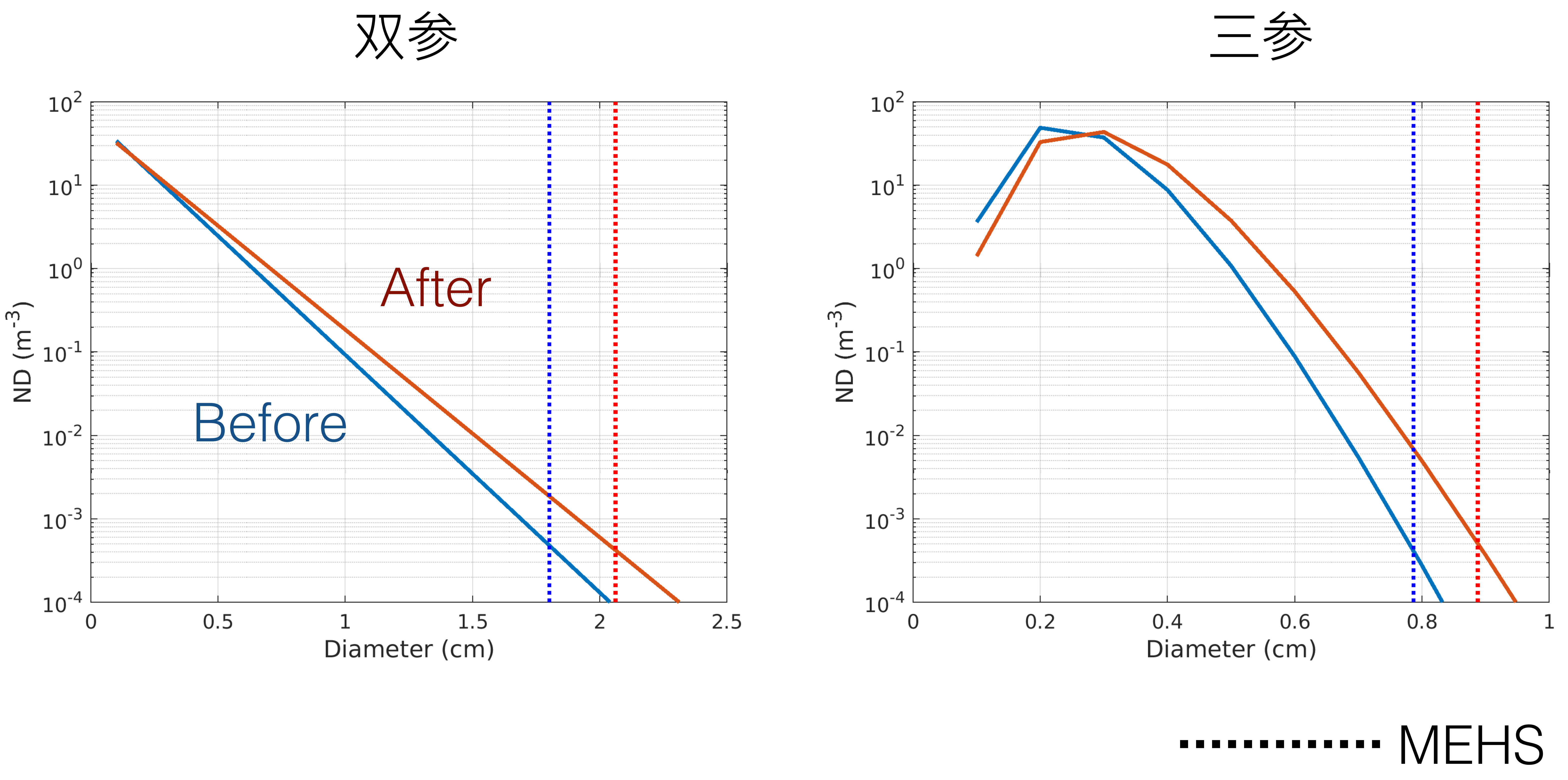
Schumann–Ludlam Limit

Schumann (1938), Ludlum (1950, 1958)

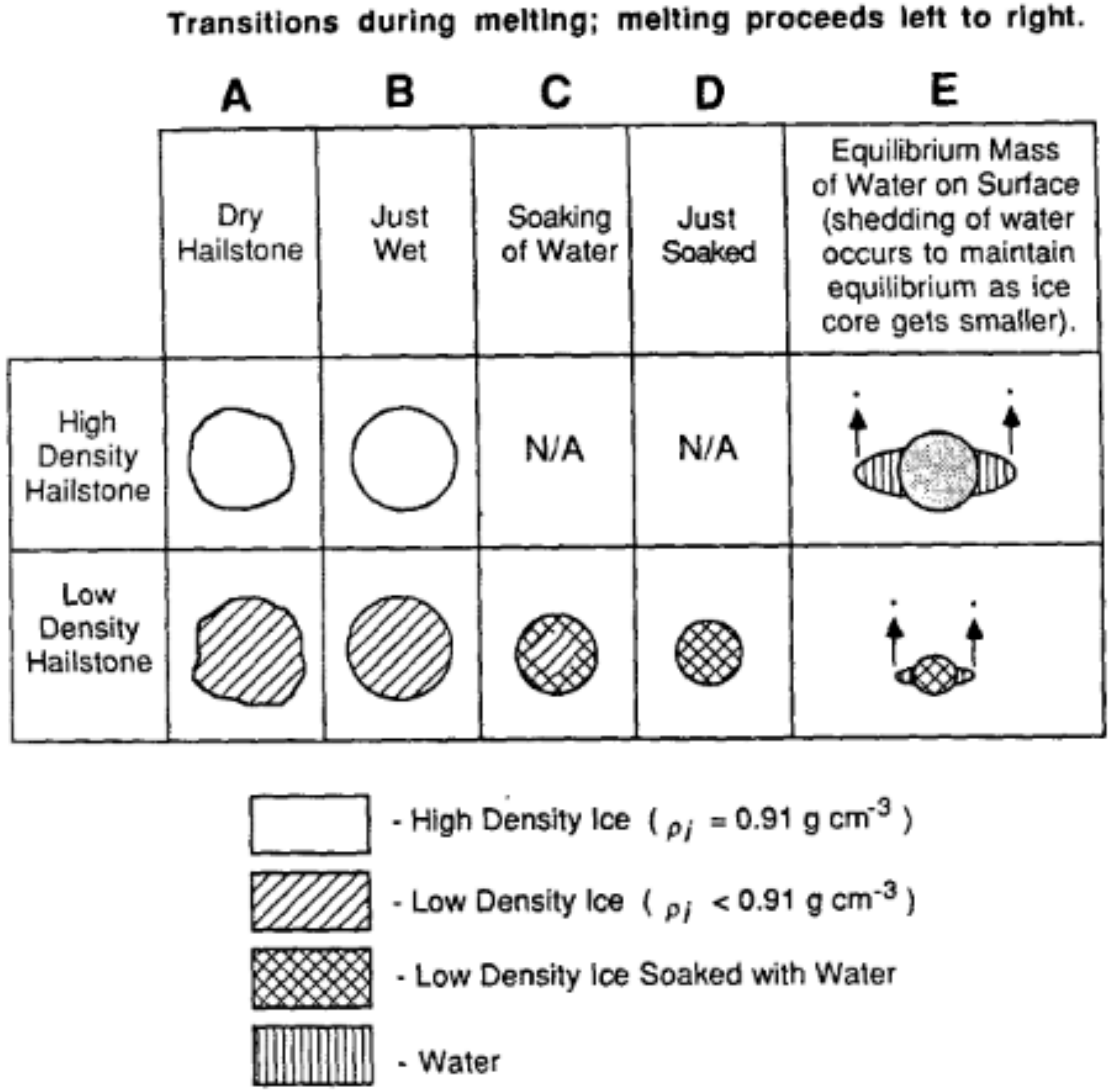


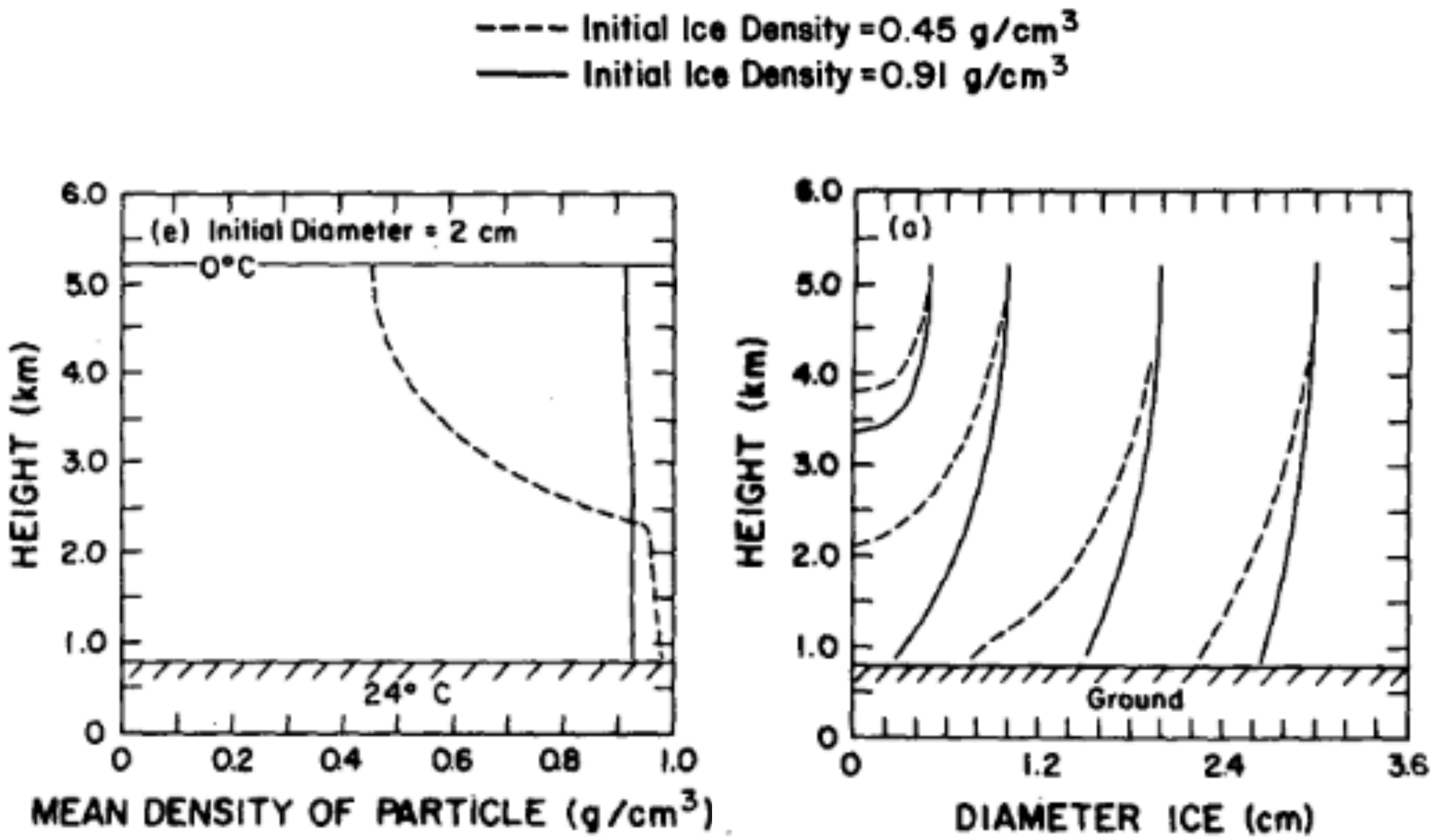
参数化方法

50% mass gain



微观融化过程特征

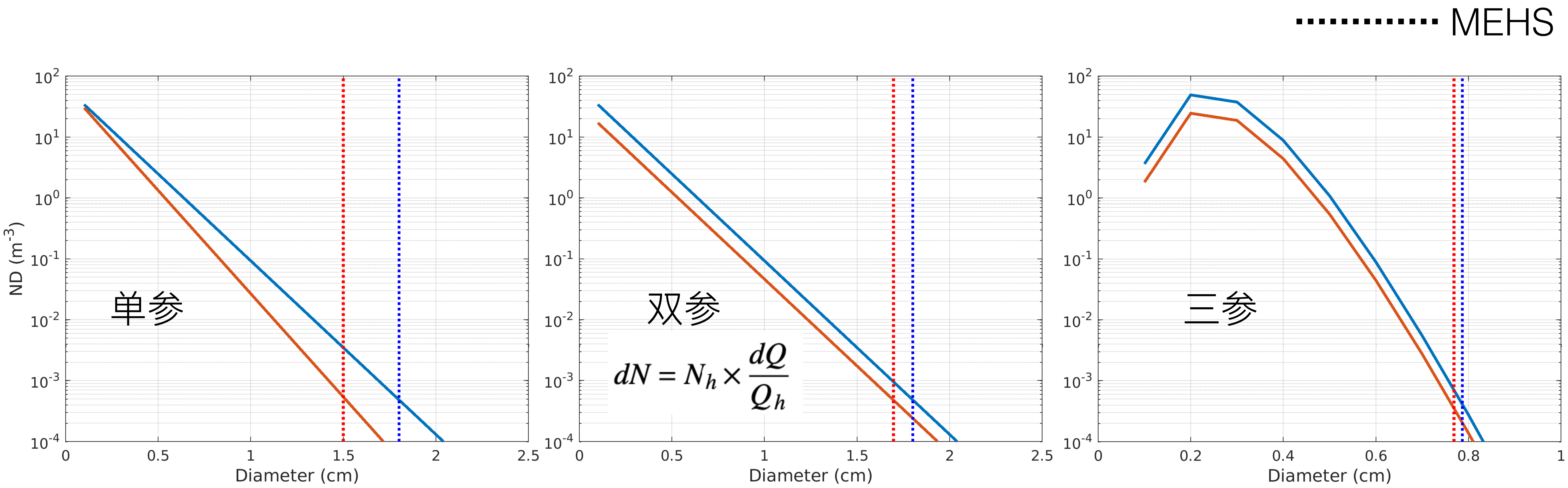




Rasmussen and Heymsfield (1987a,b)

参数化方法

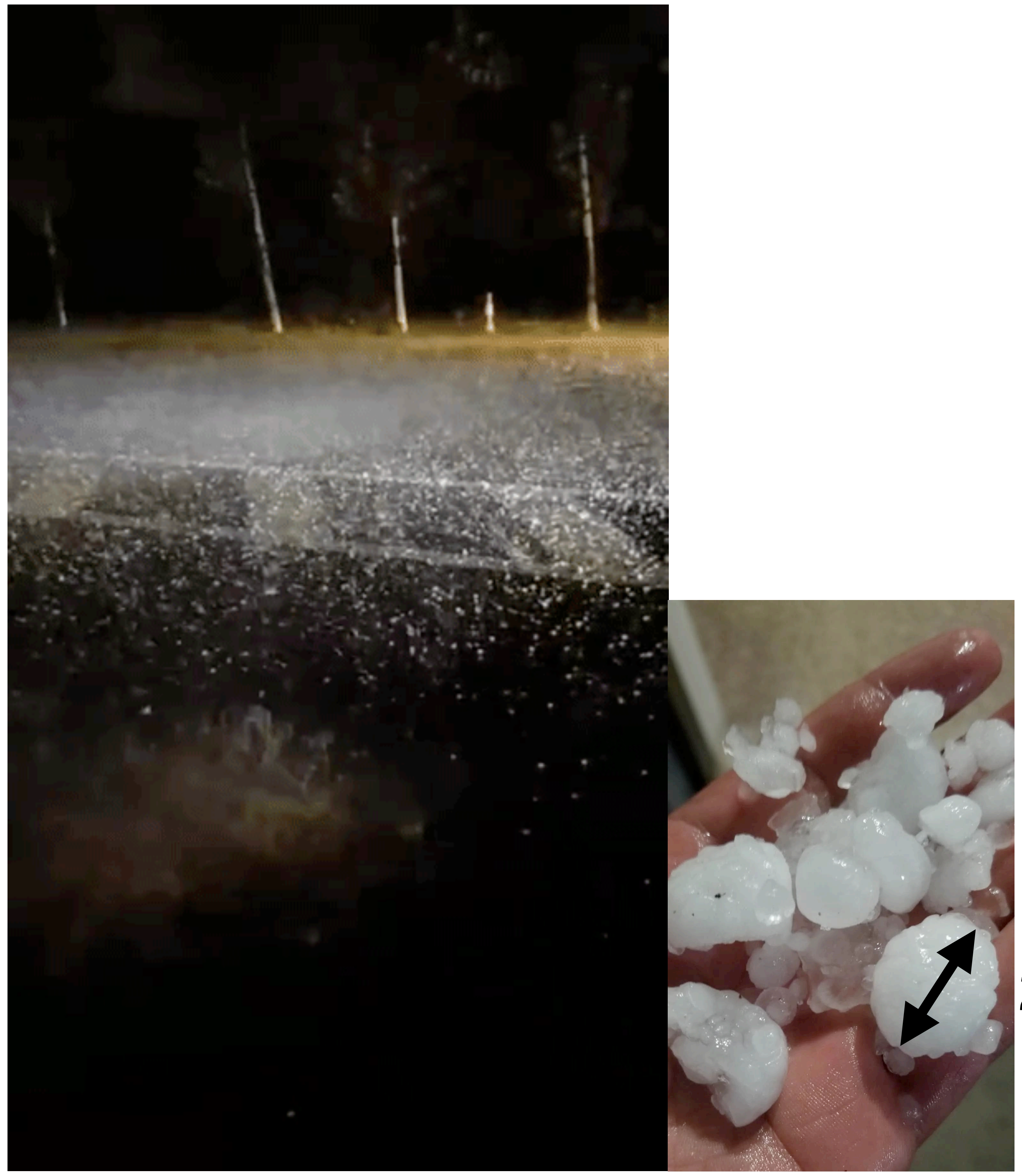
50% mass melted

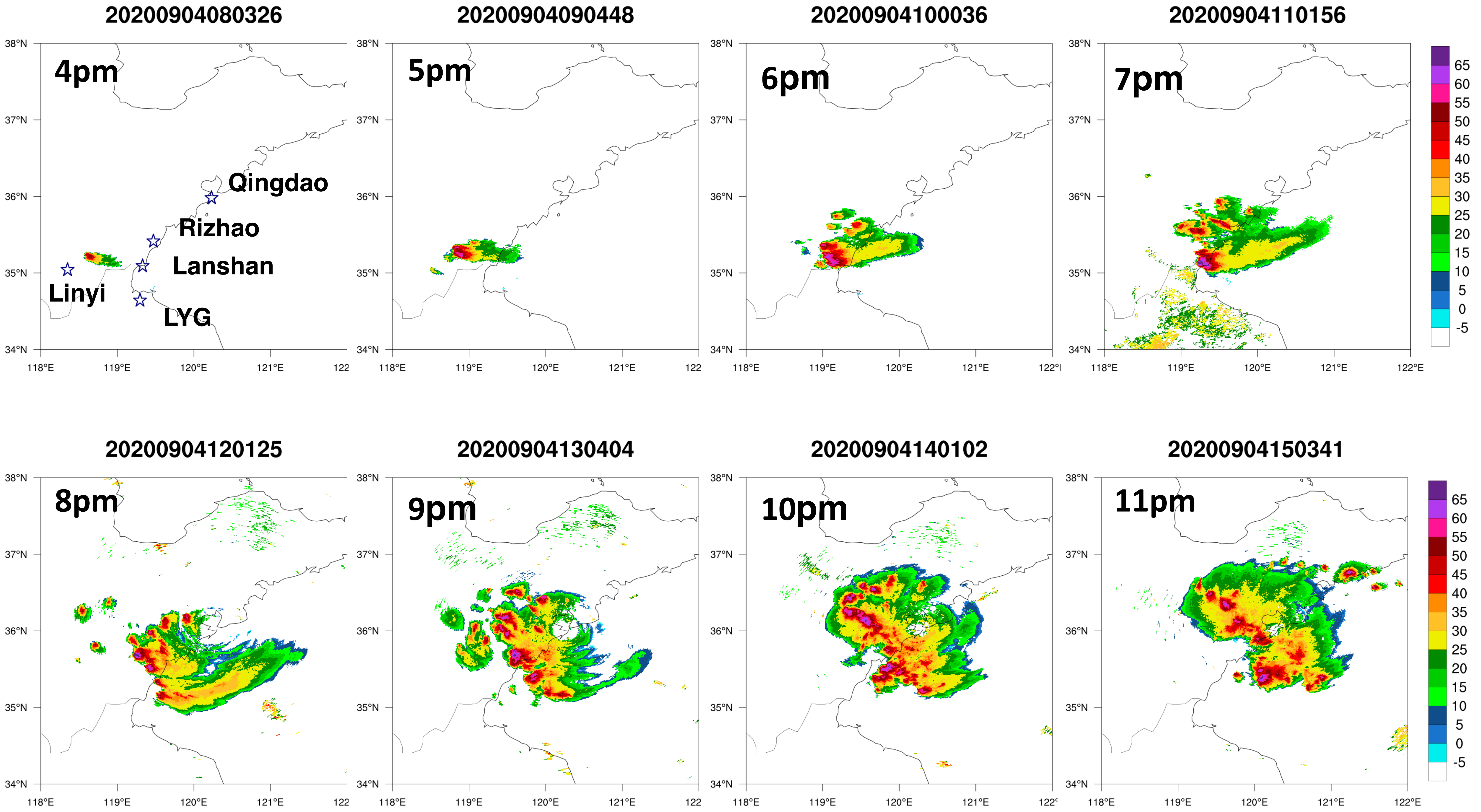


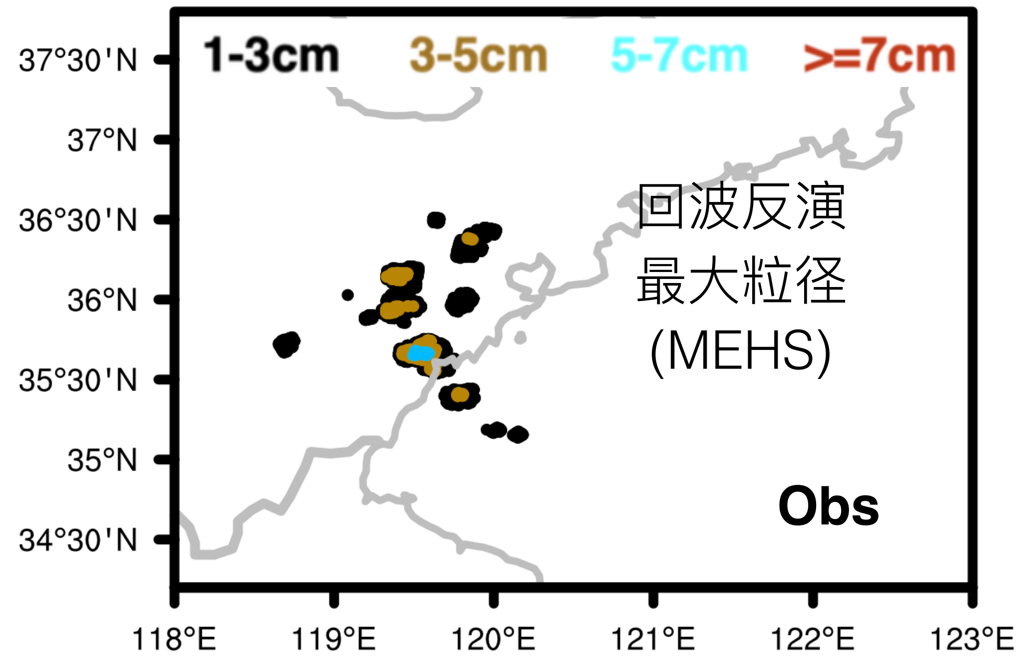
2020年9月4日山东雹暴

地面观测和空中观测

山东日照市(Rizhao)







*感谢北京气科所吴翀提供的山东雷达资料

Witt et al. (1998)

Model setup

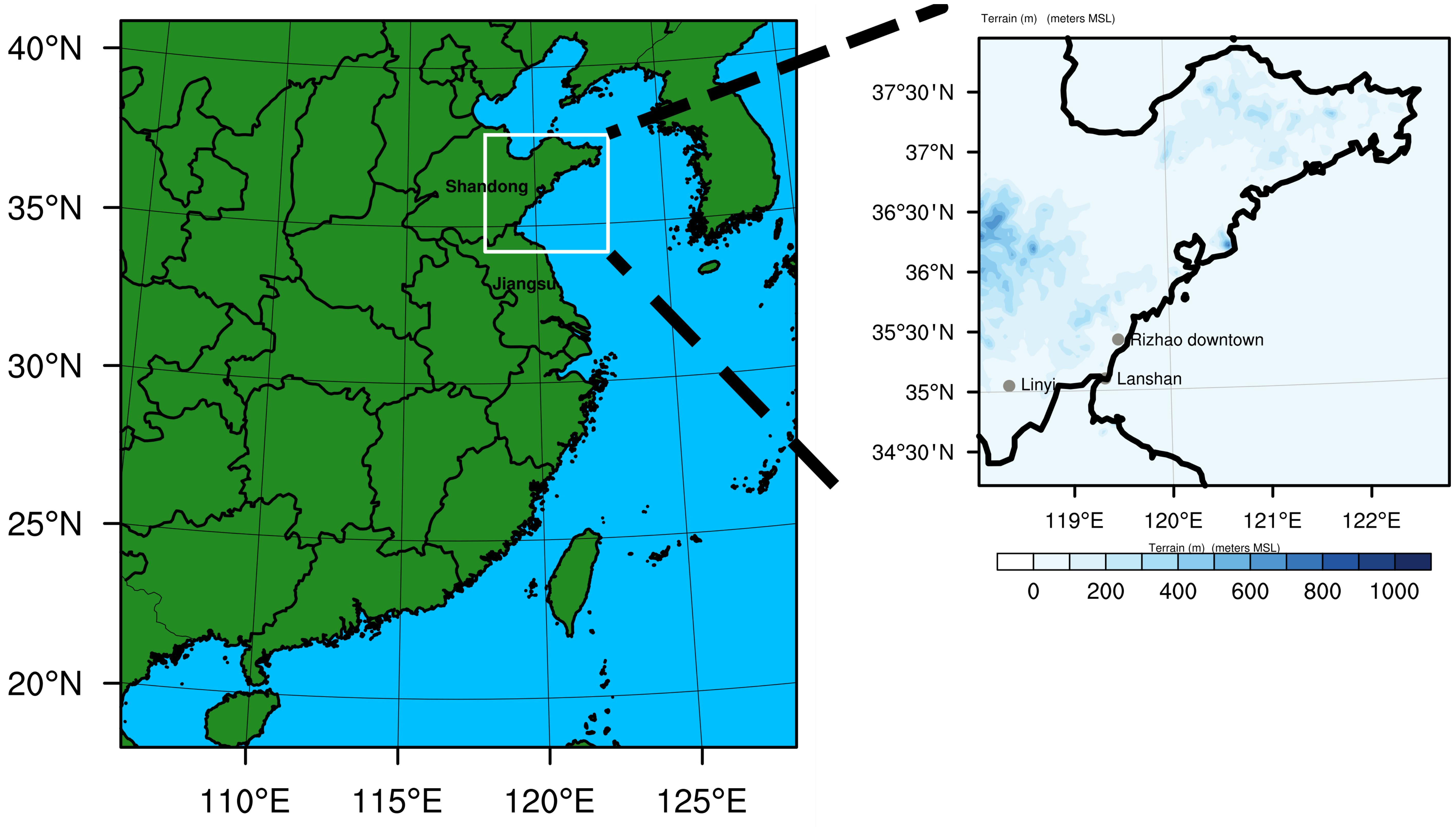


TABLE 1. The physical parameterizations, initial and boundary conditions, and simulation period used in numerical simulations. SM as single-moment, and 3M as triple-moment.

Model	WRF v4.3
Simulation time	24 h (0000 UTC 4 Sep–0000 UTC 5 Sep)
Resolution	D1: 3 km (dt = 15 s), D2: 1 km (dt = 5 s)
Vertical	51
PBL	3DTKE (Zhang et al. 2018)
Surface layer	Revised MM5 Monin–Obukhov scheme
Surface model	Unified Noah land surface model
Radiation	RRTMG SW and LW scheme (dt = 5 min)
ICBC	GFS 0.5 × 0.5
Microphysics	SM: AAT and WDM7; 3M: NTU3M
Others	Cold start, no ensemble, no data assimilation

TABLE 2. Key parameters related to the largest ice hydrometeor species in the three schemes with Q as mixing ratio, N as number concentration, A as cross-section area, N_0 as intercept parameter, and α as spectral shape parameter.

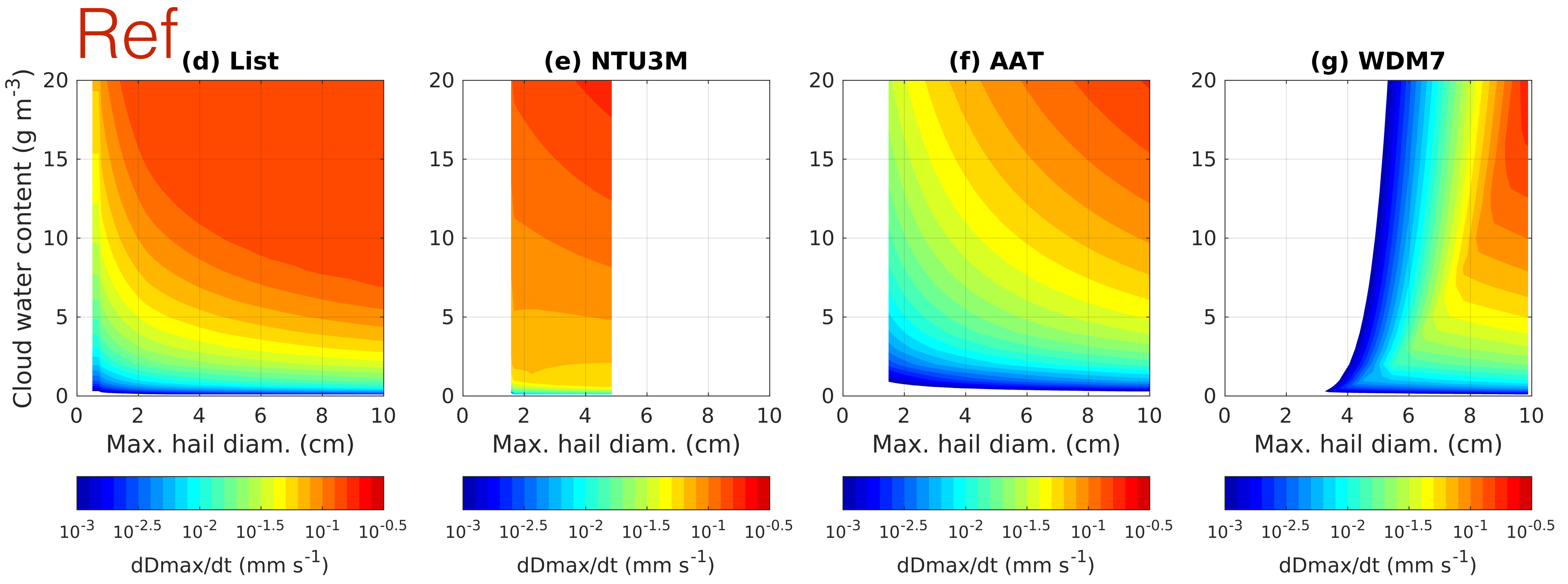
	Species	Predicted moments	Size spectrum	Density (kg m^{-3})	N_0 (m^{-4})	α
NTU3M	Hail	Q, N, A	Incomplete gamma	900	Prognostic	0–2996
AAT	Graupel	Q	Inverse exponential	500	10^2–10^6	0
WDM7	Hail	Q	Inverse exponential	912	4×10^4	0

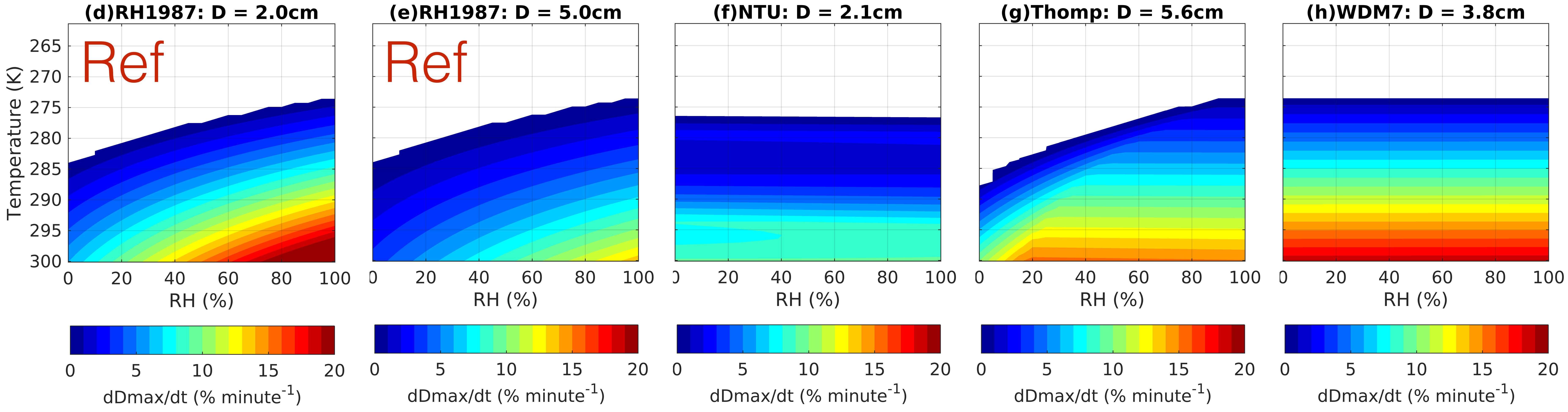
不同微物理方案的差异

1-3cm
3-5cm
5-7cm
>=7cm
NTU3M
Thompson
WDM7
Simulated MEHS
Height (km)
Qc
Qr
Qi
Qs
Qg
Qh
Nh/1000
α/100
Dmax*10
Nh/100
2cm
5.5cm
4cm
-20°C
0°C
融化
z = 4.5 km
T = -5°C
P = 587hPa

增长和融化参数化

- 物理过程 + 粒径分布 + 雹密度 = 最大直径(MEHS)的变化

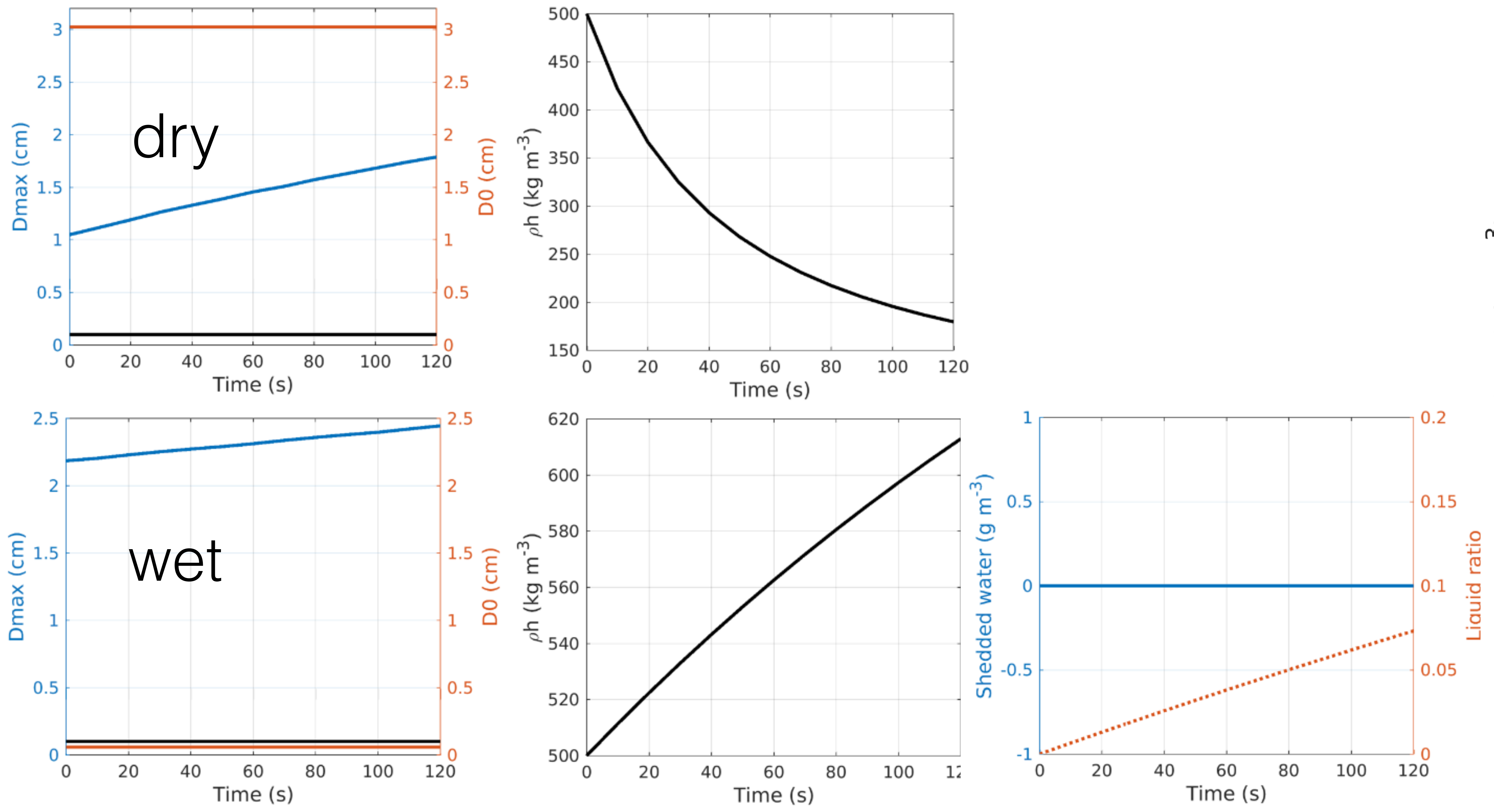


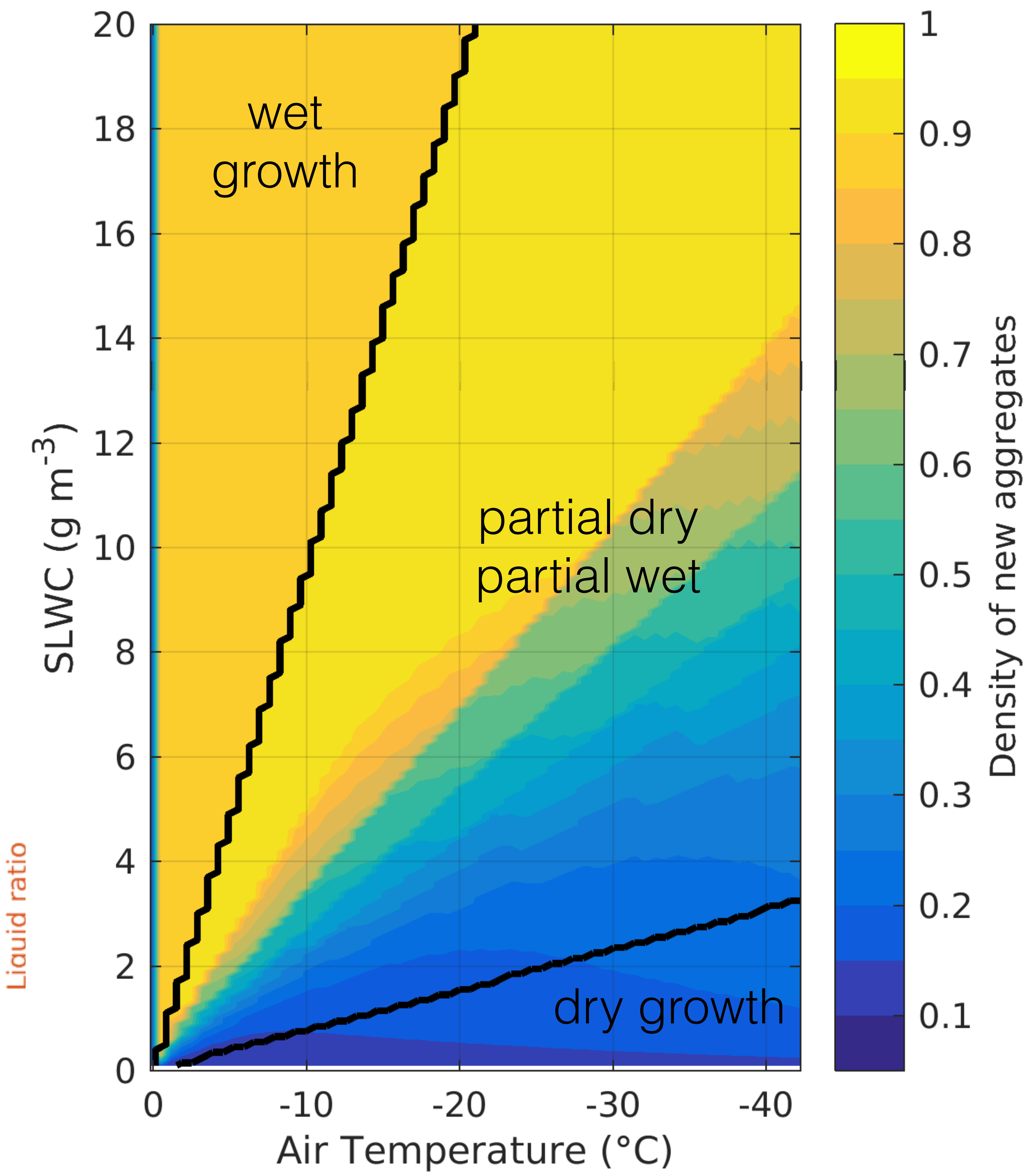


Wanchen Wu, W Huang, L Deng*, and *Wu, C. (2022). Investigation of Maximum Hail-Size Forecasting Using Bulk Microphysics Schemes, Monthly Weather Review, 150(10), 2503-2525.*

Hail model

临界尺度 $$D_{h0} = 0.01\langle \exp\{-T_c/[1.1\times 10^4(q_c + q_r) - 1.3\times 10^3 q_i + 1\times 10^{-3}]\} - 1\rangle. \quad (48)$$





一些想法

- 建构一个简易的冰雹模型。某方面是为了将来有能力自主研发，而且过程中可以享受从无到有的乐趣。
- 固态水的复杂度高，很多重要特征很难清楚定义，更不用说精确度，面临最大的困难是观测数据的取得。
- 问题太多，大问题例如观测不足、模式误差、粒径分布参数化是否限制了模拟冰雹尺度精确度的上限，常常不知道怎么解决，小问题还在努力，但不知道有没有意义。
- 还在努力，还在坚持。