High-resolution winter simulations over CO Rockies

Sensitivity to microphysics parameterization

Greg Thompson

Research Applications Laboratory, National Center for Atmospheric Research

05 Nov 2012 | ECMWF workshop on parameterization of clouds & precipitation across model resolutions

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> *"Perhaps some day in the dim future it will be possible to advance the computations faster than the weather advances ... But that is a dream."*
>
> – Lewis Fry Richardson, **Weather Prediction by Numerical Process**, 1922

L. F. Richardson, 1931

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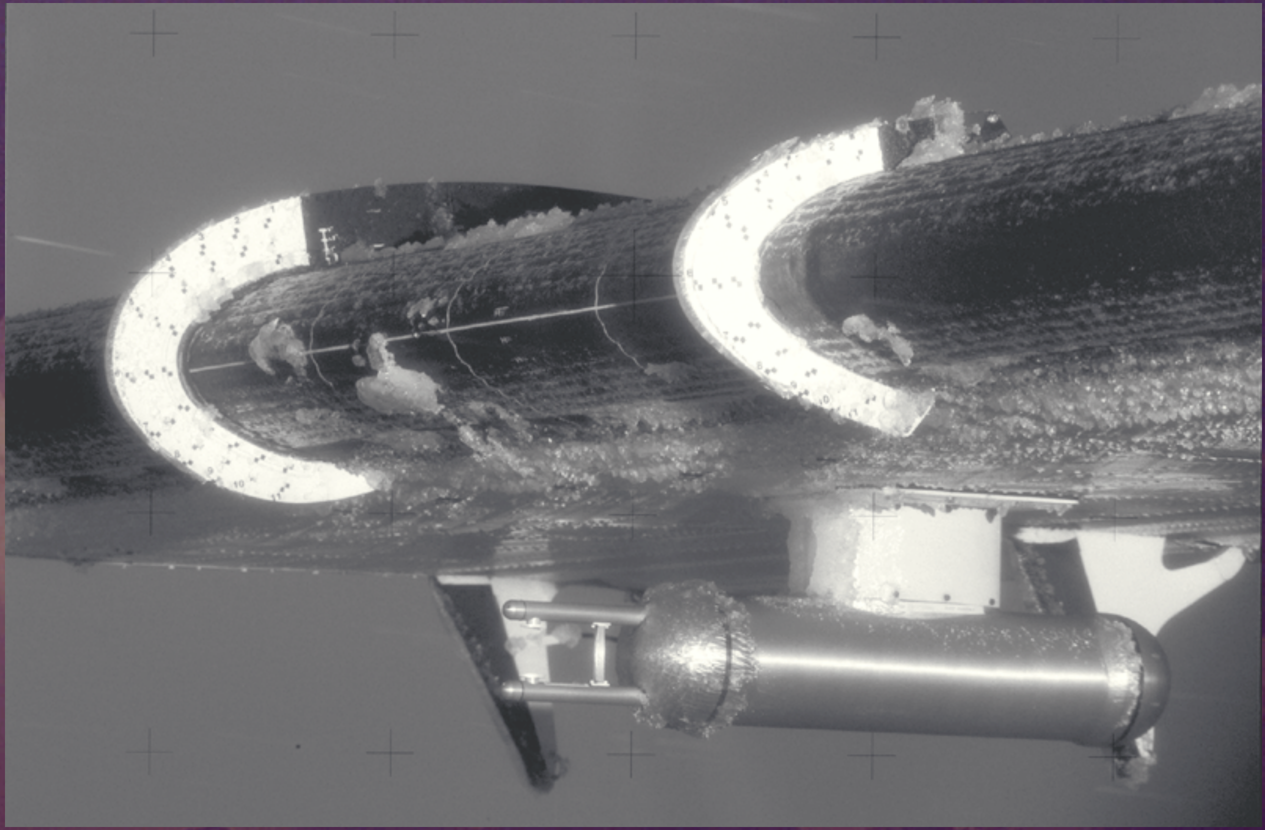
Collaborators

- Trude Eidhammer, Roy Rasmussen
- Stan Benjamin, John Brown (NOAA-ESRL)
- Paul Field, Ben Shipway, Adrian Hill (UK Met Office)
- Bill Hall (NCAR, retired)
- Hugh Morrison (NCAR-MMM)
- Kyoko Ikeda, Changhai Liu (NCAR-RAL)
- Yi Jin (NRL-COAMPS)
- Istvan Geresdi (Pecs Univ, Hungary)
- Bjorn Egil Nygaard (Oslo Univ)

Outline

- **Microphysics scheme**
- Testing
- Applications
  - Colorado Headwaters
  - Convection
  - Icing
- Summary



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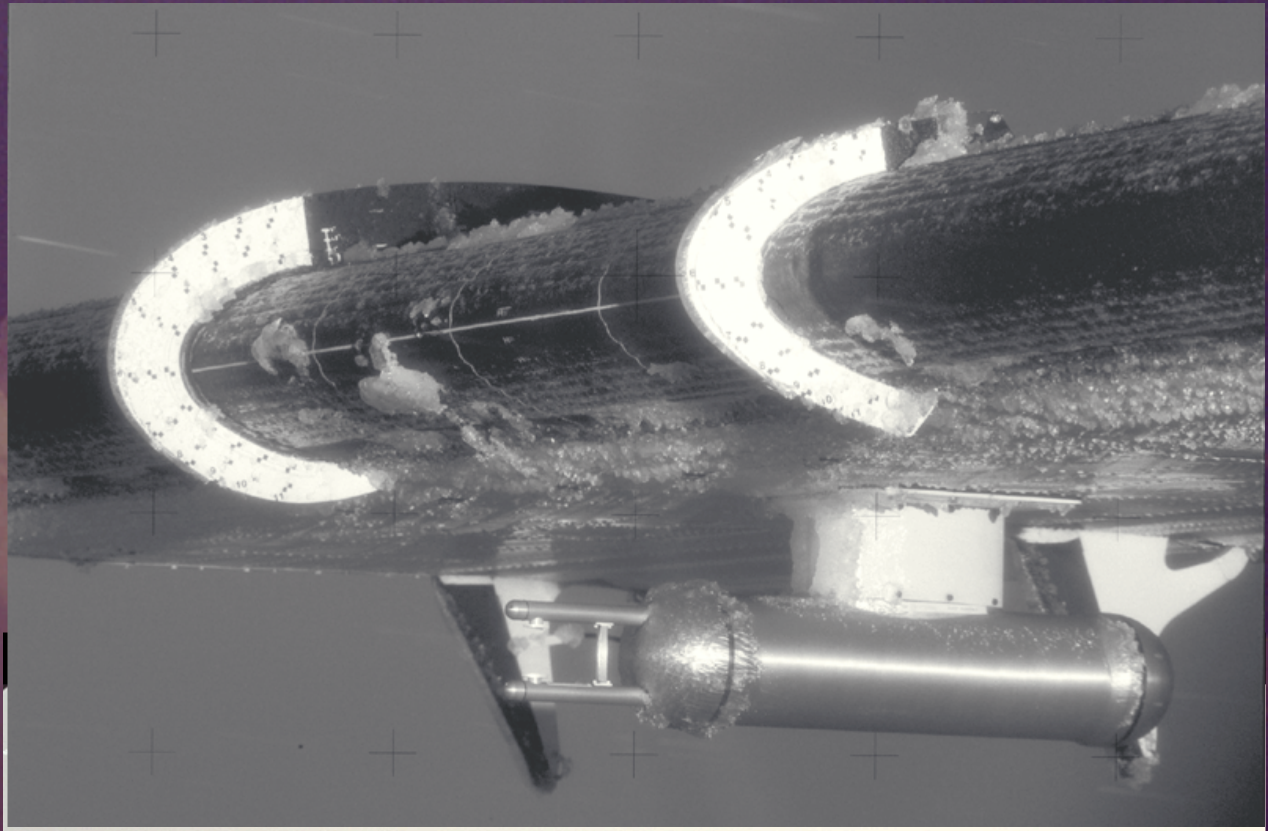
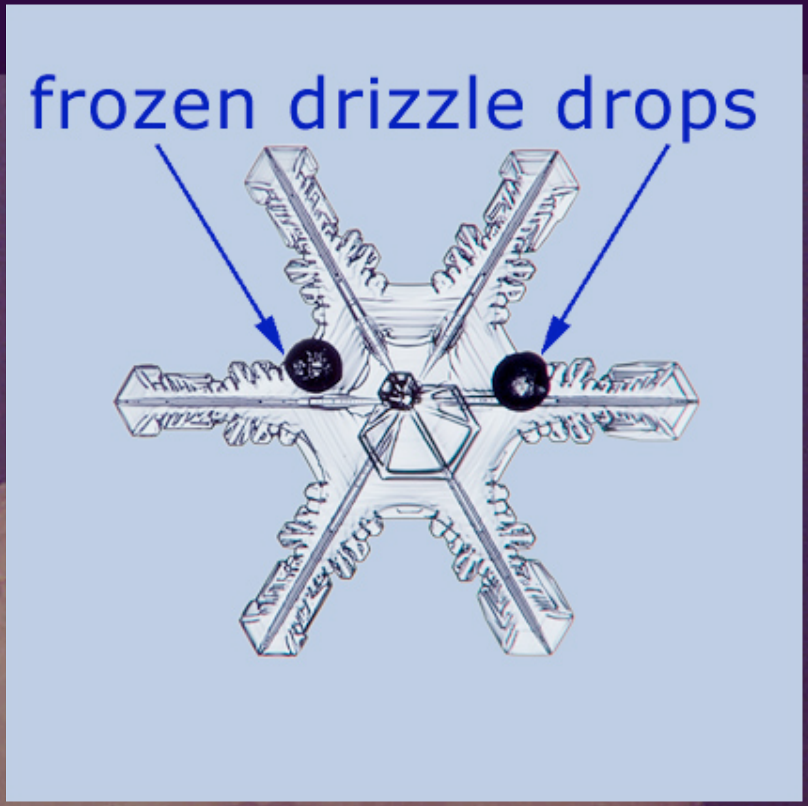


Goals/Motivation

☐ **Develop an efficient and observations-based bulk microphysical parameterization:**

- improves quantitative precipitation forecasts
  when compared to similar, existing schemes
- improves forecasts of water phase everywhere
  aloft=aircraft icing; surface=FZDZ/RA/SN
- incorporates recent microphysical observations
  AIRS / IMPROVE / ICE-L / NASA-SLDRP
- is sufficiently optimized/fast
  real-time needs (WRF-Rapid Refresh)
- uses clean, well-documented code
  can be modified rapidly to increase complexity and perform sensitivity studies



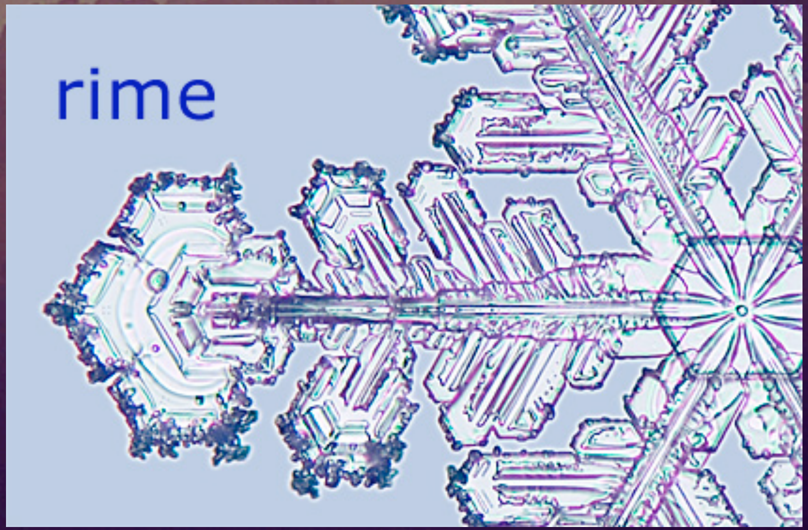
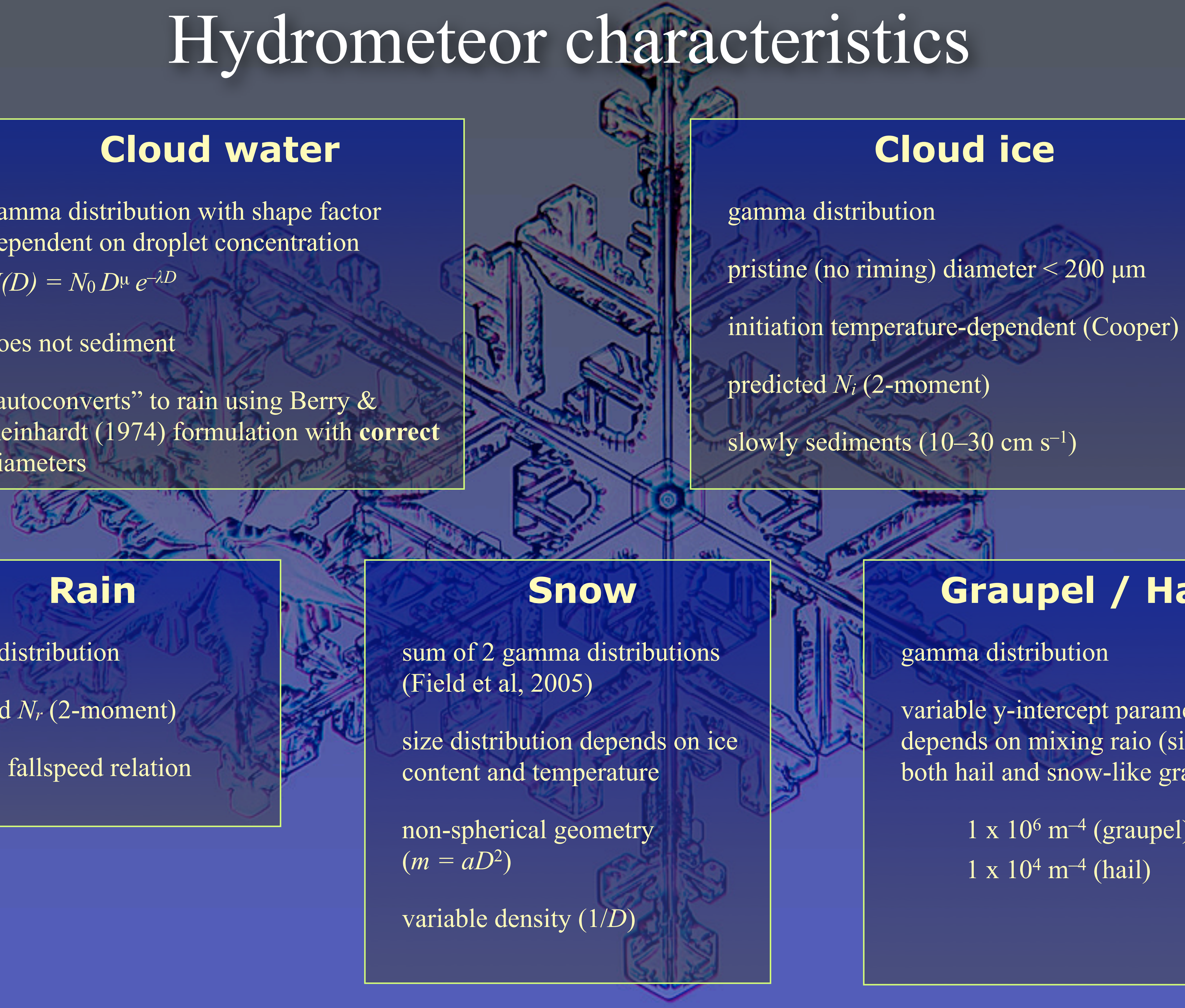



Photo Coutesy of NASA Glenn

Hydrometeor characteristics



Cloud water

gamma distribution with shape factor dependent on droplet concentration

$N(D) = N_0 D^{\mu} e^{-\lambda D}$

does not sediment

“autoconverts” to rain using Berry & Reinhardt (1974) formulation with **correct** diameters

Cloud ice

gamma distribution

pristine (no riming) diameter < 200 µm

initiation temperature-dependent (Cooper)

predicted N_i (2-moment)

slowly sediments (10–30 cm s^{-1})

Rain

gamma distribution

predicted N_r (2-moment)

accurate fallspeed relation

Snow

sum of 2 gamma distributions (Field et al, 2005)

size distribution depends on ice content and temperature

non-spherical geometry ($m = aD^2$)

variable density ($1/D$)

Graupel / Hail

gamma distribution

variable y-intercept parameter depends on mixing raio (simulate both hail and snow-like graupel):

1×10^6 m^{-4} (graupel)

1×10^4 m^{-4} (hail)

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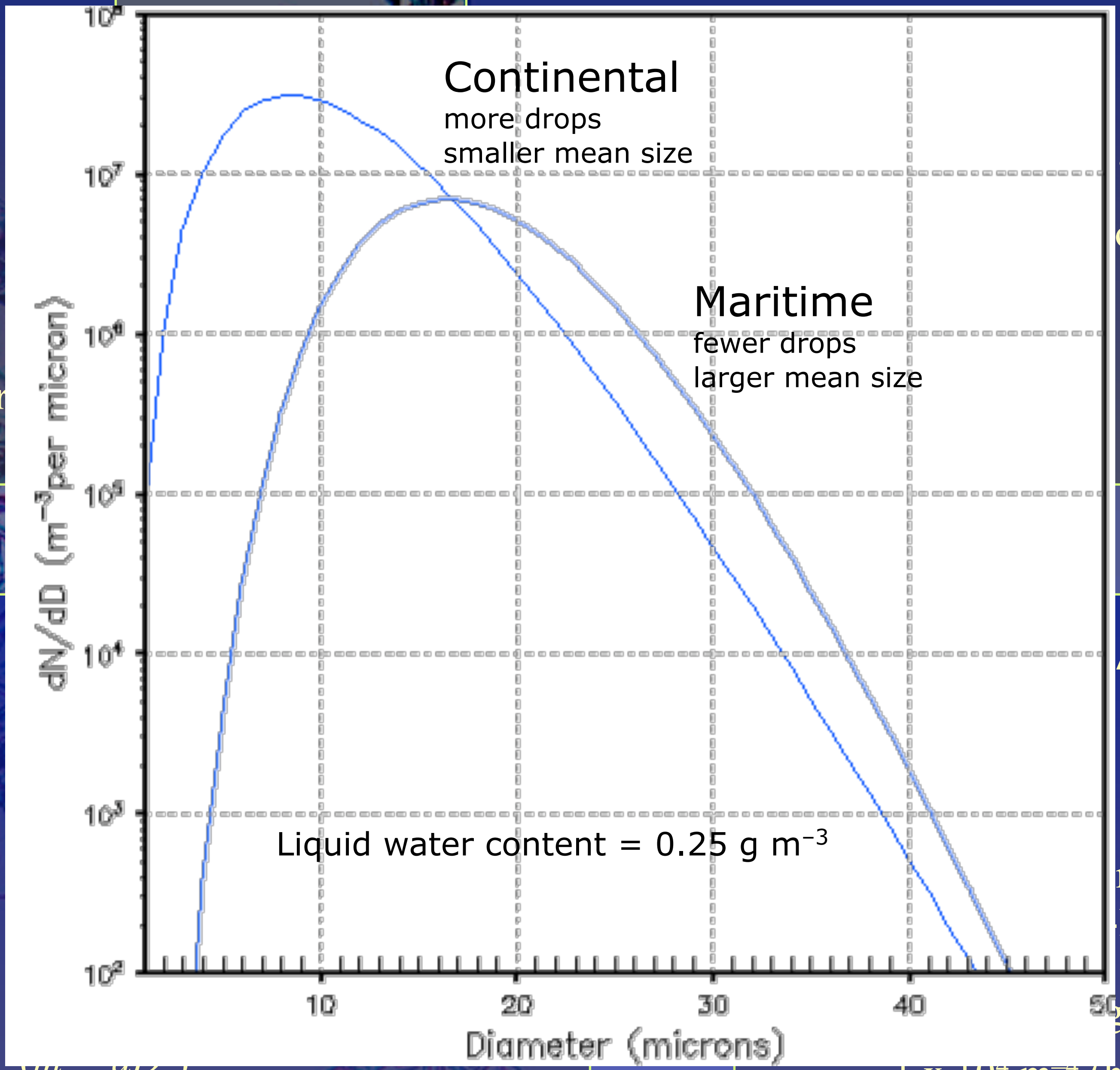

Rain

gamma distribution

predicted N_r (2-moment)

accurate fallspeed relation

variable density ($1/D$)

/ Hail

parameter

raio (simulate

-like graupel):

graupel)

1 x 10^4 m^{-4} (hail)

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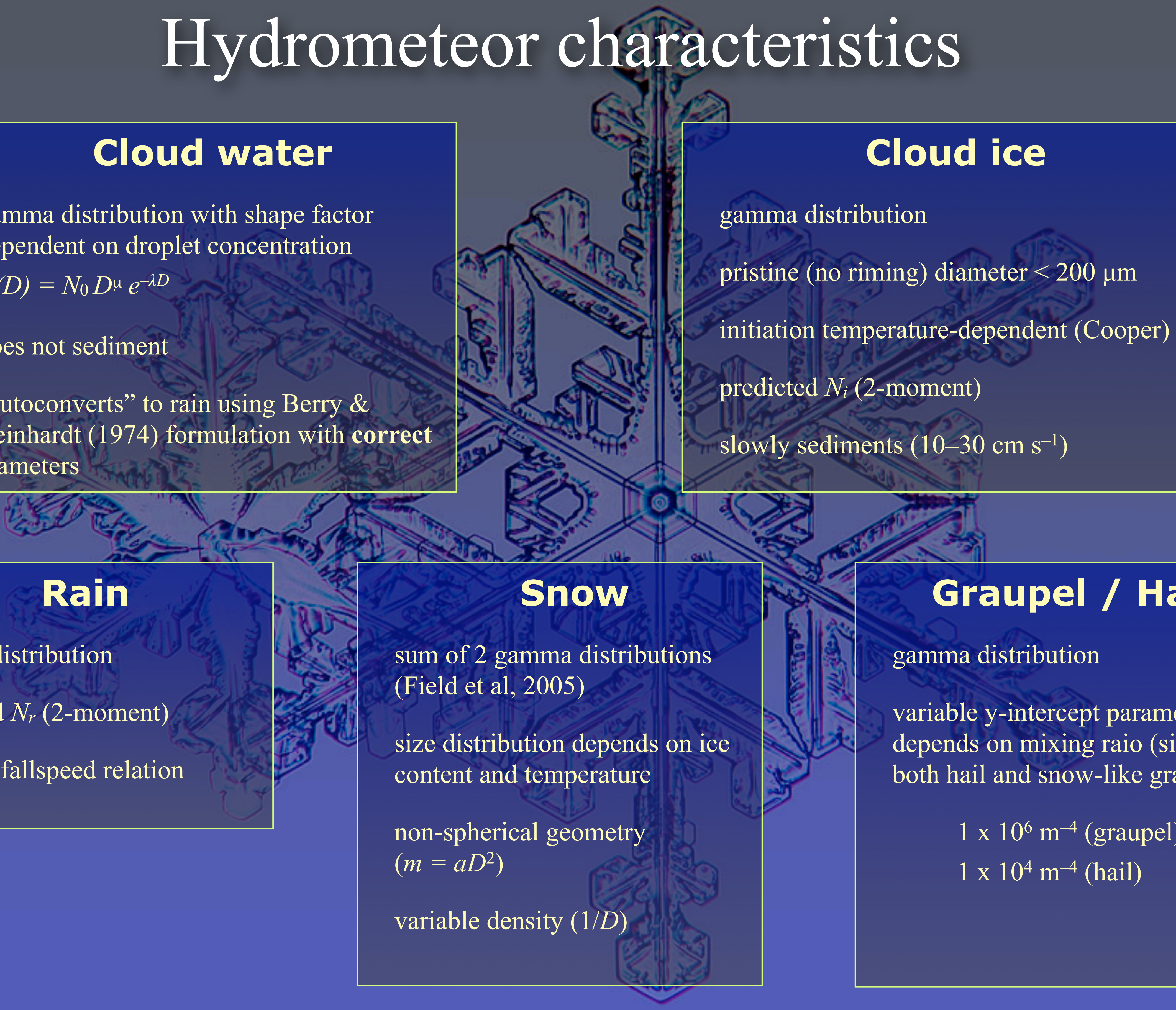

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Cloud water

gamma distribution with shape factor dependent on droplet concentration

$N(D) = N_0 D^{\mu} e^{-\lambda D}$

does not sediment

“autoconverts” to rain using Berry & Reinhardt (1974) formulation with correct diameters

New

explicit CCN from aerosols (sulfates + sea salts)

predicted N_c (2-moment)

Cloud ice

gamma distribution

pristine (no riming) diameter < 200 µm

initiation temperature-dependent (Cooper)

predicted N_i (2-moment)

slowly sediments (10–30 cm s^{-1})

New

heterogeneous freezing on dust/mineral > 0.5 microns

homogeneous freezing of deliquesced aerosols following Koop et al (2000)

Rain

gamma distribution

predicted N_r (2-moment)

accurate fallspeed relation

Snow

sum of 2 gamma distributions (Field et al, 2005)

size distribution depends on ice content and temperature

non-spherical geometry ($m = aD^2$)

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variable y-intercept parameter depends on mixing raio (simulate both hail and snow-like graupel):

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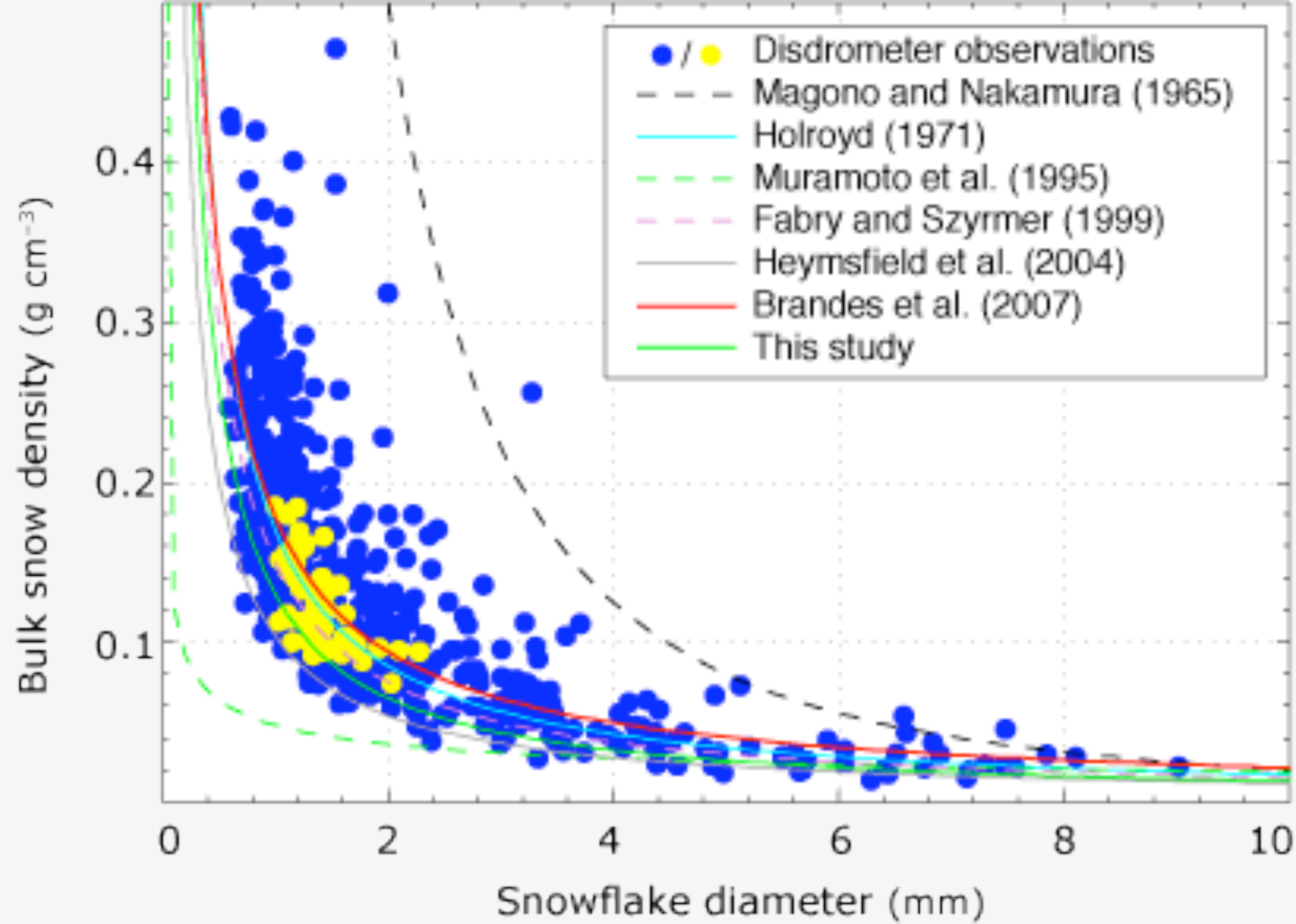
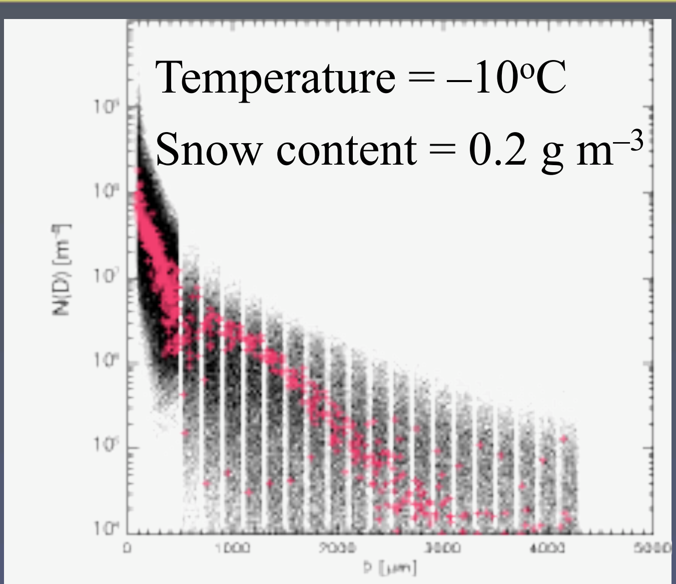
Snow (details)

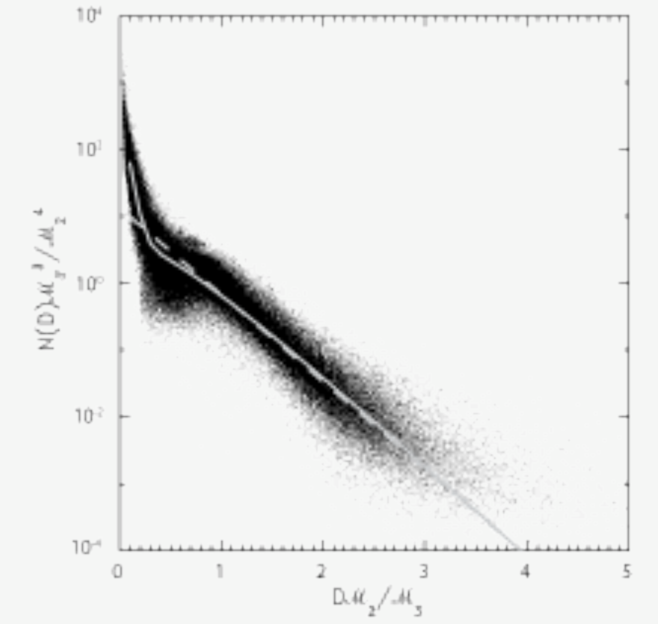
Snow density varies 1/*D*

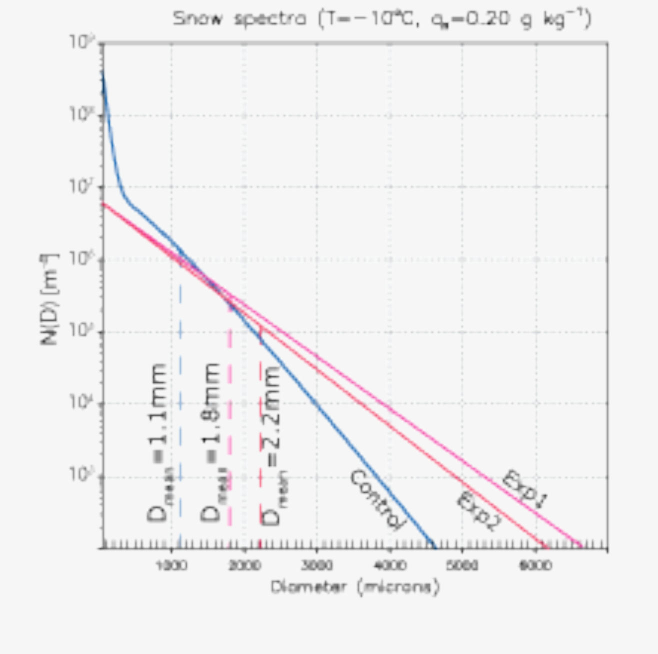




Temperature = –10ºC

Snow content = 0.2 g m^{-3}

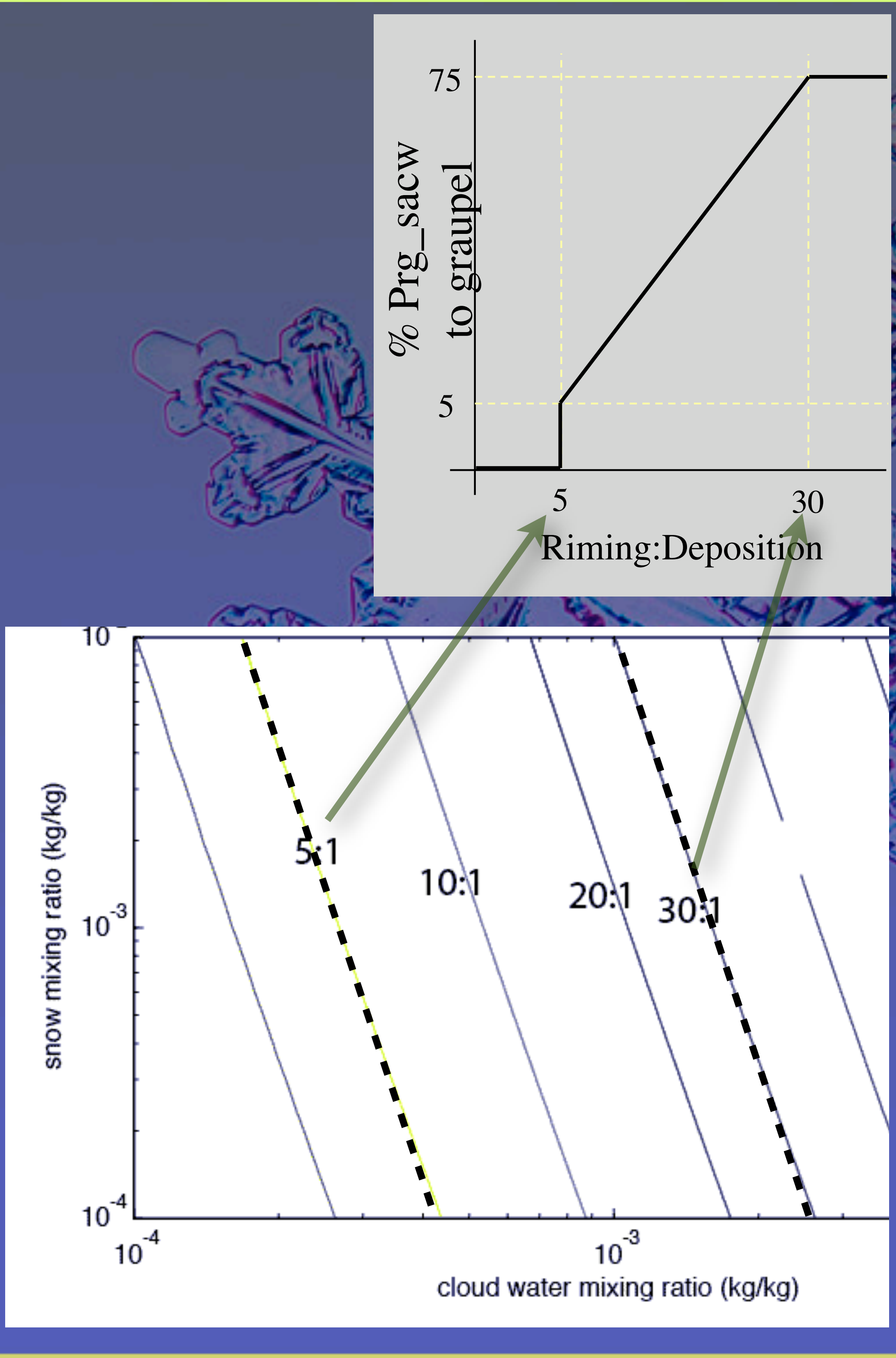




Graupel (details)

Rimed Snow

converts to graupel more smoothly than other schemes



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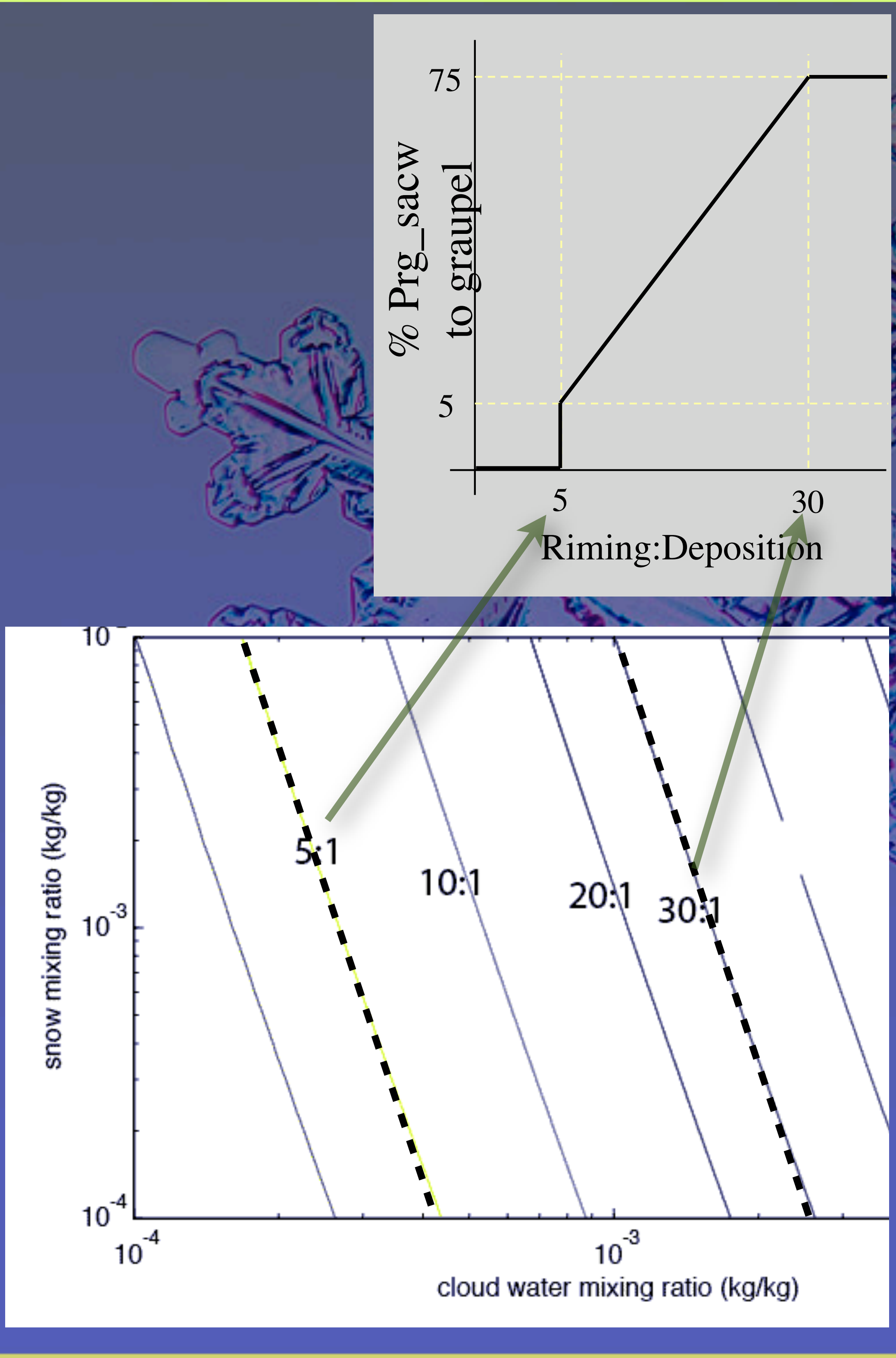
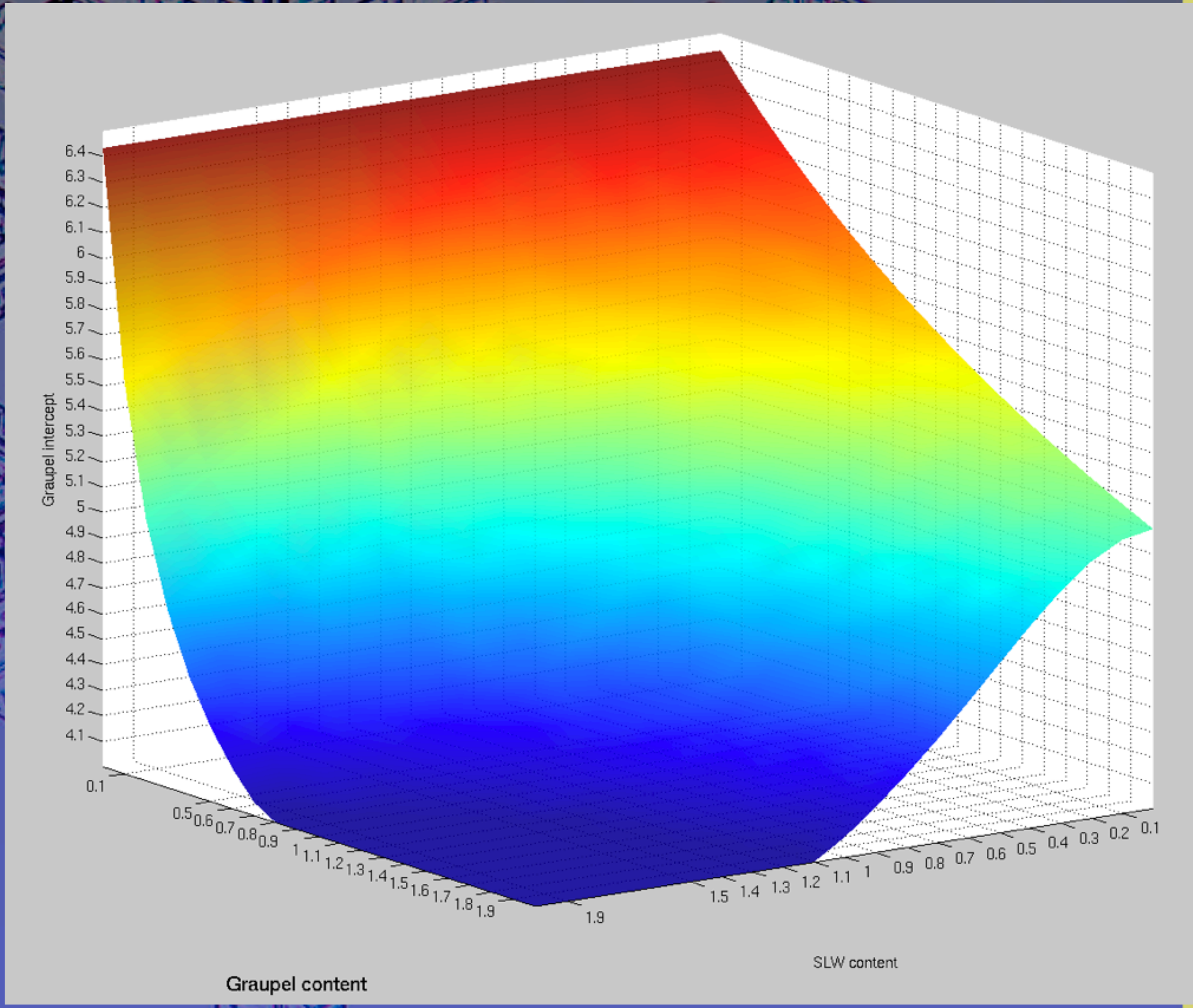
Mimics hail

variable y-intercept parameter allows terminal velocity 15+ m/s





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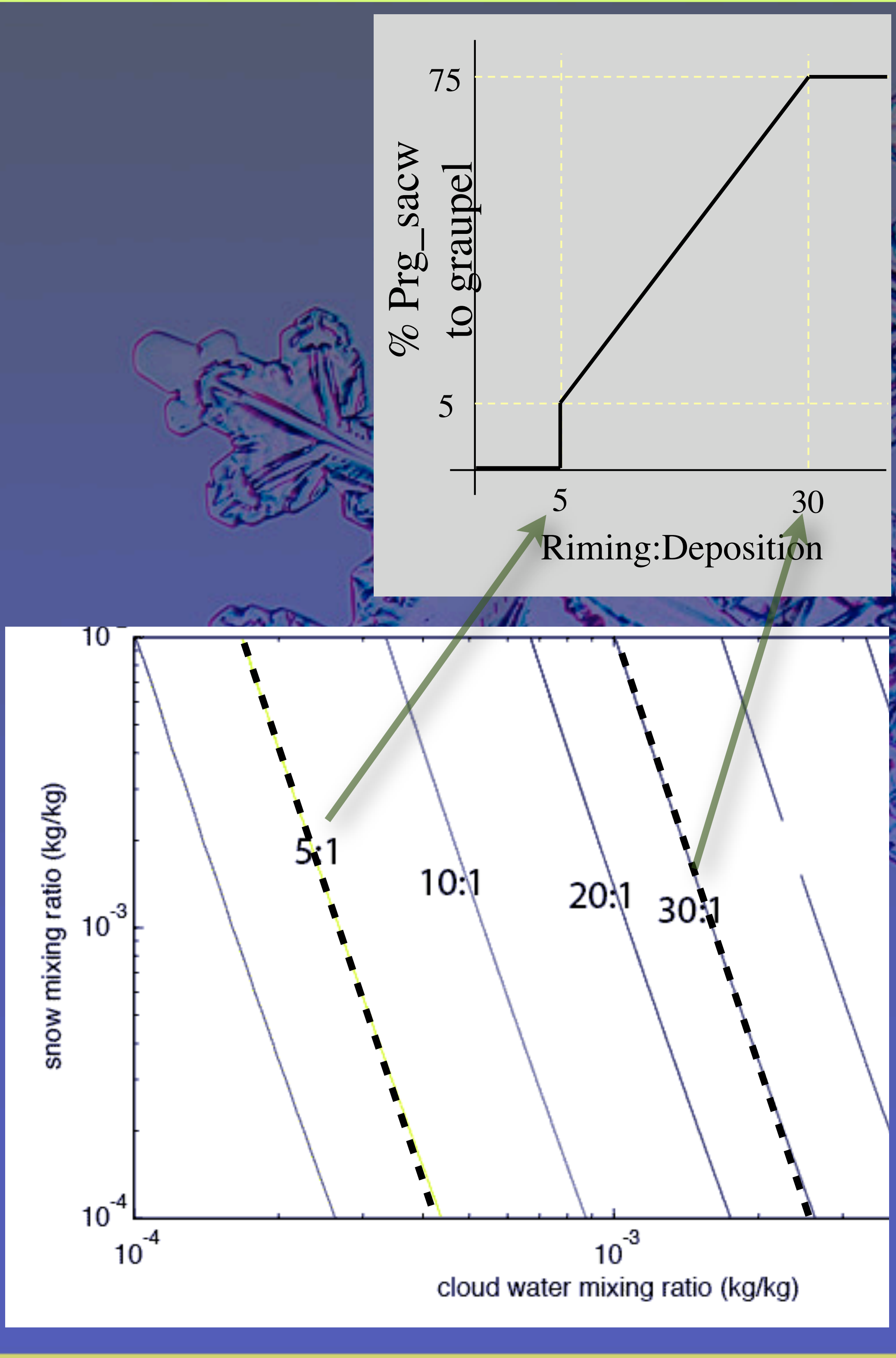
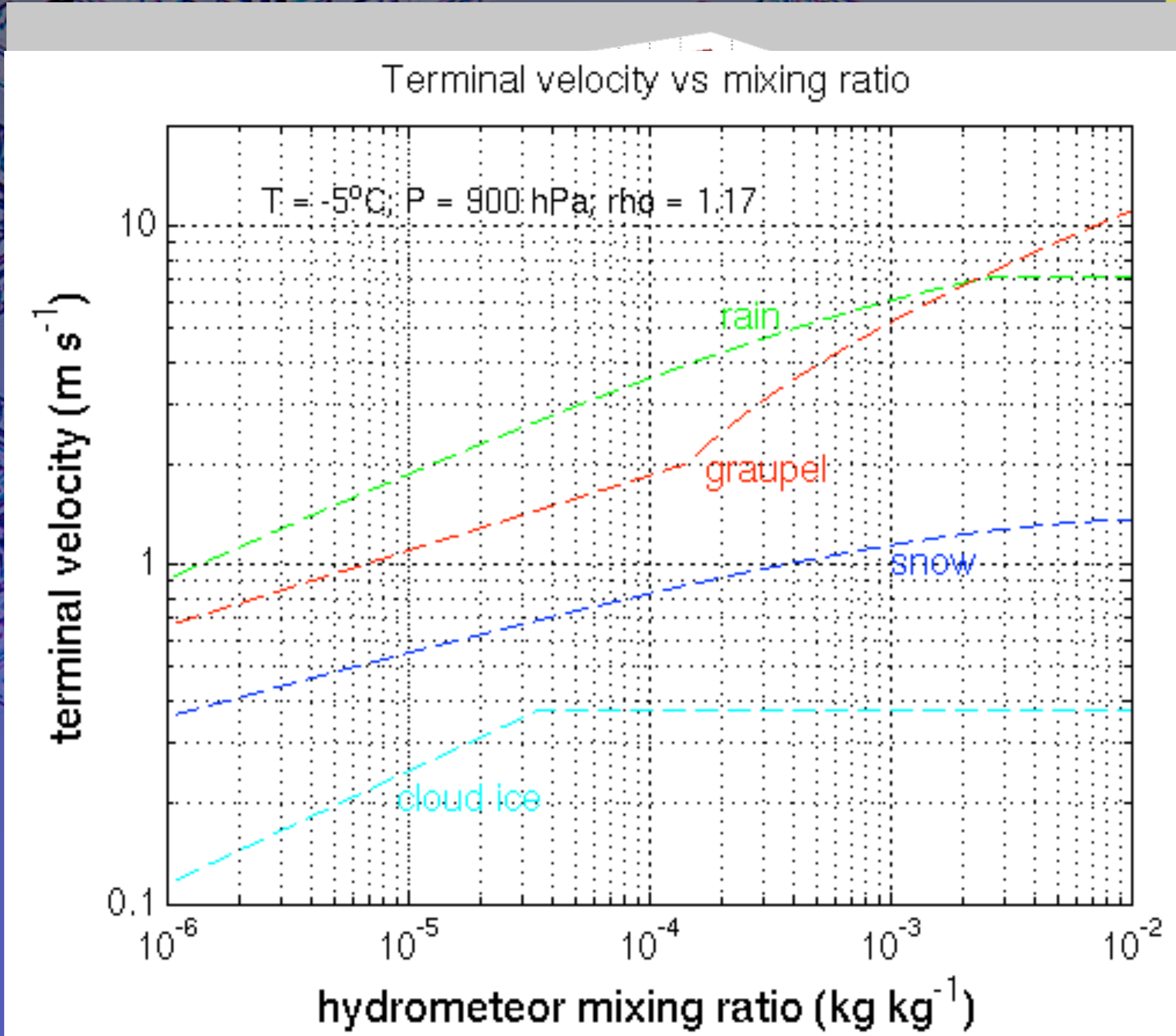
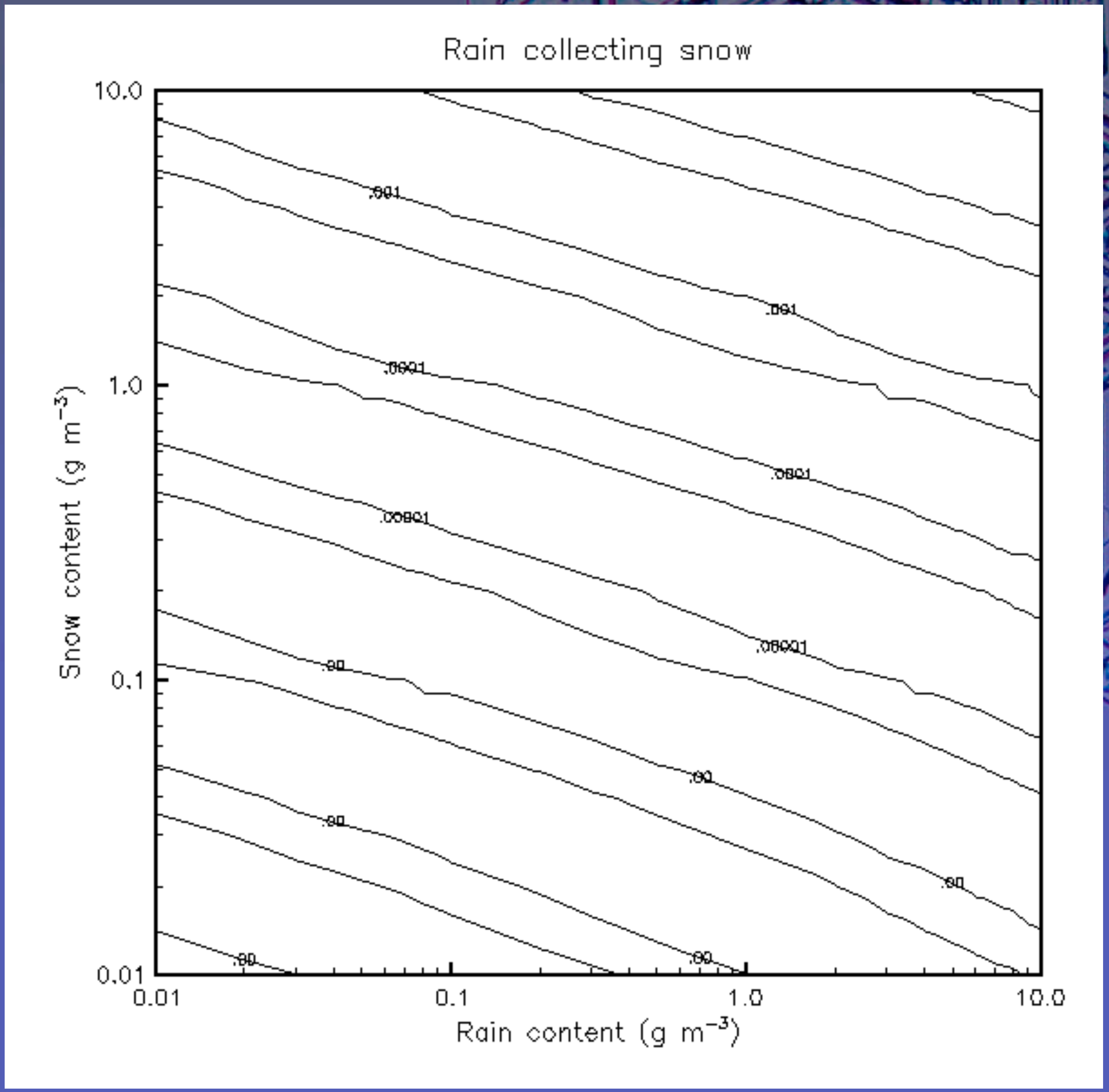
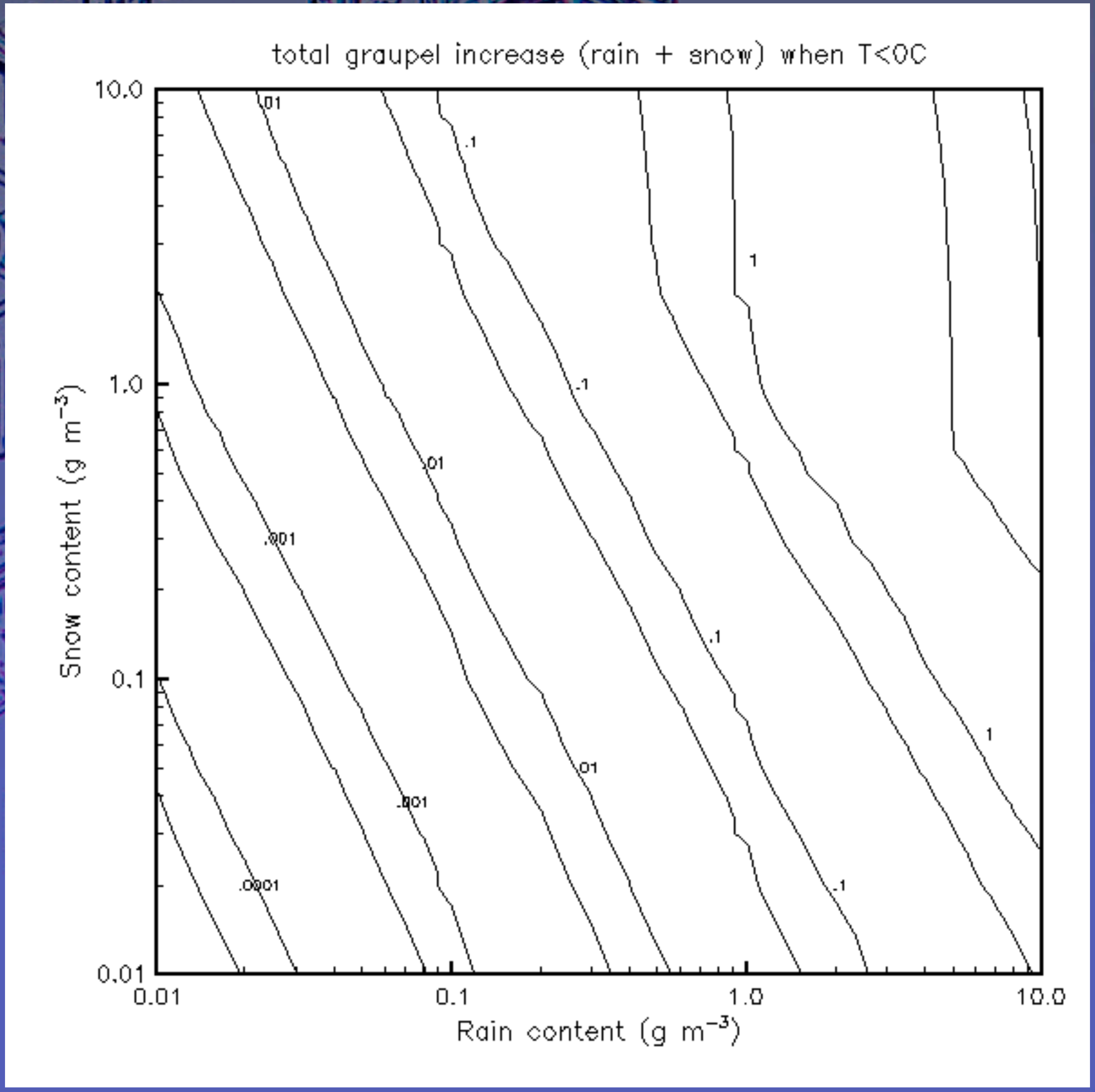




Collection equation

$$\frac{d(r_y)}{dt} = \frac{\pi}{4}\int_0^{\infty}\int_0^{\infty} E_{xy}\, m(D_x)\left(D_x + D_y\right)^2\left[v_x(D_x) - v_y(D_y)\right]N_x(D_x)\,N_y(D_y)\,dD_x dD_y$$





Physical process and code improvements

Property or source/sink	Deficiency in prior scheme(s)	Improvement
Cloud water	Monodisperse or exponential distribution	Generalized gamma with variable shape parameter
Rain	Single-moment assumes exponential distrib with constant y-intercept	Double-moment (warm-rain vs. melted snow/graupel); improve size-sorting sedimentation
Snow	Constant density, spherical snow assumes exponential distrib with constant y-intercept	Variable density (based on size) and realistic size distributions
Graupel/hail	Exponential with constant intercept parameter	Variable y-intercept parameter attempts to mimic graupel and hail
Autoconversion	Simple threshold	Follows results of bin model
Collision/collection	Oversimplified with 100% collection efficiency and improper mathematical simplification of true double-integral	Explicit size-dependent collection efficiency and explicit bin-model solution of collection equation double-integral
Graupel production	Snow riming threshold to create all graupel	Snow riming to form graupel is less abrupt, more continuous
Sedimentation	Melting snow/graupel mathematically correct not physically correct	Snow/graupel fall faster as they melt, not slower
Saturation adjust	Ice nucleation RH(ice)=100% & aggressive ice production	Explicit vapor deposition, no auto-adjust & much less aggressive ice initiation

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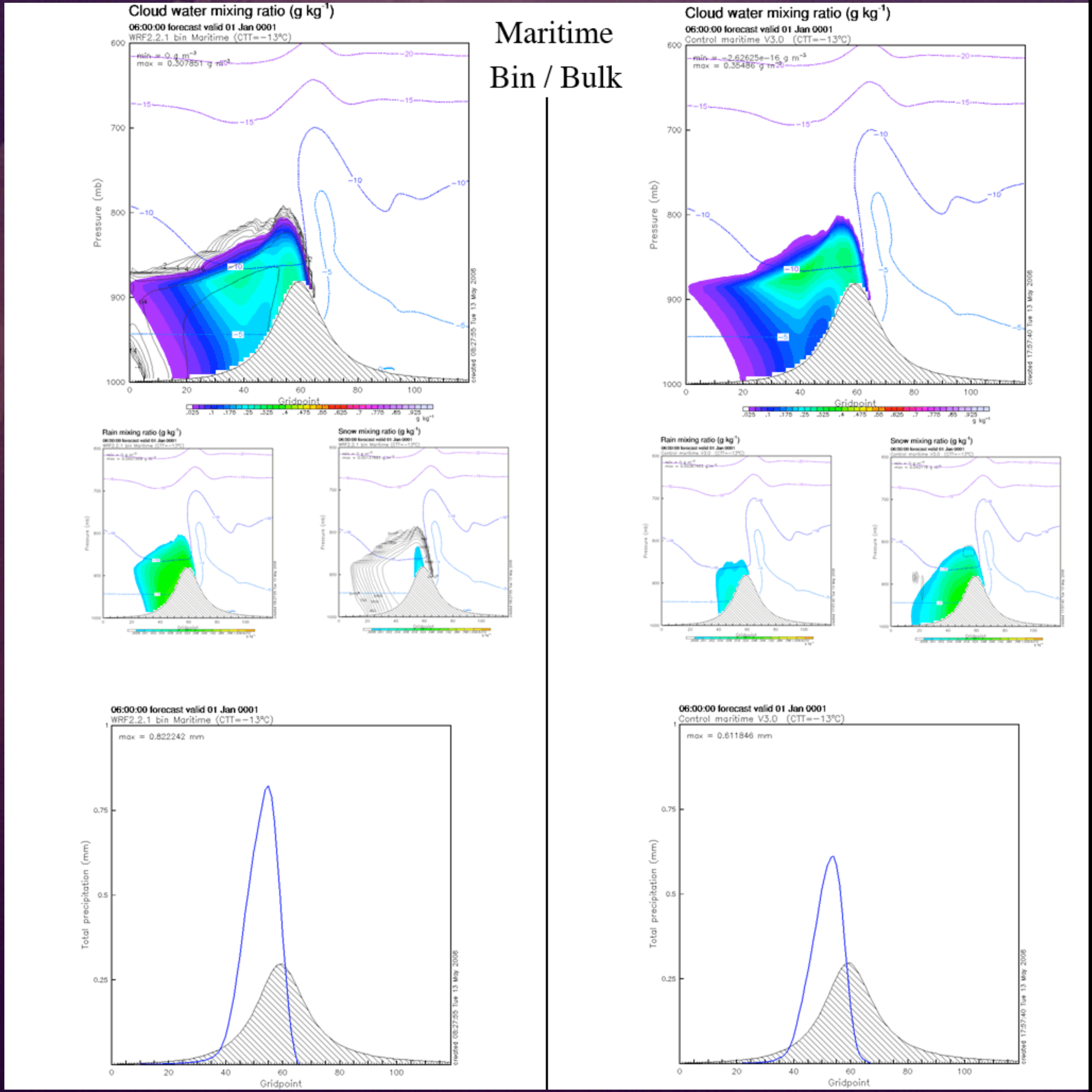
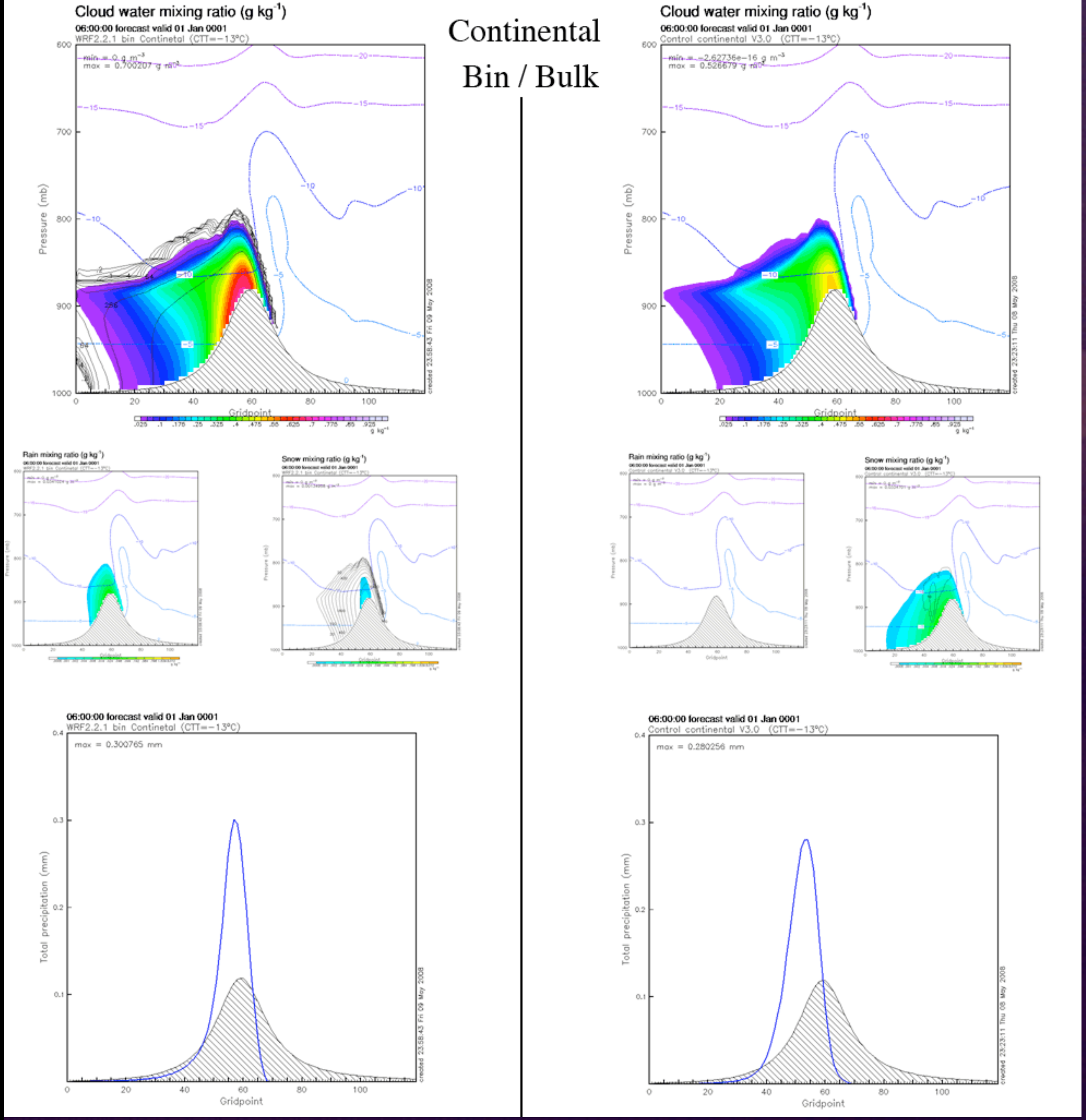
Comparisons to explicit/bin model

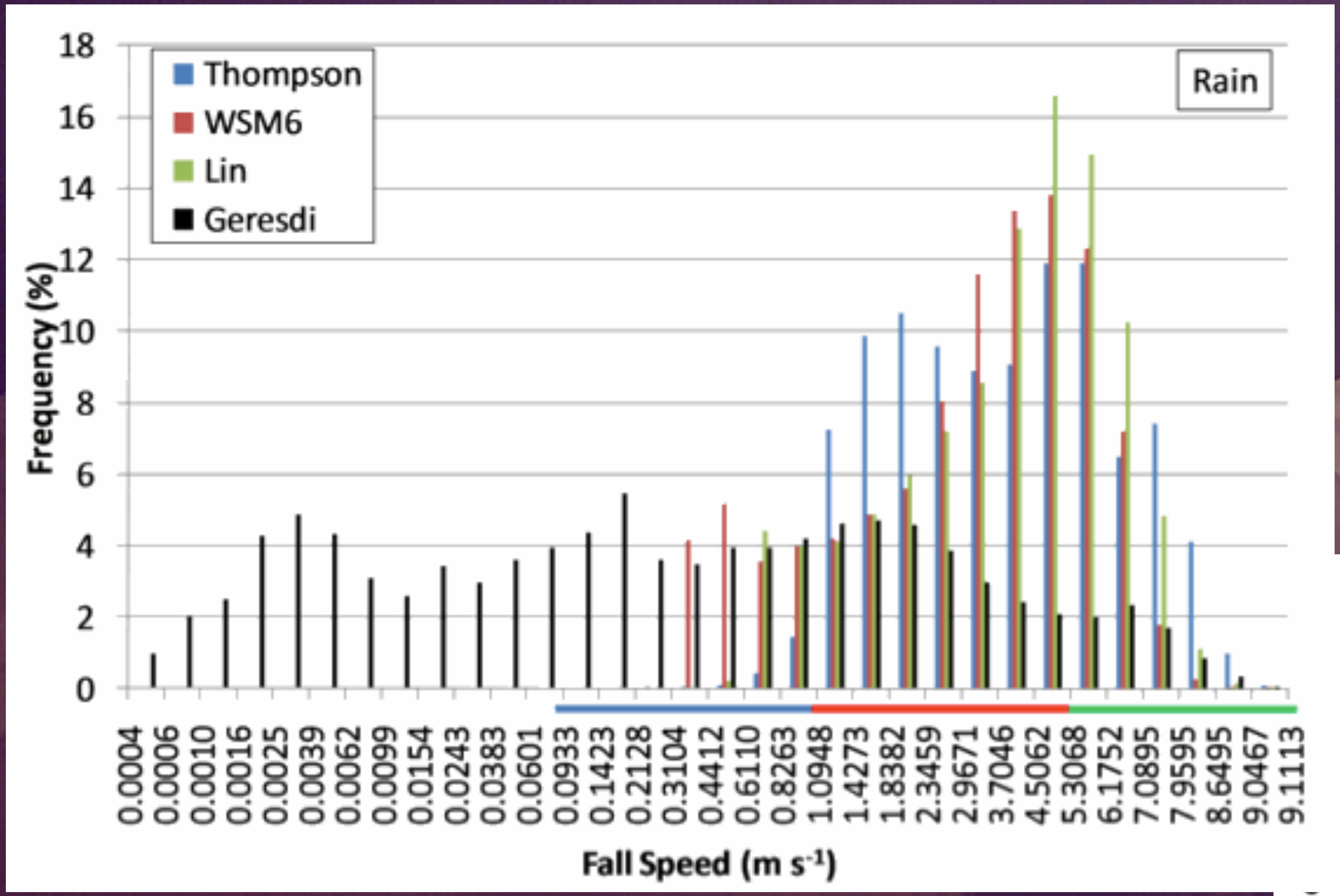
Maritime (25 cm^{-3})

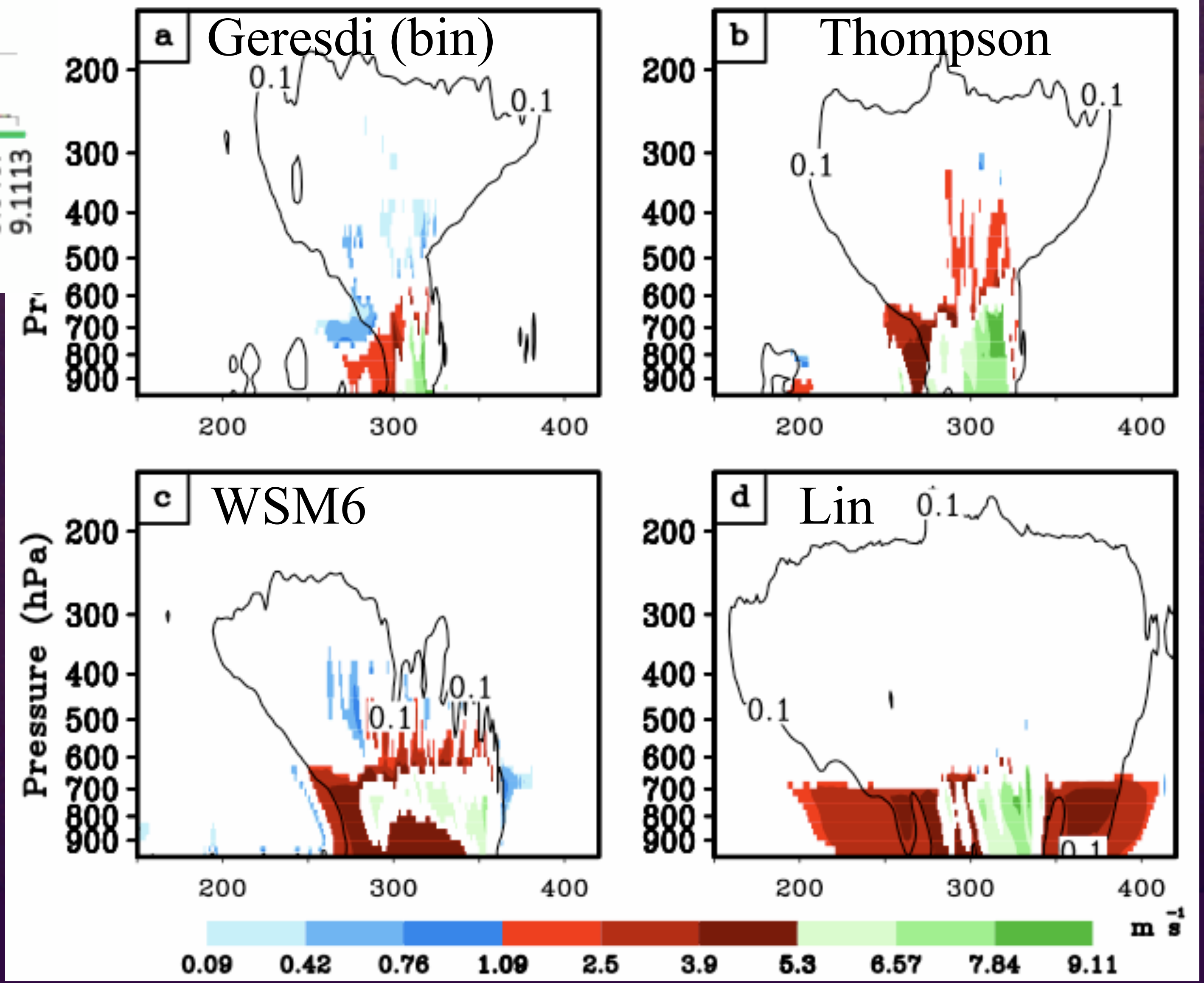
Continental (300 cm^{-3})



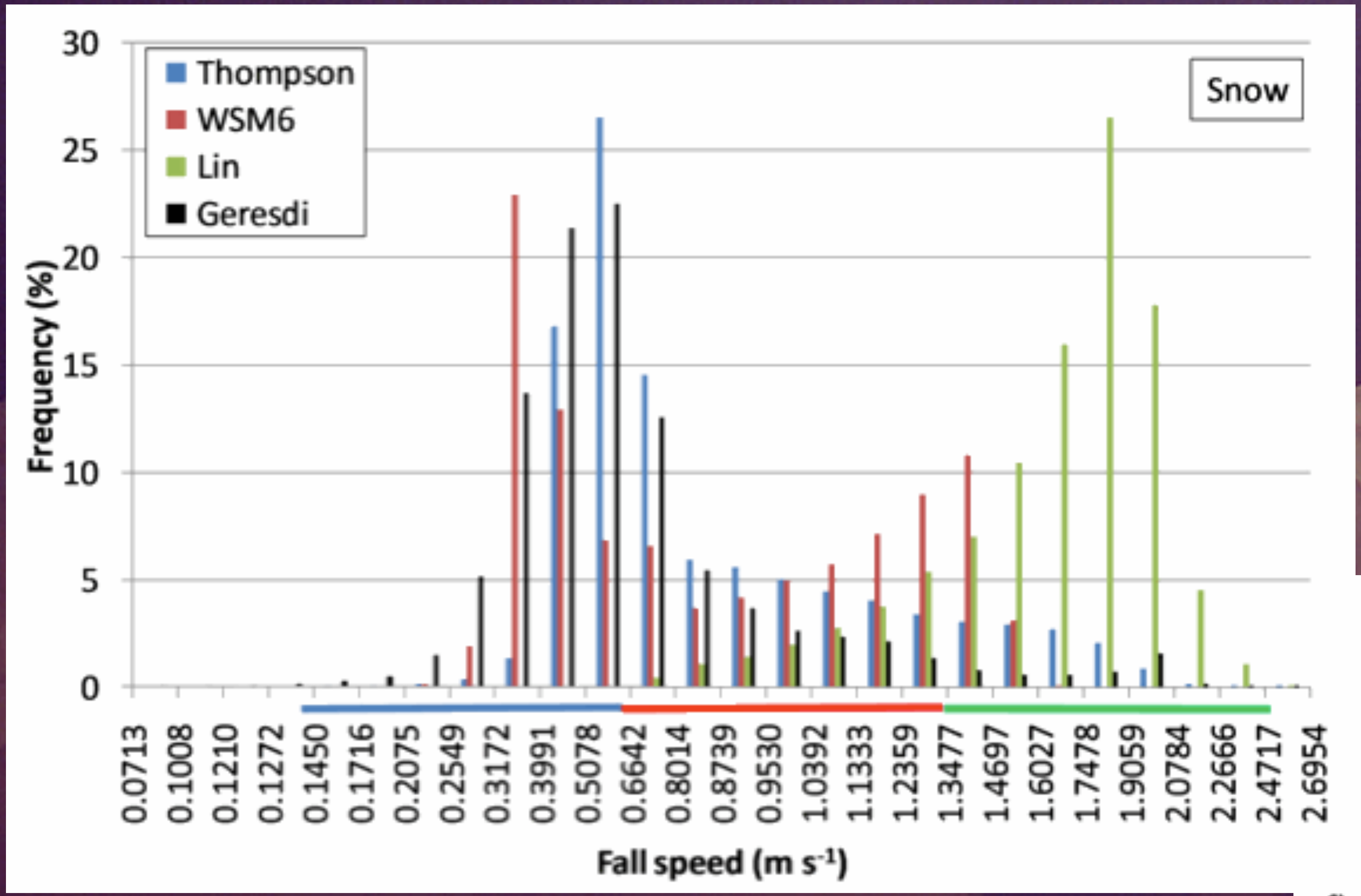


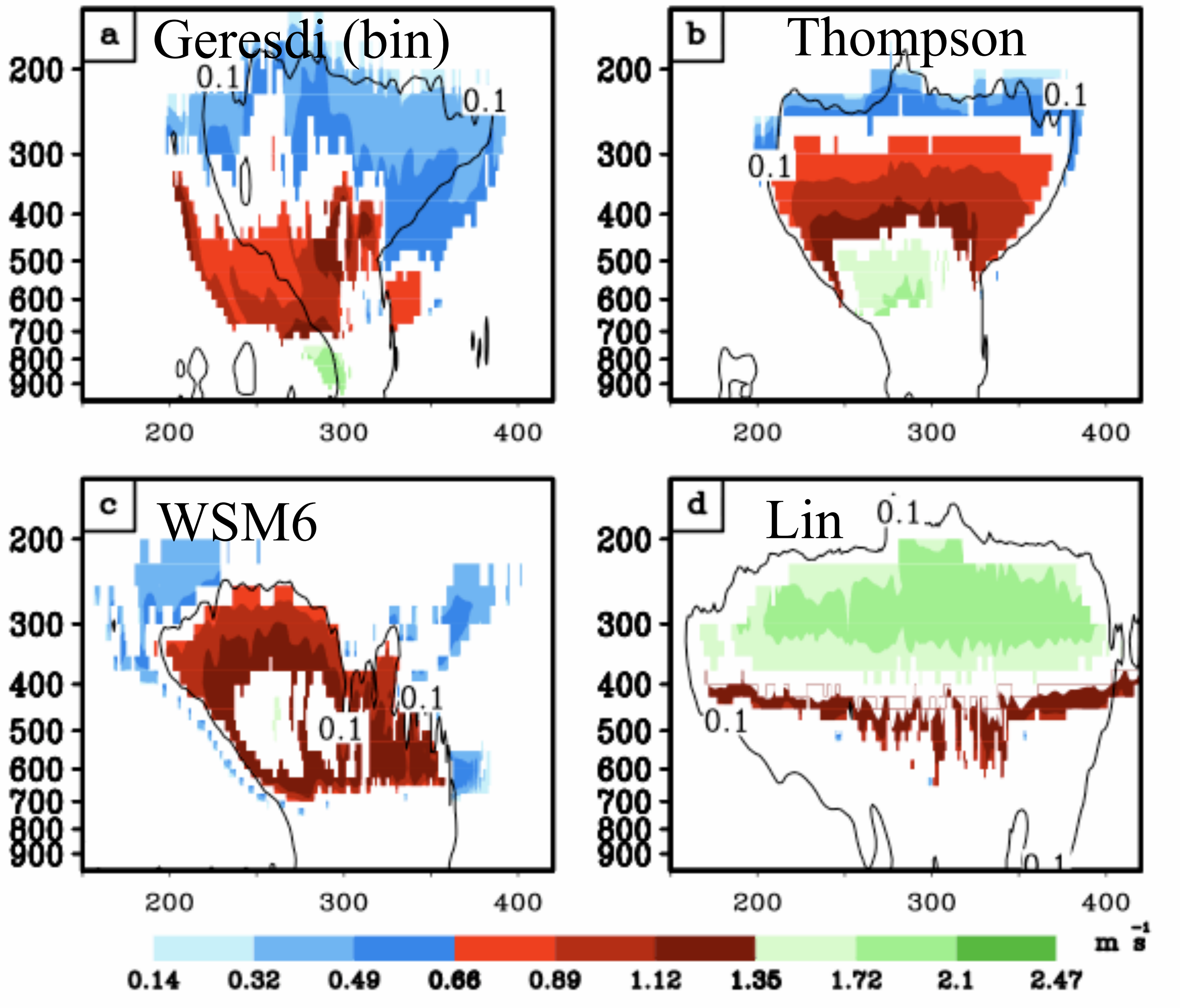
Bin vs. bulk rain fallspeeds



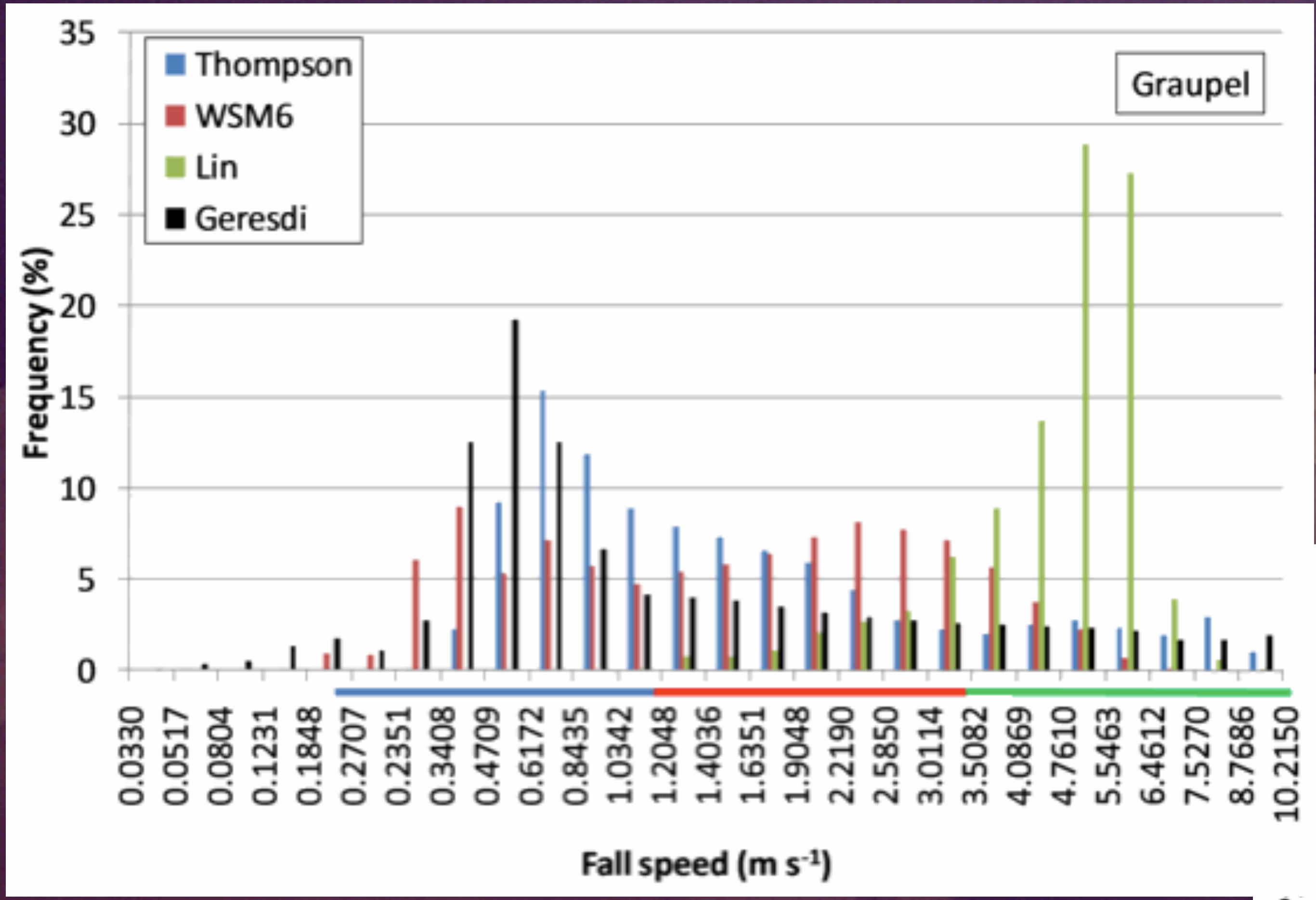


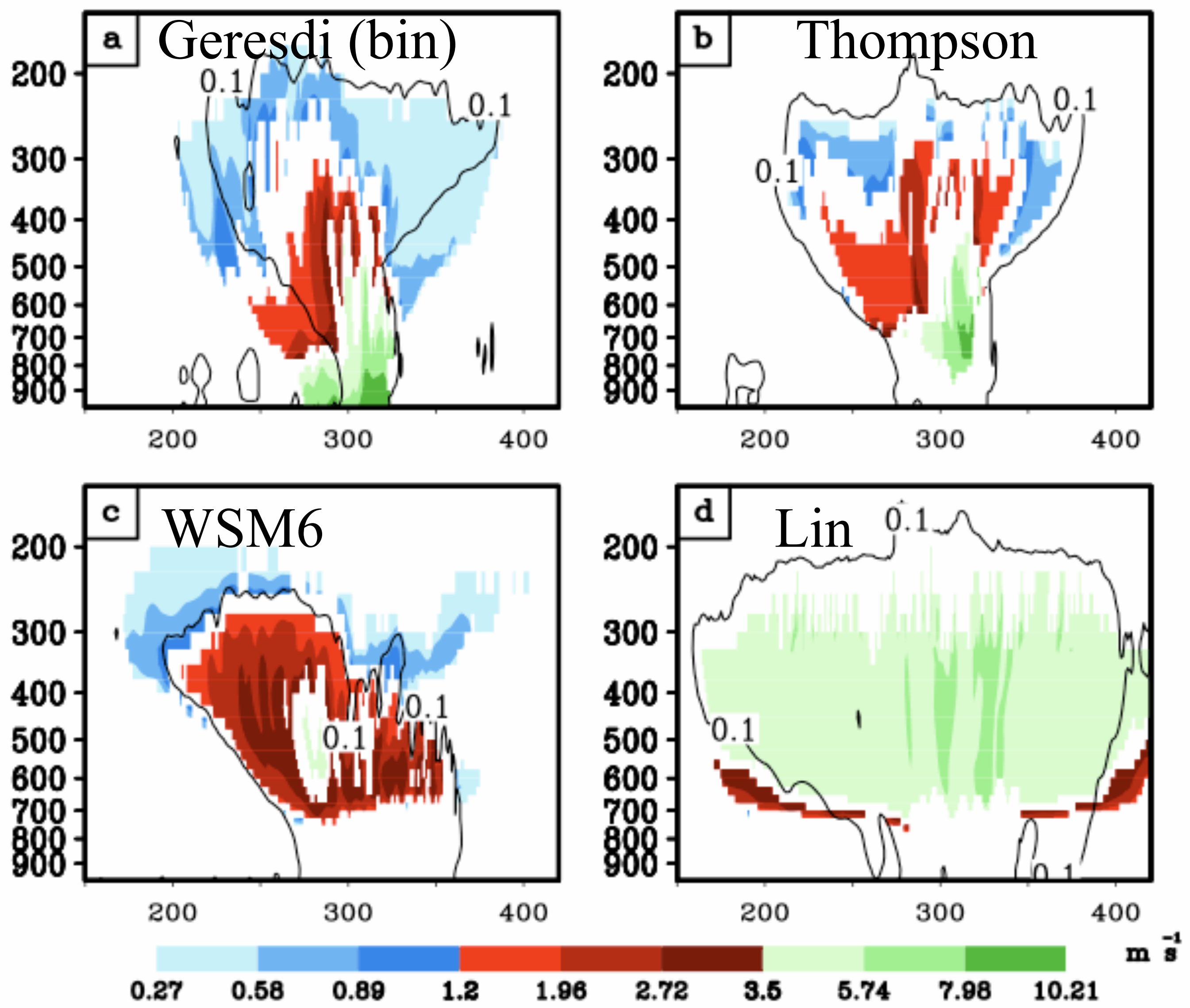
Bin vs. bulk snow fallspeeds



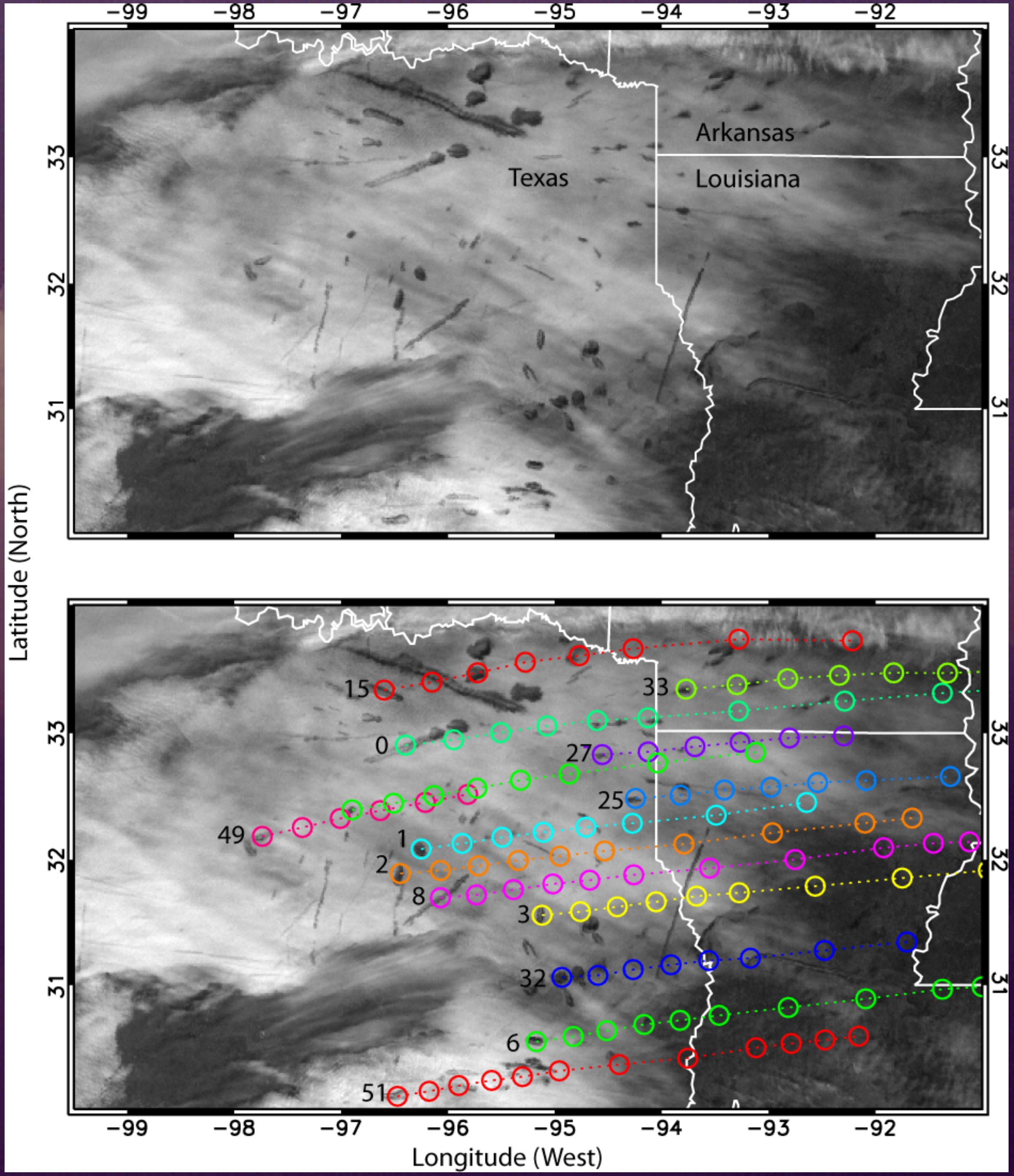


Bin vs. bulk graupel fallspeeds

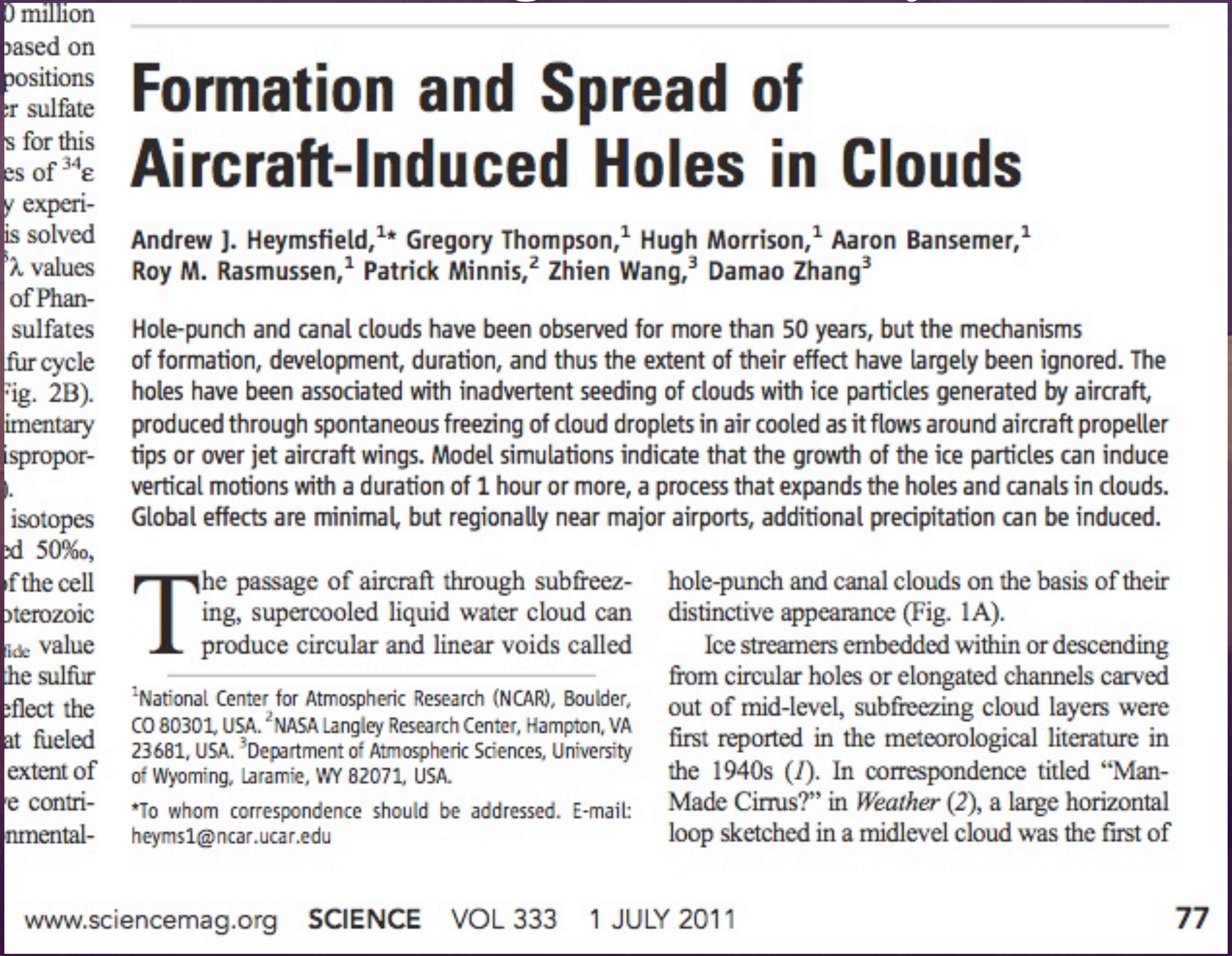




Tests: “Hole cloud” simulation



Science magazine, July 2011



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Formation and Spread of Aircraft-Induced Holes in Clouds

Andrew J. Heymsfield,[1]* Gregory Thompson,[1] Hugh Morrison,[1] Aaron Bansemer,[1] Roy M. Rasmussen,[1] Patrick Minnis,[2] Zhien Wang,[3] Damao Zhang[3]

Hole-punch and canal clouds have been observed for more than 50 years, but the mechanisms of formation, development, duration, and thus the extent of their effect have largely been ignored. The holes have been associated with inadvertent seeding of clouds with ice particles generated by aircraft, produced through spontaneous freezing of cloud droplets in air cooled as it flows around aircraft propeller tips or over jet aircraft wings. Model simulations indicate that the growth of the ice particles can induce vertical motions with a duration of 1 hour or more, a process that expands the holes and canals in clouds. Global effects are minimal, but regionally near major airports, additional precipitation can be induced.

The passage of aircraft through subfreezing, supercooled liquid water cloud can produce circular and linear voids called hole-punch and canal clouds on the basis of their distinctive appearance (Fig. 1A).

Ice streamers embedded within or descending from circular holes or elongated channels carved out of mid-level, subfreezing cloud layers were first reported in the meteorological literature in the 1940s (*1*). In correspondence titled "Man-Made Cirrus?" in *Weather* (*2*), a large horizontal loop sketched in a midlevel cloud was the first of

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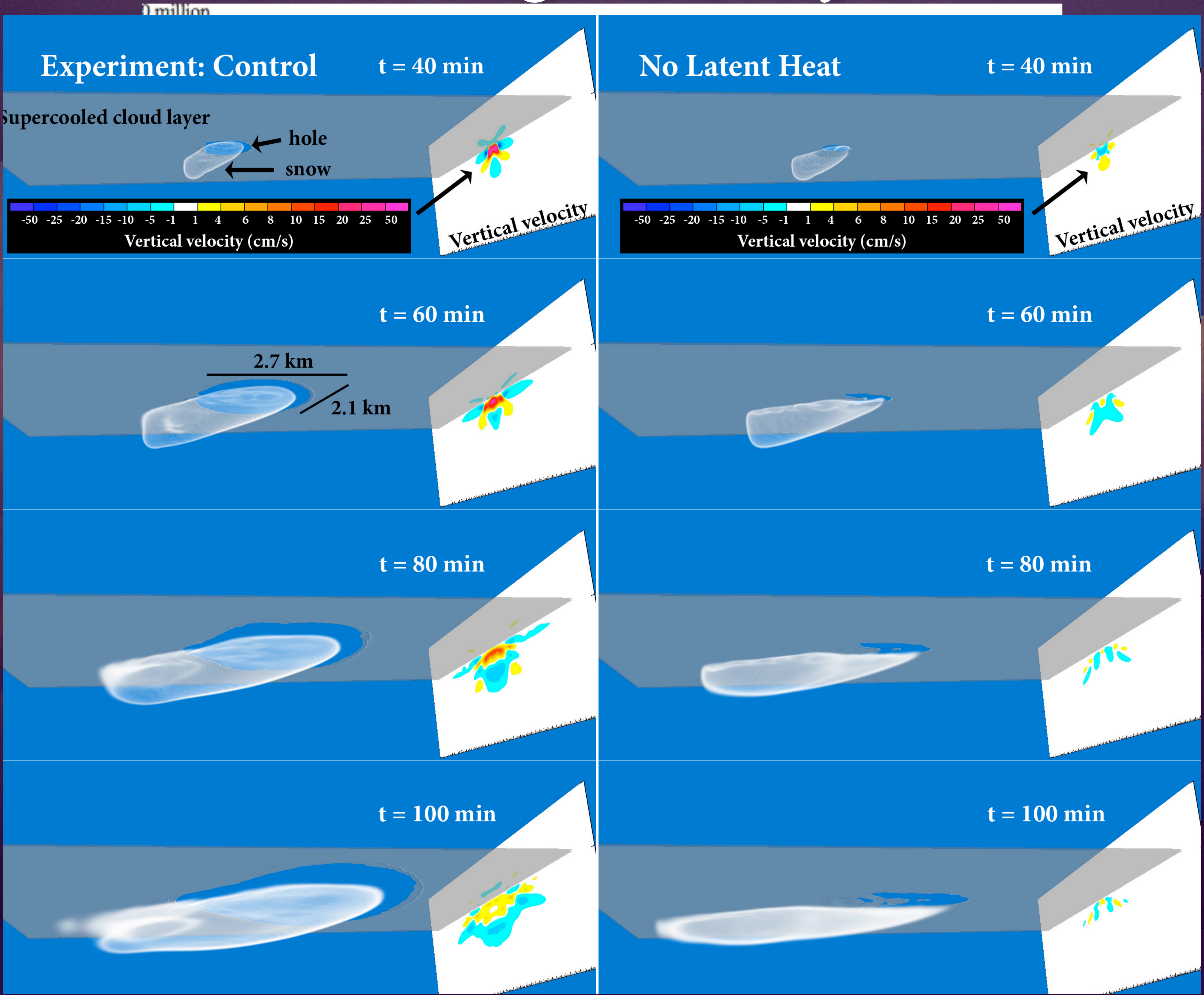
[1] National Center for Atmospheric Research (NCAR), Boulder, CO 80301, USA. [2] NASA Langley Research Center, Hampton, VA 23681, USA. [3] Department of Atmospheric Sciences, University of Wyoming, Laramie, WY 82071, USA.

*To whom correspondence should be addressed. E-mail: heyms1@ncar.ucar.edu

Science magazine, July 2011



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- Microphysics scheme
- Testing
- **Applications**
  - **Colorado Headwaters**
  - Convection
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Colorado Headwaters project

- Predict Colorado mountain snowfall and resulting stream runoff
- High-resolution, 2 km grid spacing, excellent terrain representation, NARR forcing
- Four seasons, 6-month duration:
  - 01 Nov 2007 – 30 Apr 2008 (above average)
  - 2005 – 2006 (average year)
  - 2003 – 2004 (average year)
  - 2001 – 2002 (below average)
- Verified against SNOTEL observations
- Sensitivity experiments:
  - 2^{o}C warmer & constant RH (2005–2006)
  - CCSM year 2050
  - microphysics: Thompson et al, 2008 vs. other
- Extended 8-year run @4km spacing

WRF simulations by Changhai Liu
preliminary analysis by Kyoko Ikeda

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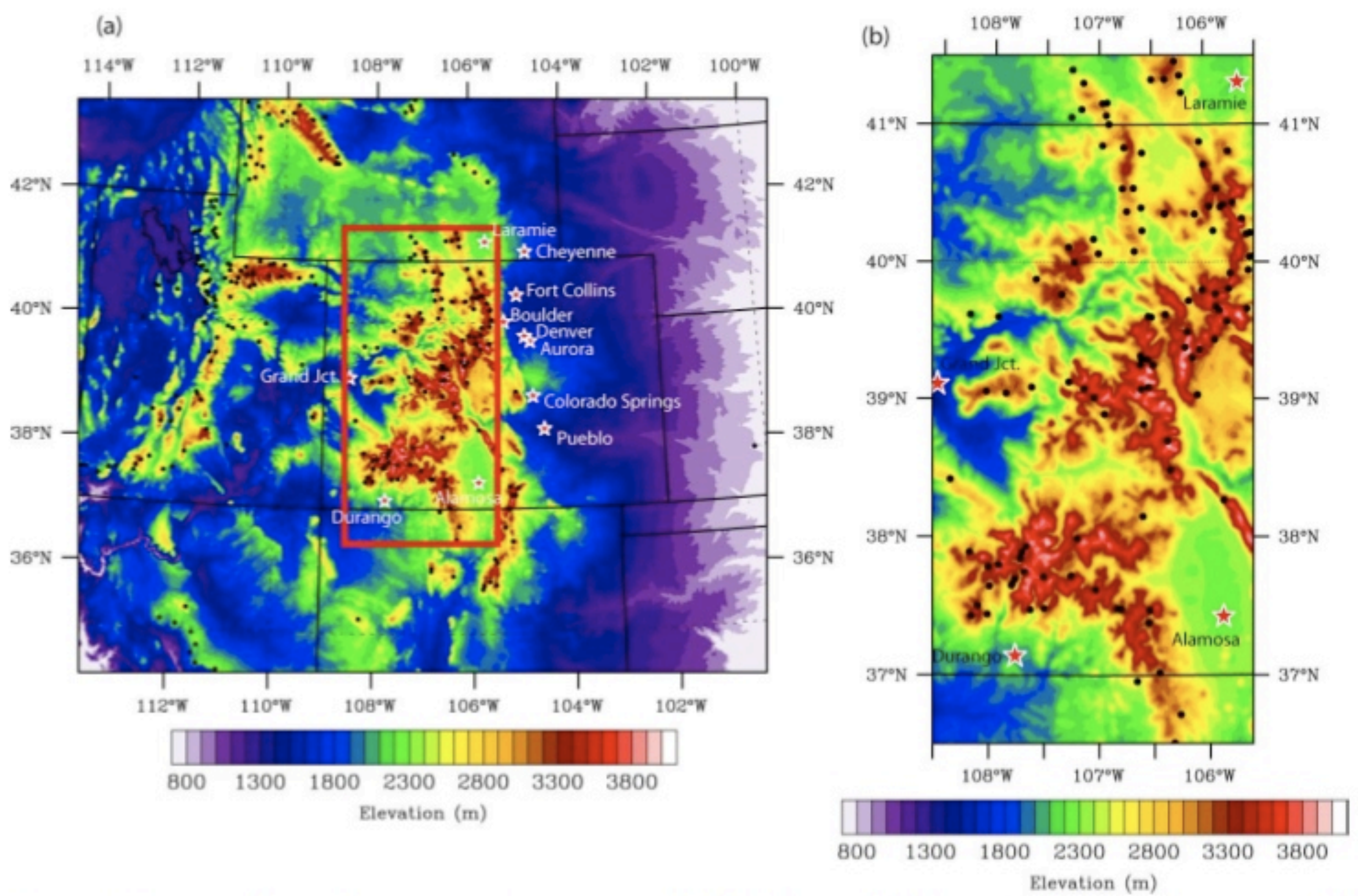

Figure 1: Retrospective model domain and location of SNOTEL sites (black dots). (a) full model domain (b) sub-domain focused over the Colorado Headwaters region.

WRF simulations by Changhai Liu
preliminary analysis by Kyoko Ikeda

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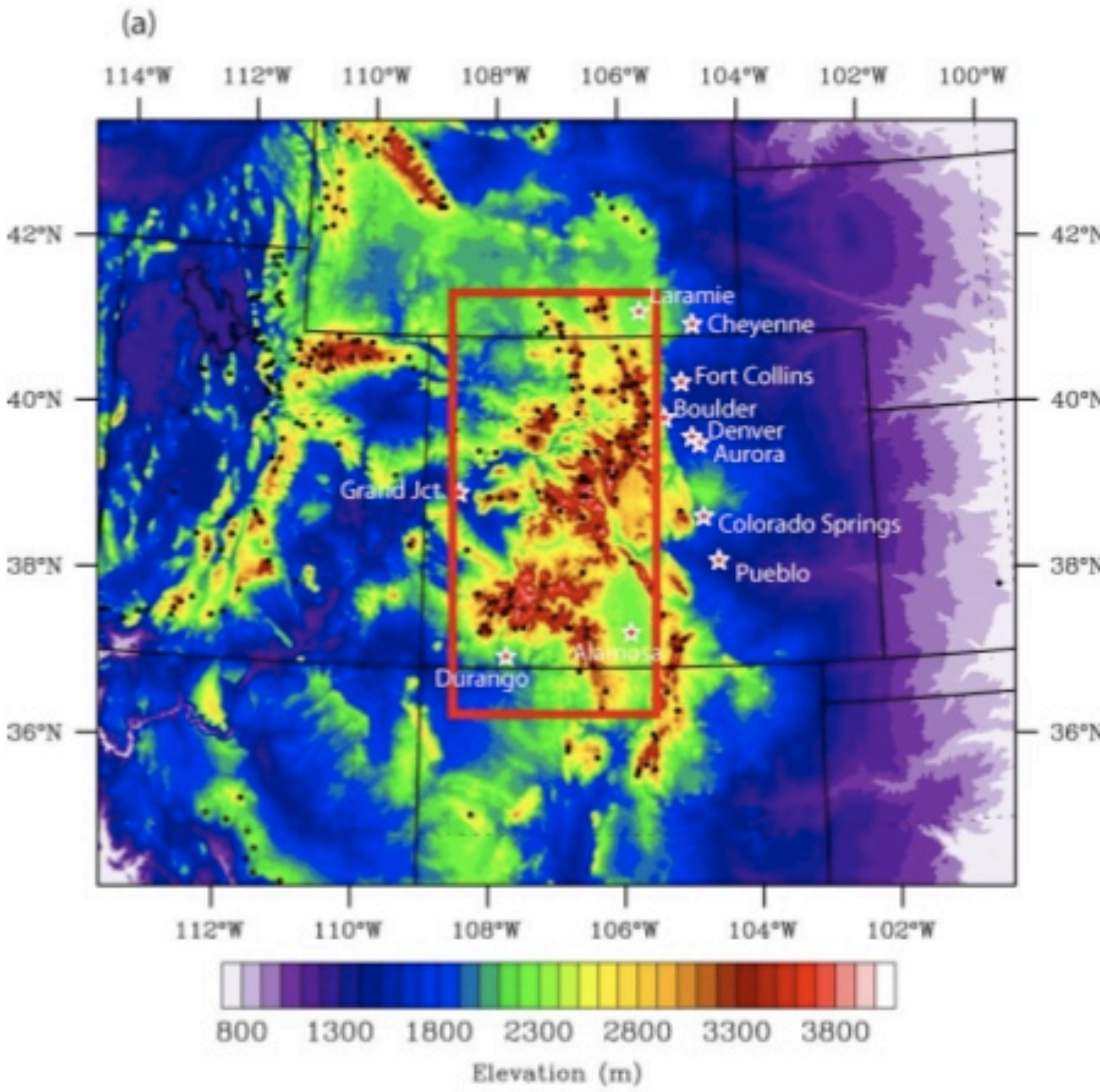

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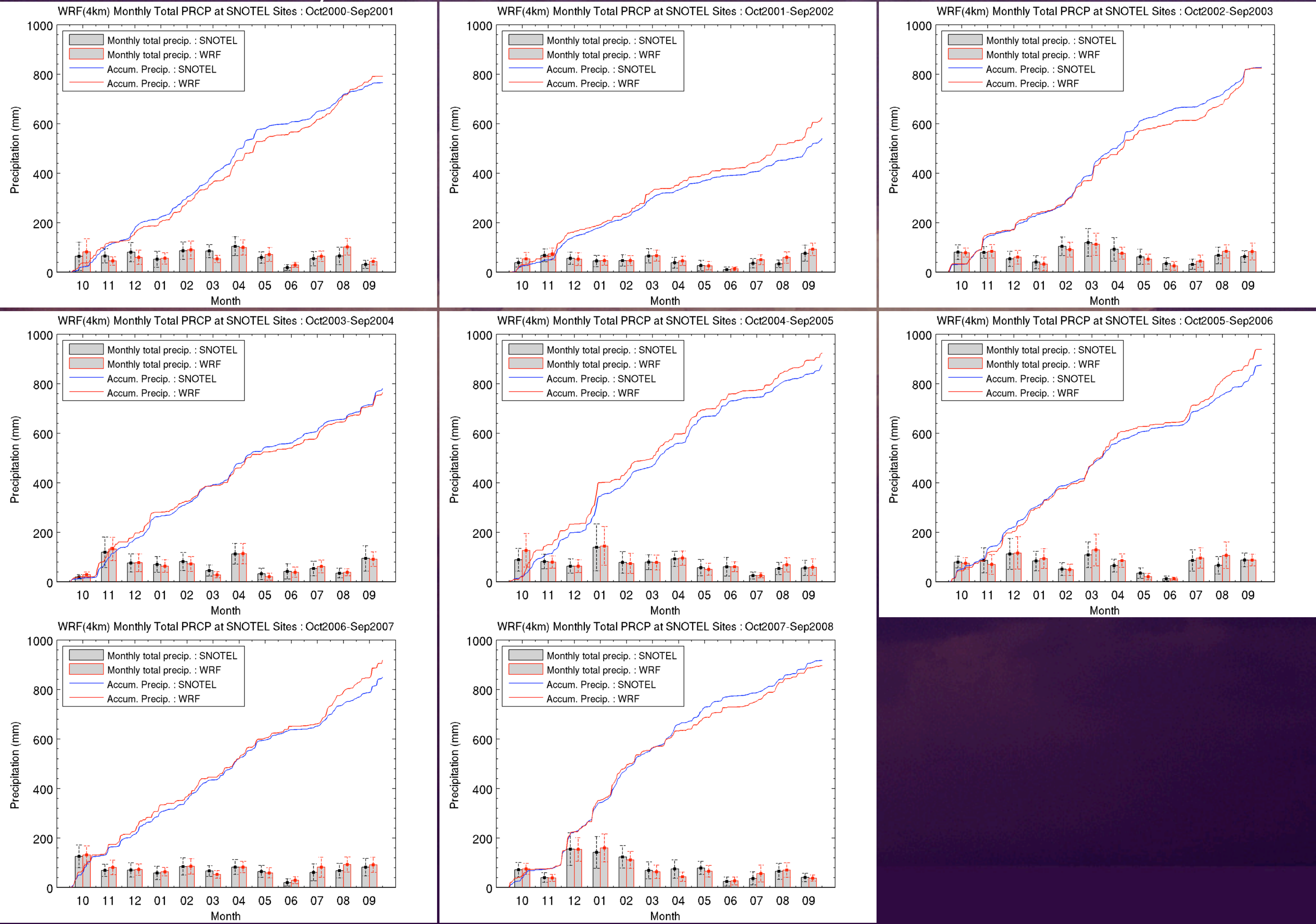
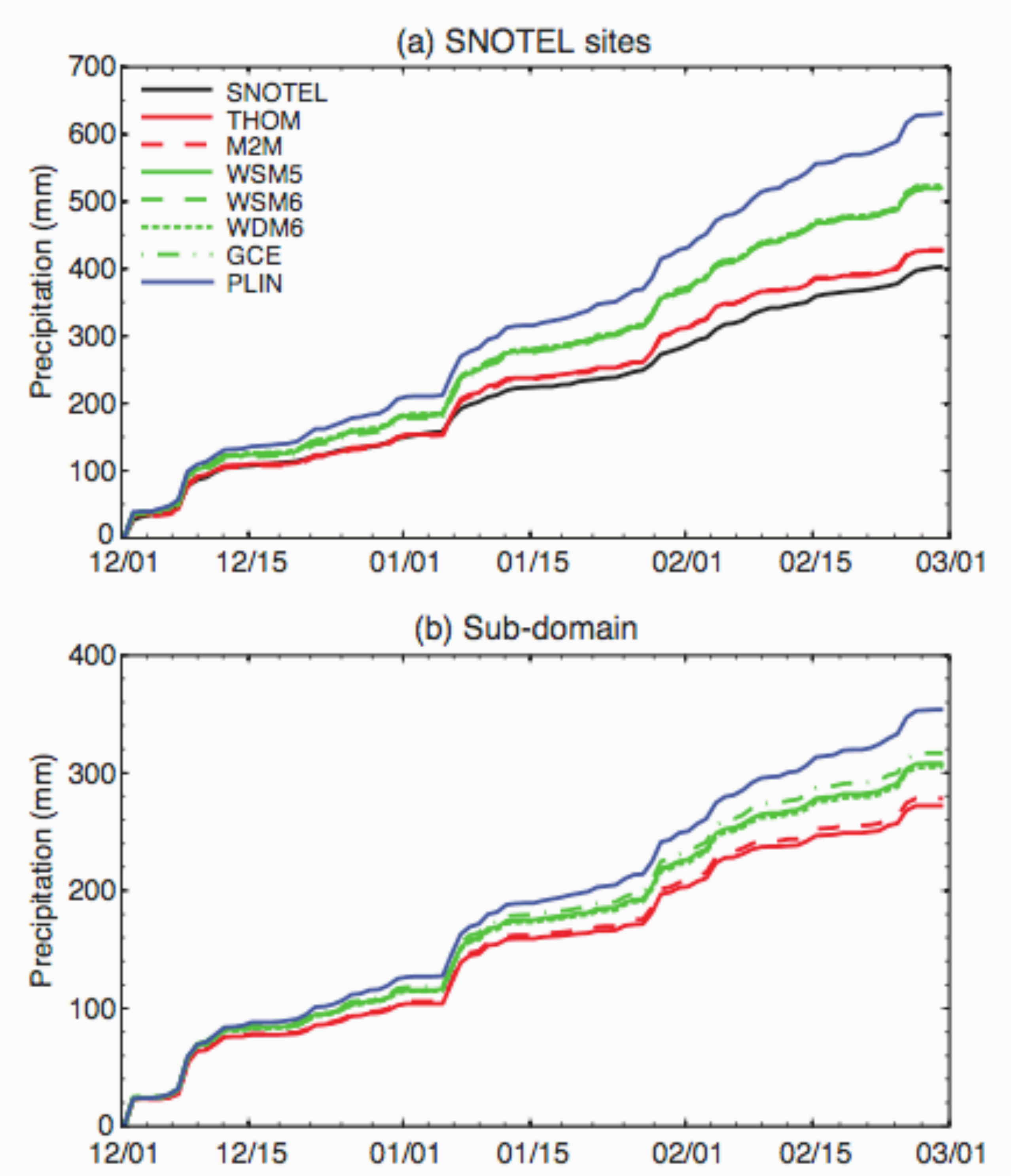
8 year WRF simulation vs. Obs.



Microphysics sensitivity



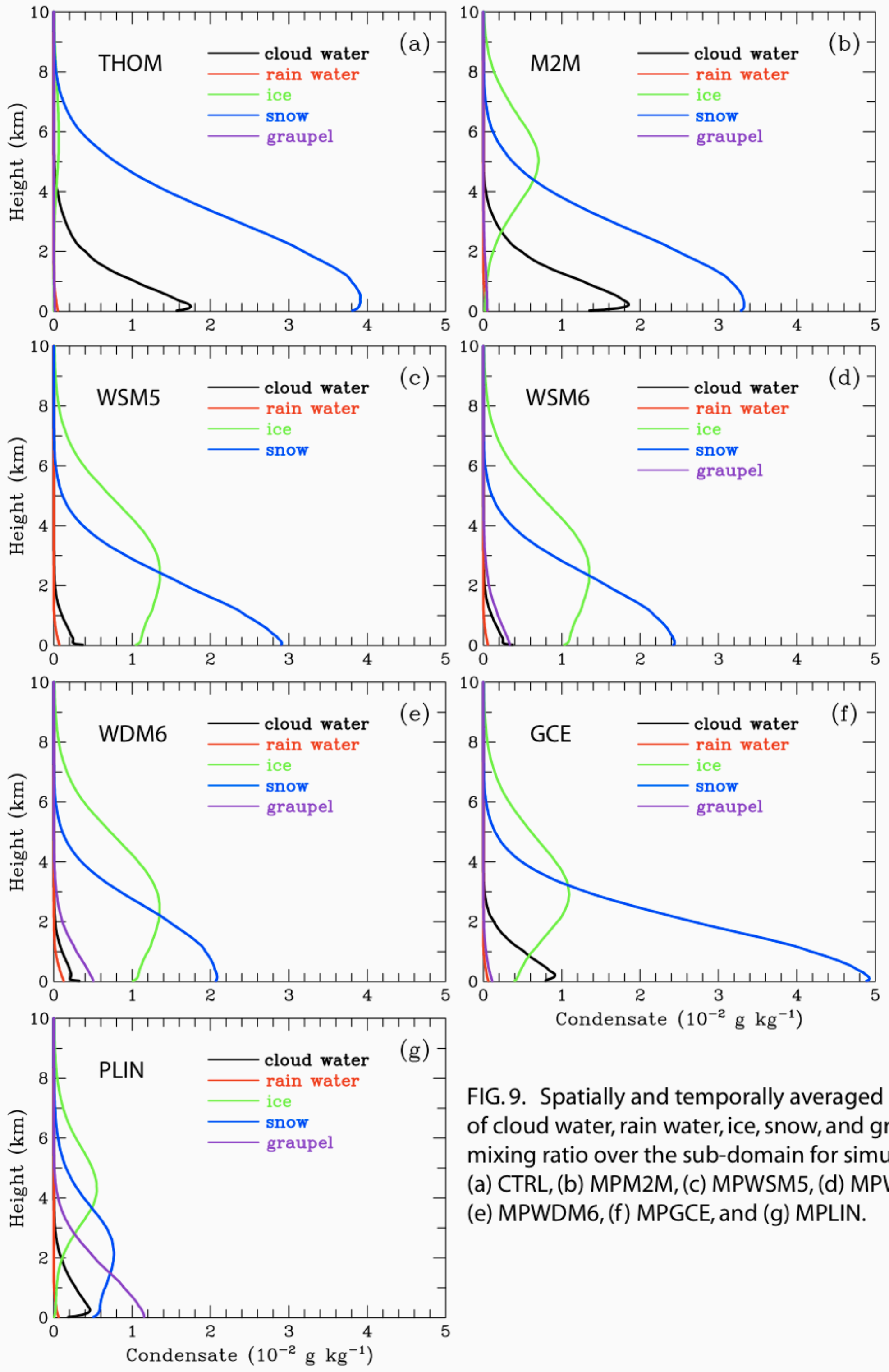


FIG. 9. Spatially and temporally averaged profiles of cloud water, rain water, ice, snow, and graupel mixing ratio over the sub-domain for simulations (a) CTRL, (b) MPM2M, (c) MPWSM5, (d) MPWSM6, (e) MPWDM6, (f) MPGCE, and (g) MPLIN.

Resolution sensitivity

Total Precipitation (mm)

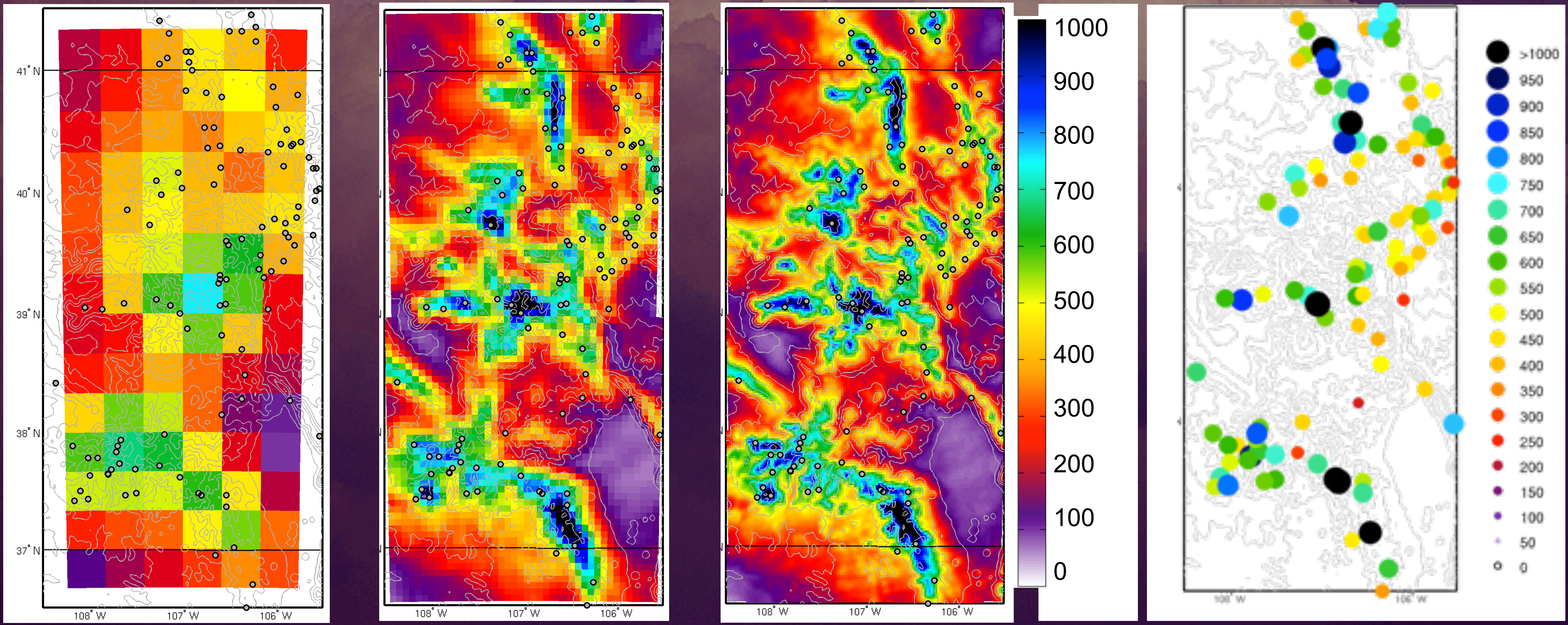
1 Nov 2007 – 30 Apr 2008

36-km WRF

6-km WRF

2-km WRF

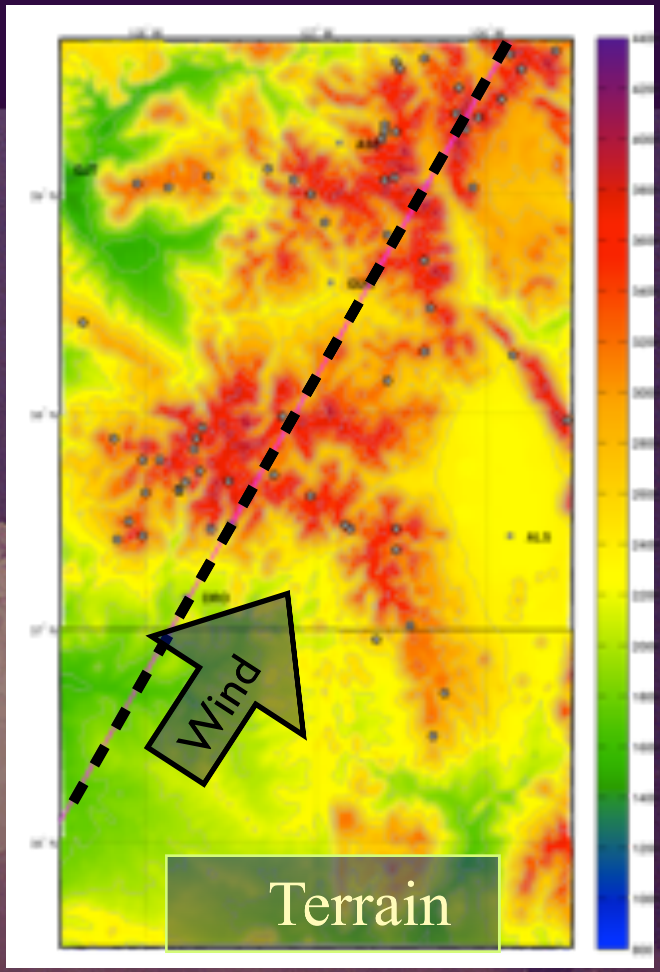
SNOTEL obs.



Resolution sensitivity

Vertical velocity (m/s)

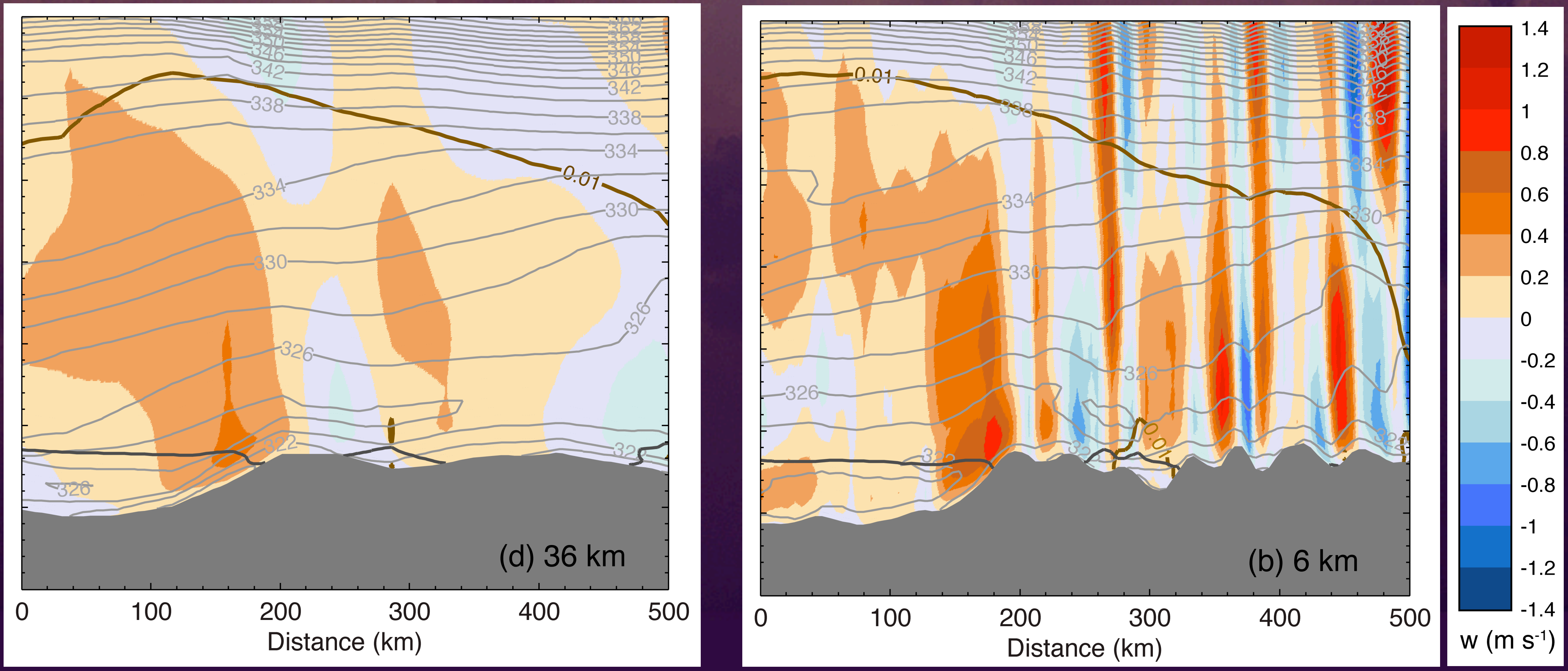
0000 UTC 1 Dec 2007



Terrain

36-km WRF

6-km WRF



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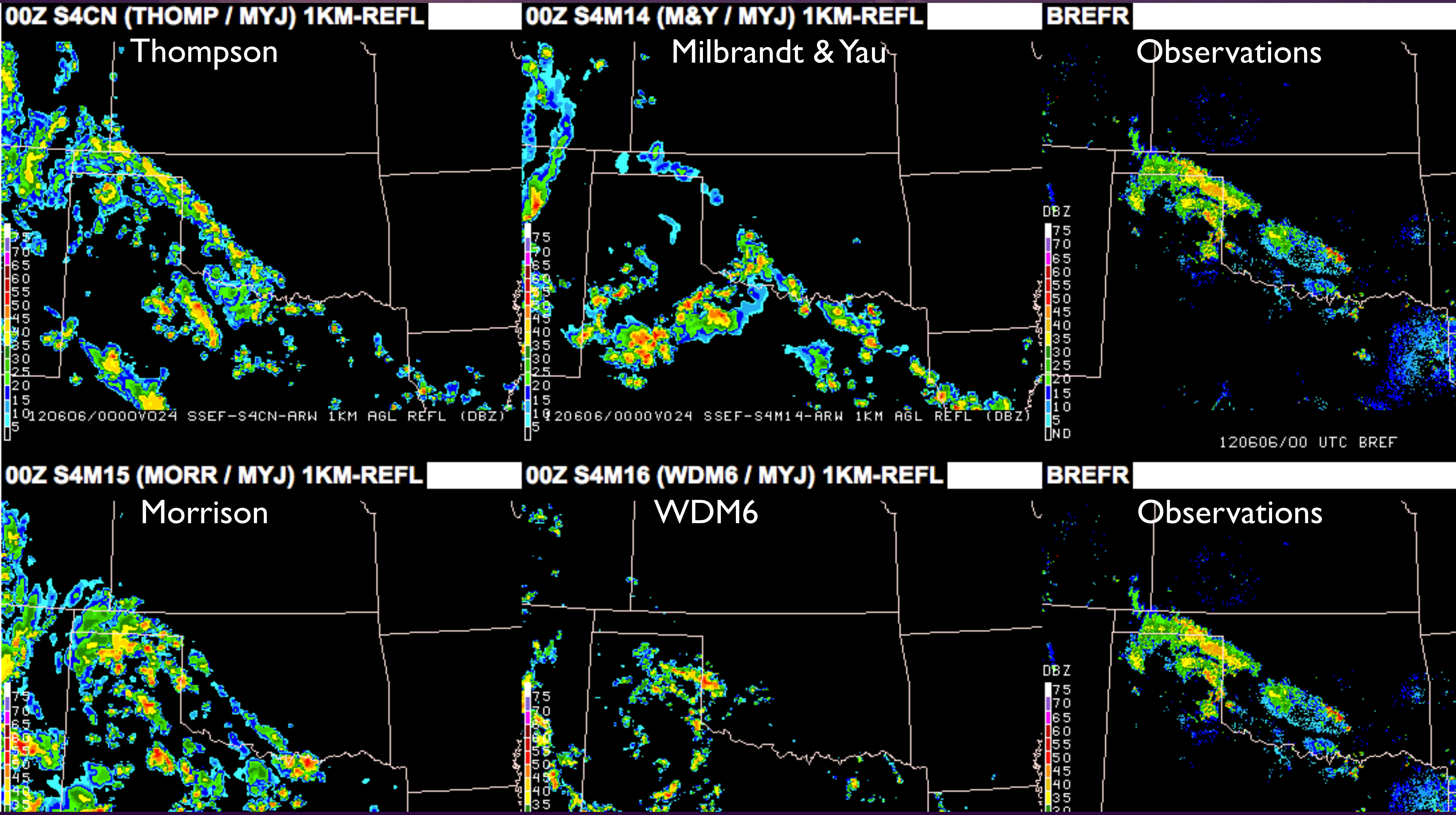
Forecasting convection

NSSL Spring Experiment Program - 25 members mostly WRF (4-km)

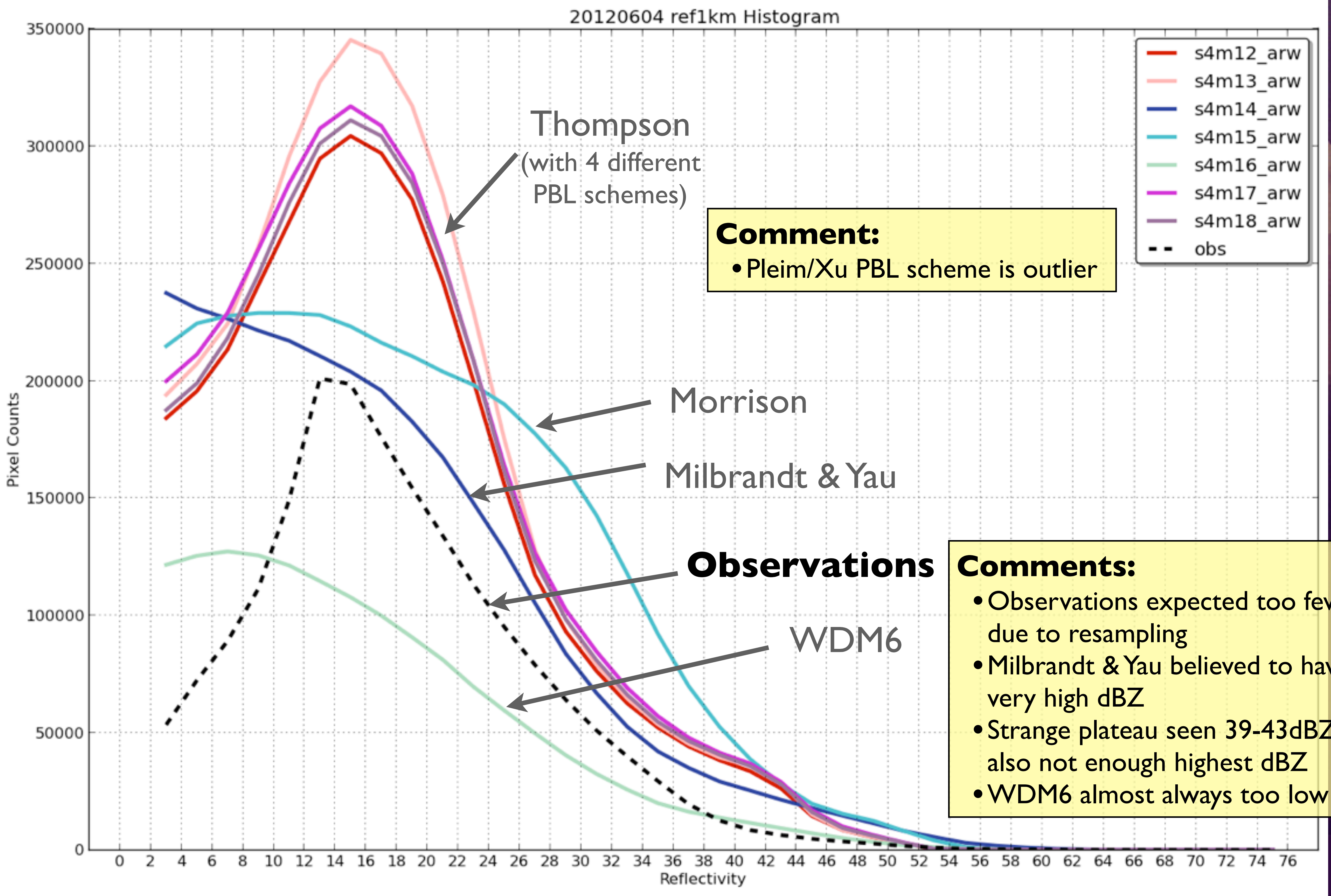
- Thompson, Morrison, Milbrandt & Yau, WDM6 microphysics comparison
- Other ensemble members (PBL, initialization data, WRF_NMM, etc.)



Forecasting convection

Microphysics comparison, reflectivity histograms:

- Nearly same pattern seen all season long



Thompson (with 4 different PBL schemes)

Morrison

Milbrandt & Yau

Observations

WDM6

Comment:

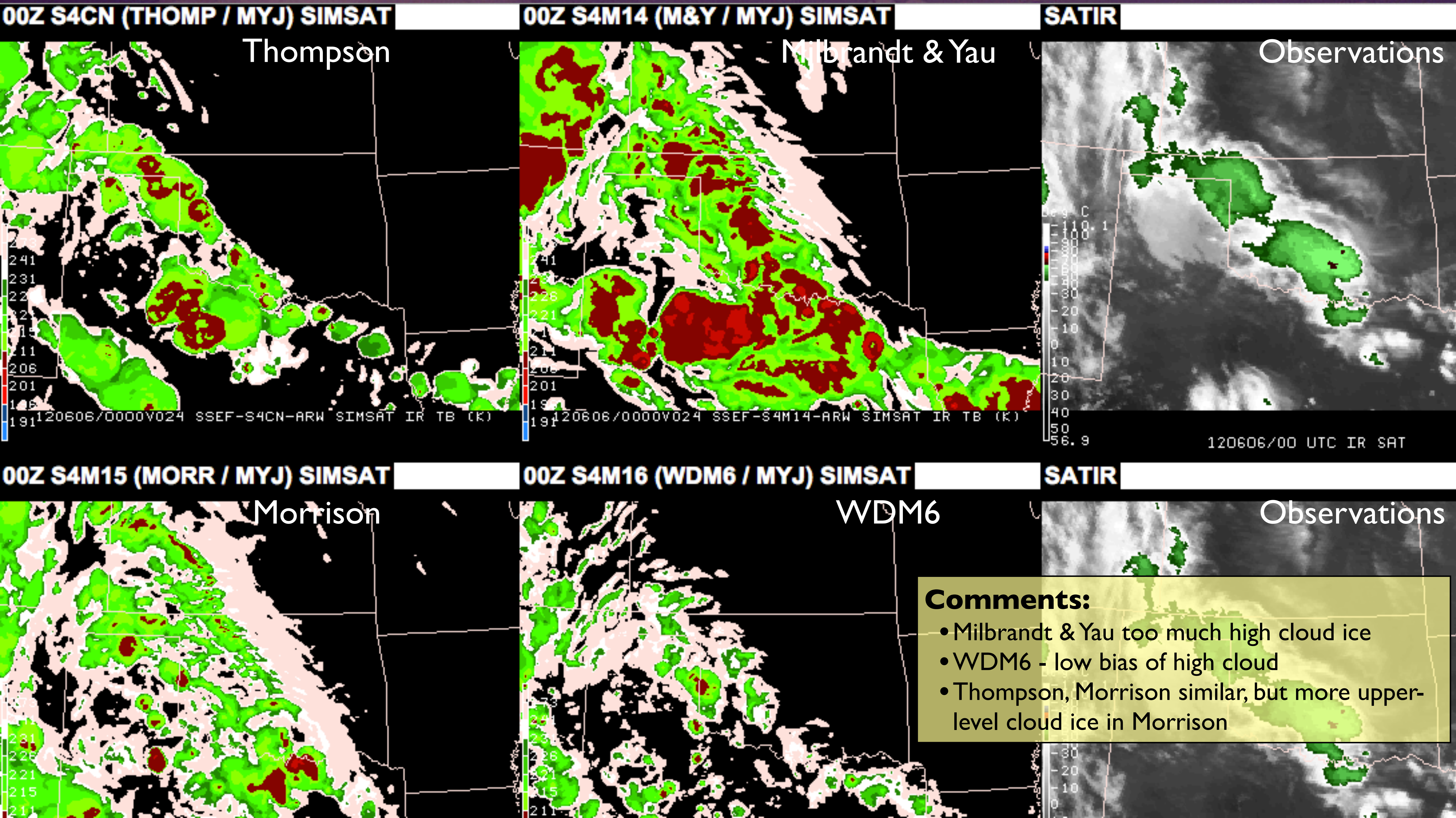
- Pleim/Xu PBL scheme is outlier

Comments:

- Observations expected too few high values due to resampling
- Milbrandt & Yau believed to have too frequent very high dBZ
- Strange plateau seen 39-43dBZ in Thompson, also not enough highest dBZ
- WDM6 almost always too low dBZ

Forecasting convection

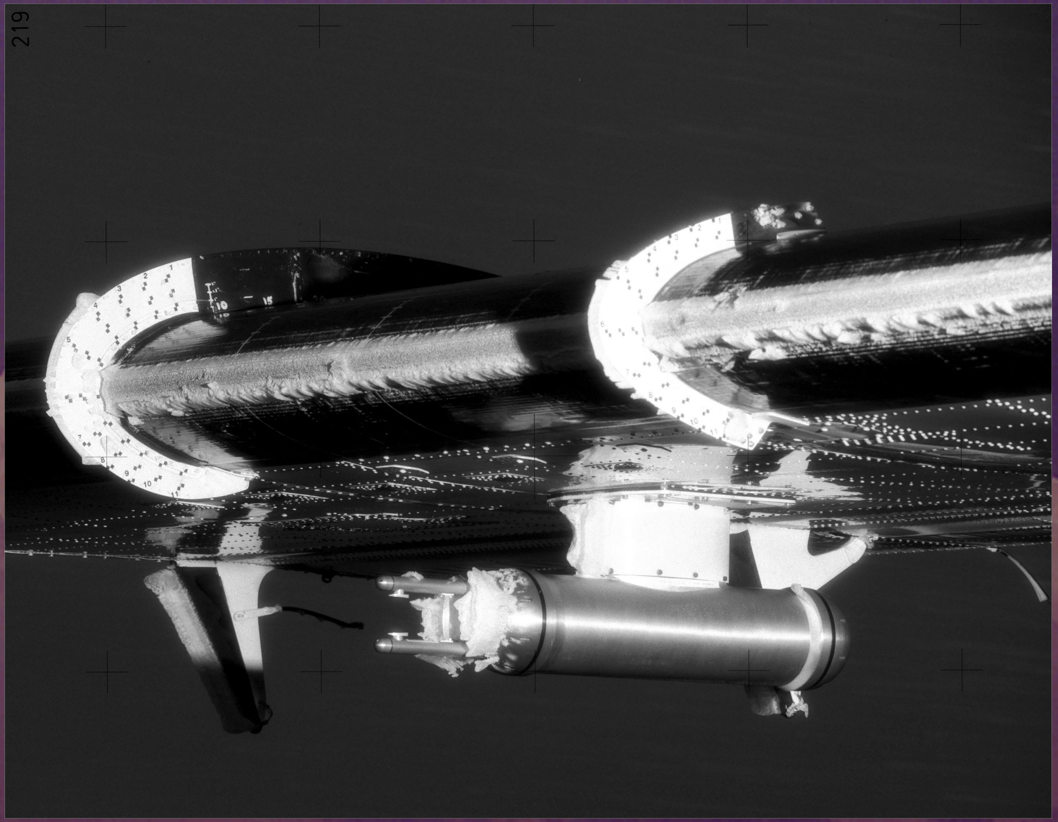
Microphysics comparison, synthetic IR satellite:
- Nearly same pattern seen all season long

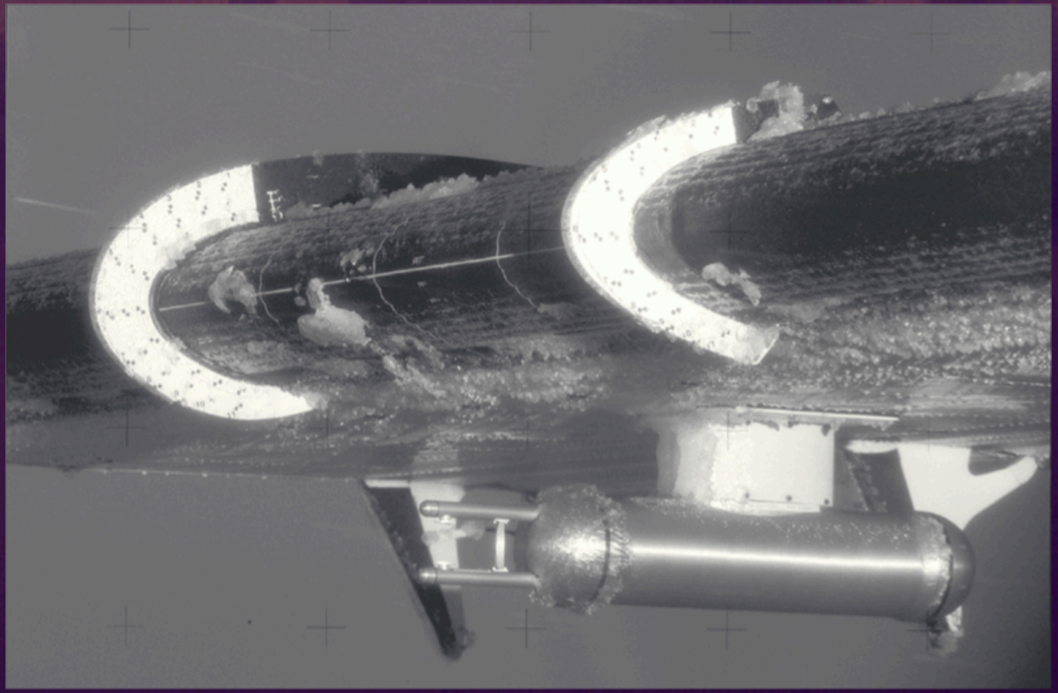


Comments:
- Milbrandt & Yau too much high cloud ice
- WDM6 - low bias of high cloud
- Thompson, Morrison similar, but more upper-level cloud ice in Morrison

Outline

- Microphysics scheme
- Testing
- **Applications**
  - Colorado Headwaters
  - Convection
  - **Icing**
- Summary





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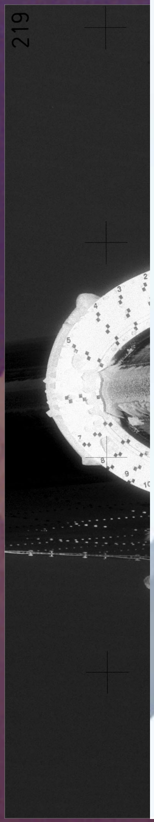

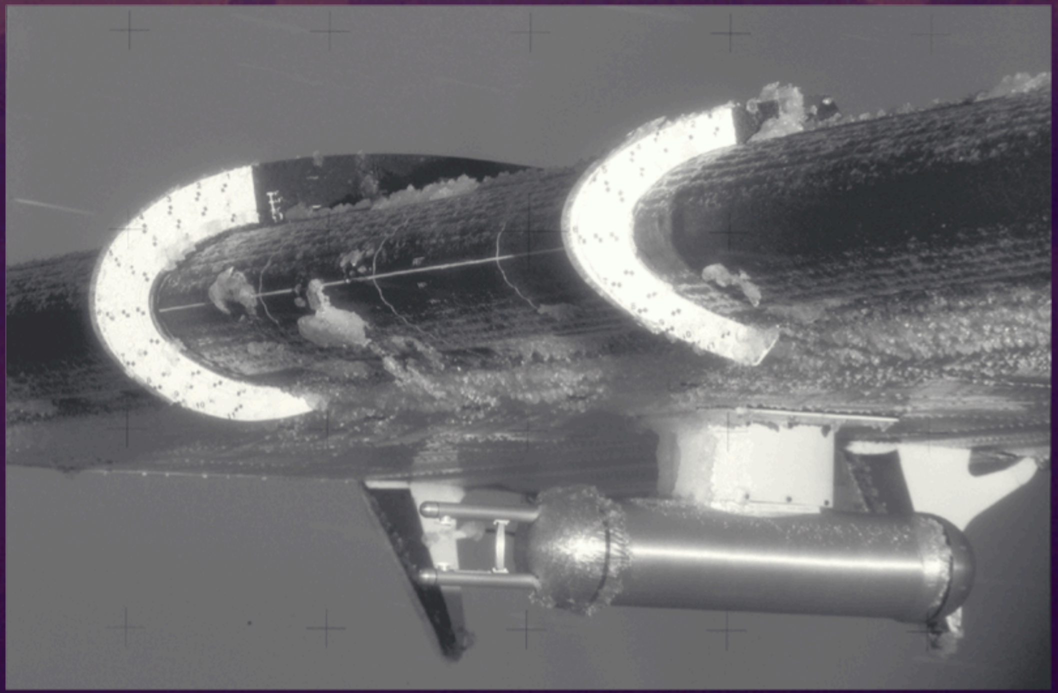

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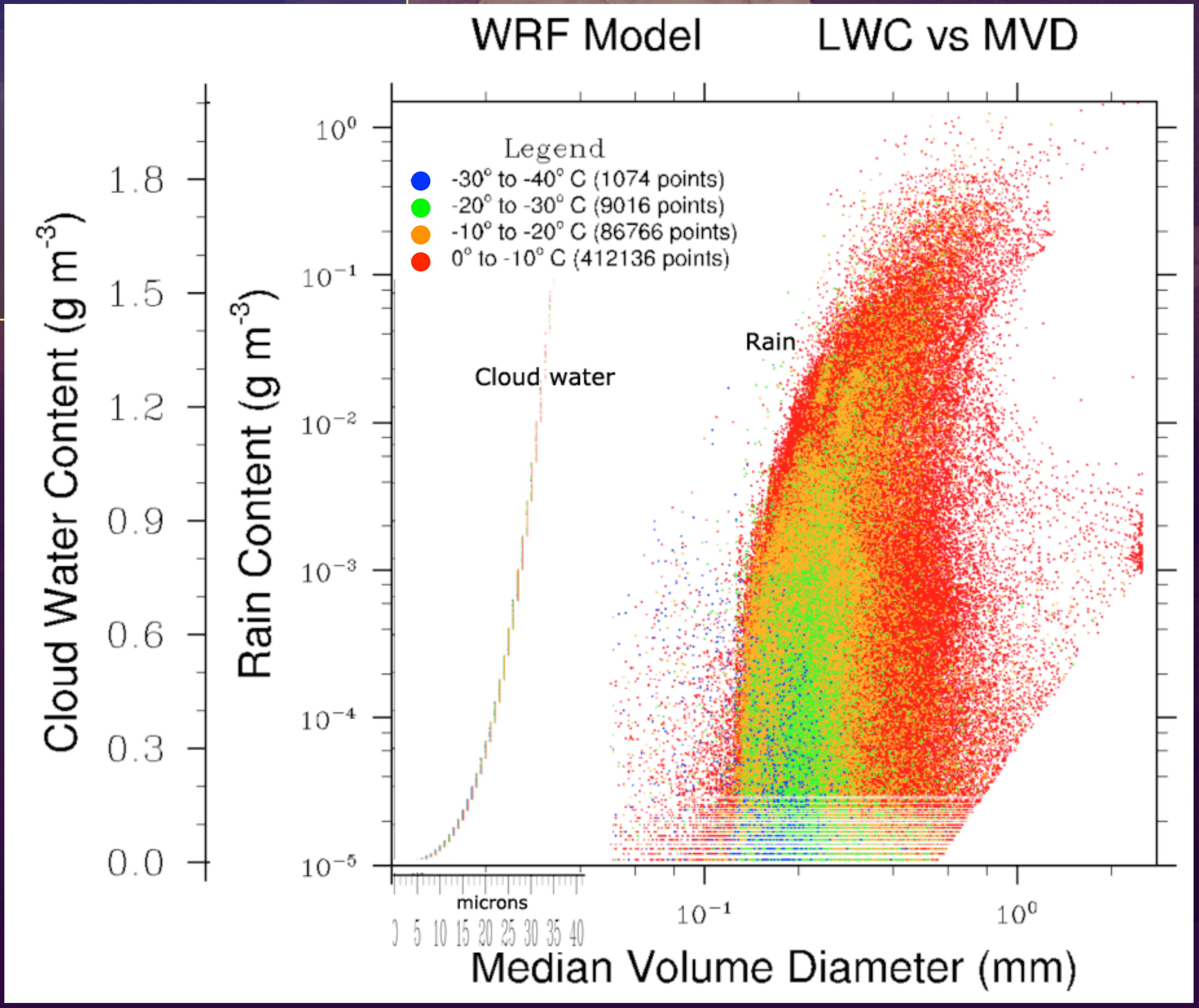
Icing - comparison to pilot reports

- Objectives
  - •Can the model explicitly predict icing?
  - •Does model LWC and/or MVD correlate with icing PIREP severity?
- Data
  - •8.25 years WRF model simulations
  - •01 Oct 2000 – 31 Dec 2008
  - •Very high resolution but limited region
  - •Corresponding icing PIREPs

for each PIREP, retrieve 36 neighboring WRF grid cells (3 rings, approx 20km region)
match vertical level plus one WRF model level below
match to nearest hour WRF time



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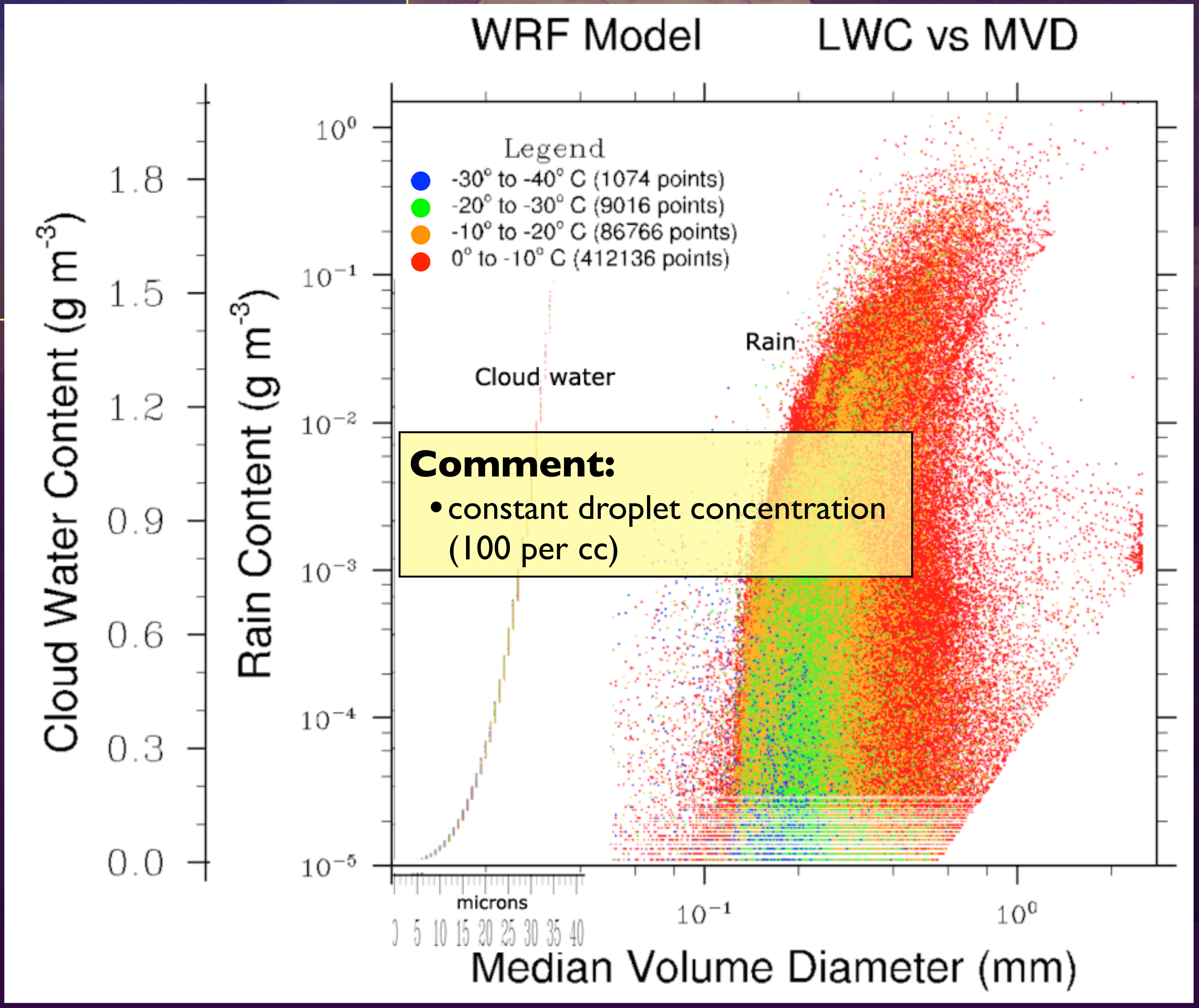


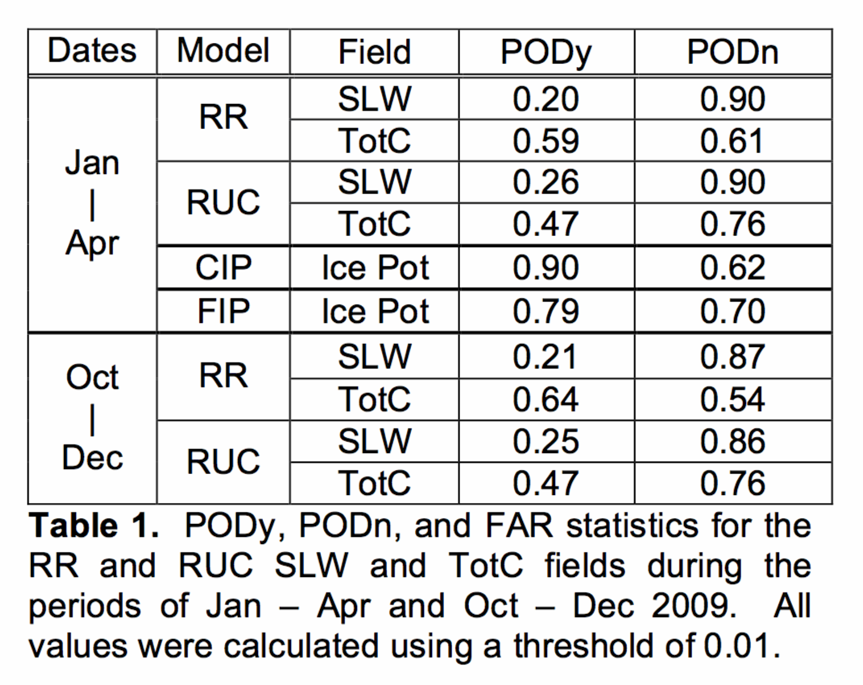
Comment:
- constant droplet concentration (100 per cc)

Icing - comparison to pilot reports

Probability of Detection

Trace	Light	Moderate	Severe	All
237 / 422	2211 / 4303	1491 / 2611	64 / 94	3998 / 7430
55%	51%	57%	68%	54%

A **significant** increase over prior RUC & Rapid Refresh results



Dates	Model	Field	PODy	PODn
Jan | Apr	RR	SLW	0.20	0.90
		TotC	0.59	0.61
	RUC	SLW	0.26	0.90
		TotC	0.47	0.76
	CIP	Ice Pot	0.90	0.62
	FIP	Ice Pot	0.79	0.70
Oct | Dec	RR	SLW	0.21	0.87
		TotC	0.64	0.54
	RUC	SLW	0.25	0.86
		TotC	0.47	0.76

Table 1. PODy, PODn, and FAR statistics for the RR and RUC SLW and TotC fields during the periods of Jan – Apr and Oct – Dec 2009. All values were calculated using a threshold of 0.01.

Reference: Wolff and McDonough, 2010

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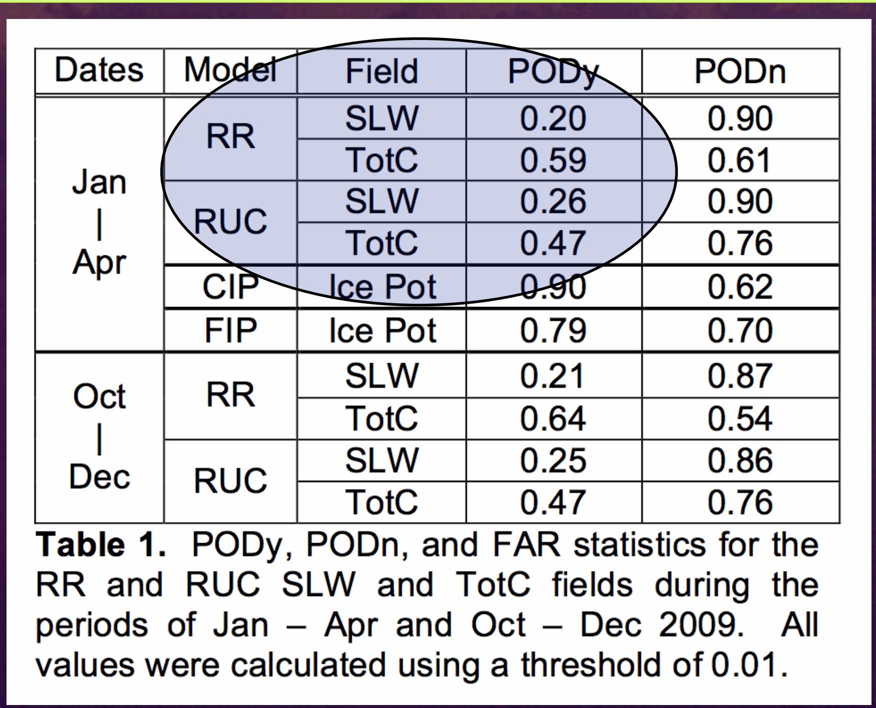

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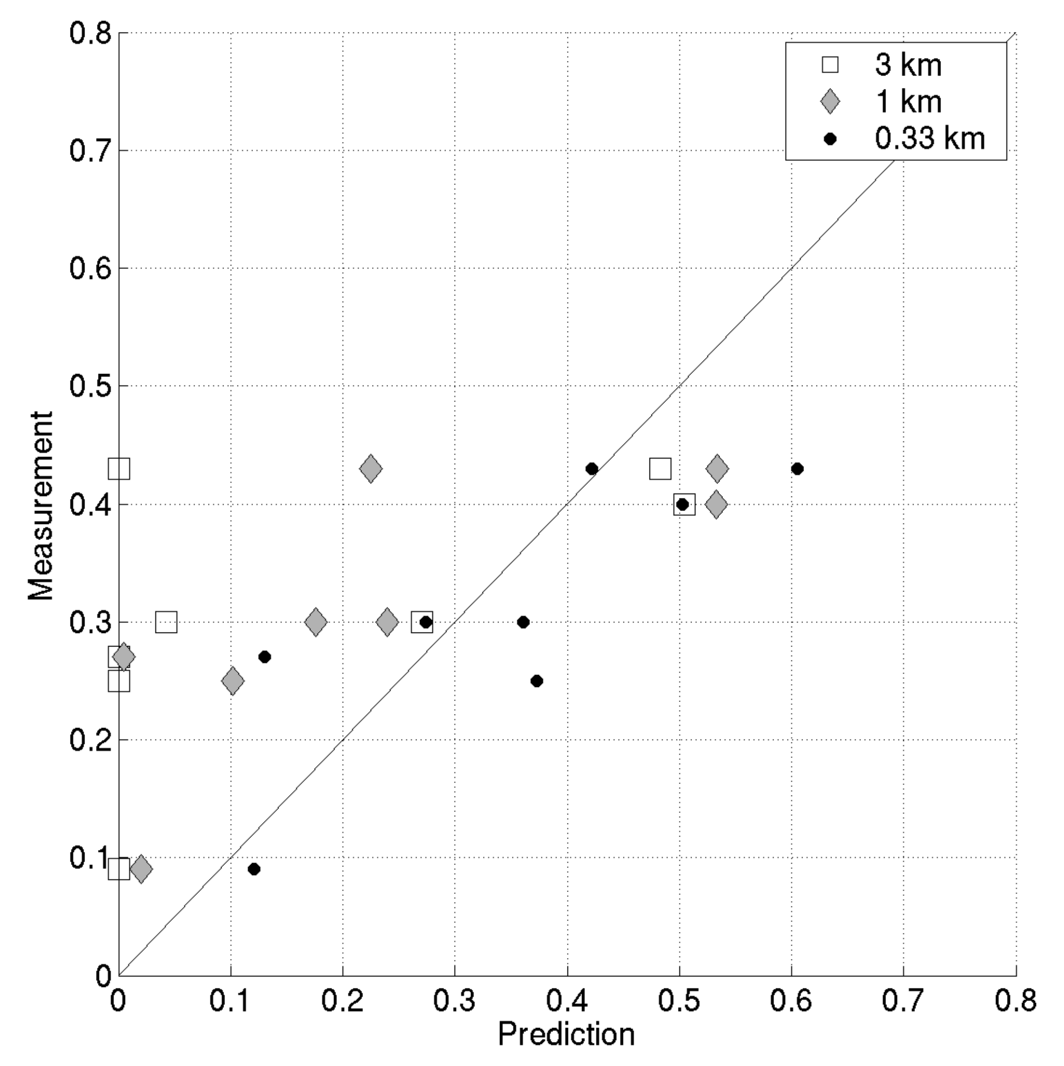
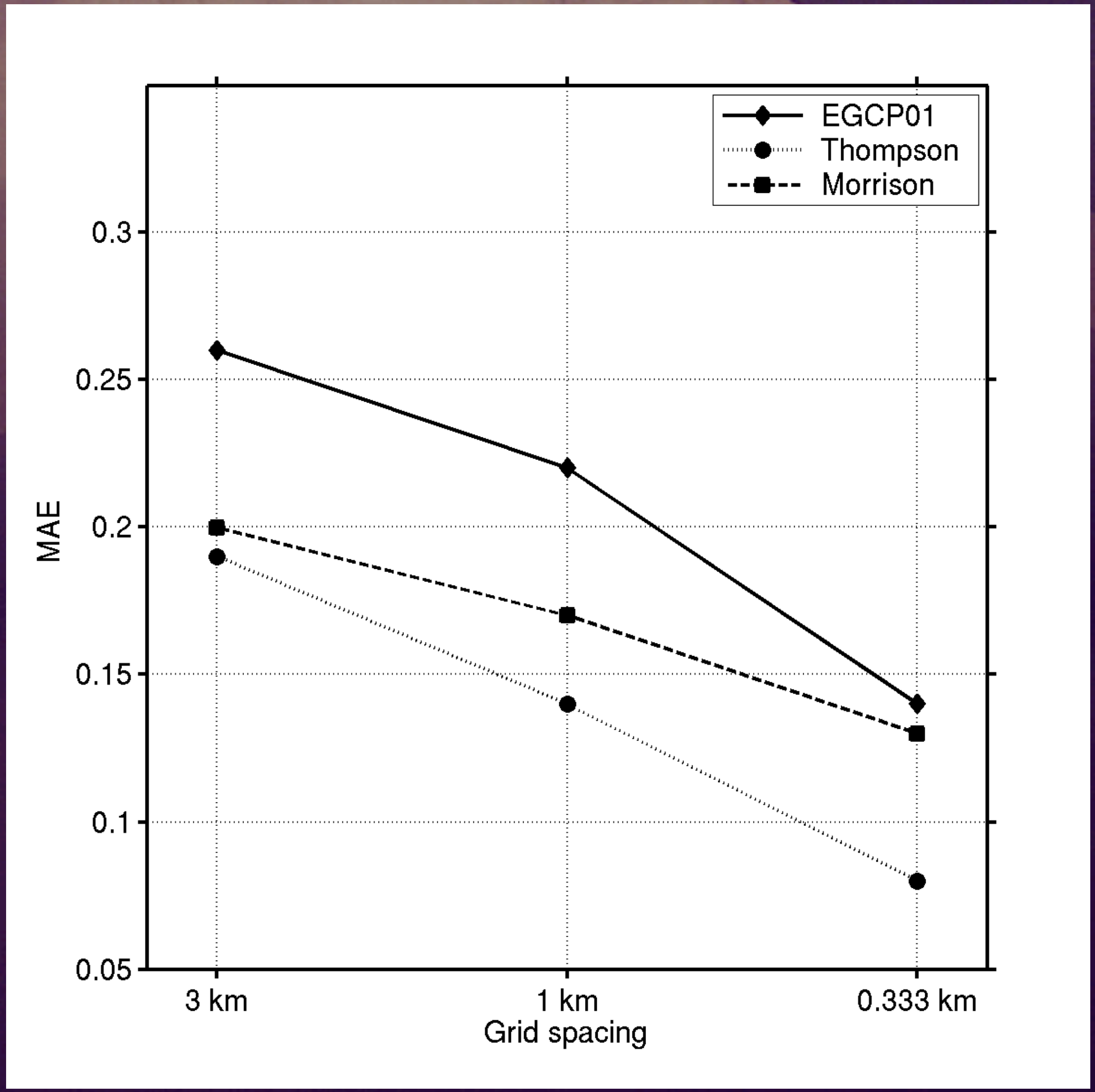
Icing - ground icing case (Finland)

Predicted v. observed liquid water content



Mean absolute error, different microphys.



Courtesy of Bjorn Egil Nygaard

Summary

- Numerous updates/improvements from “legacy” Lin, Farley, Orville (1983) scheme(s) that keep getting duplicated
- Well-tested, flexible, documented code
- Many applications: QPF, icing, winter weather, summer convection
- First steps of aerosol-cloud-precipitation feedbacks
    - ✦ initial indications are successful - primary effects working

NWP road ahead: mostly sunny or partly cloudy?

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Thank you!!

Backup slides