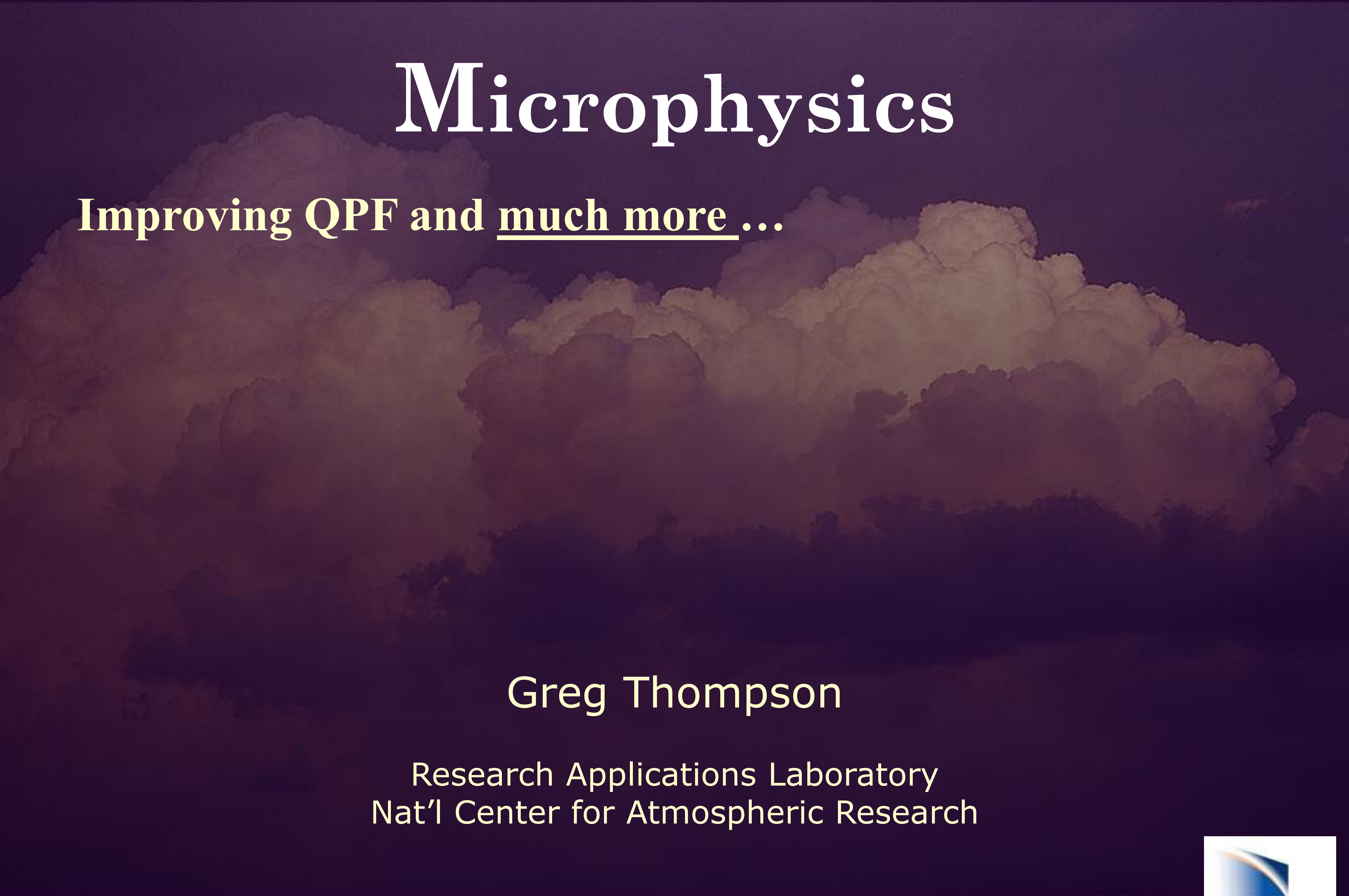
Microphysics

Improving QPF and much more …



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Outline

- Background
- Tests
- Results
- Applications
- Future

NCAR-RAL microphysics research

Goals:

- Improve forecasts of water phase at surface (QPF) and aloft (aircraft icing)
- Incorporate observations from field programs
- Transition to operations (RUC, WRF-RR)

Sponsor:

- FAA – Aviation Weather Research Program

Participants:

- NCAR: Greg Thompson, Roy Rasmussen, Trude Eidhammer

Collaborators:

- John Brown (NOAA-ESRL), Hugh Morrison (NCAR-MMM), Yi Jin (NRL), Istvan Geresdi (Univ of Pecs, Hungary)

Major deficiencies of bulk micro

Autoconversion

extremely threshold dependent
droplet number concentration issue

Ice nucleation

vapor deposition (at 100% RH_i)
Hallet-Mossop
contact/immersion

Collision/Collection

efficiencies typically 1.0
Wisner or Mizuno approximations

Species choices

habit – snow: constant density spheres
graupel vs. hail
assumed number distribution
constant intercept parameter

Graupel source terms

most prolific resulting from nearly all water freezing processes:
snow riming
ice collisions with drops
depositional growth

Sedimentation

melting snow/graupel
excessive artificial size sorting (2-moment)

Lin, Farley, Orville (1983)
Rutledge & Hobbs (1984)
Ferrier (1993)
Meyers et al (1997)
Seifert & Beheng (2001)
Reisner et al (1998)
Hong et al (2004)
Thompson et al (2008)
Morrison et al (2005)
Milbrandt & Yau (2005)

Microphysics improvements

Property or Source/Sink	Deficiency in prior schemes	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); proper size-sorting sedimentation.
Snow	Constant density, spherical snow assumes exponential distrib with constant y-intercept	Variable density (based on size) and assumes sum of 2 gamma distributions based on 9000 observations from mid-latitude storm systems
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; depends on characteristic diameters that vary according to clean vs. polluted air.
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 of melting snow/graupel	Mathematically correct not physically correct!	Snow/graupel fall faster as they melt, not slower.

Example: cloud water distribution

Affects “autoconversion”

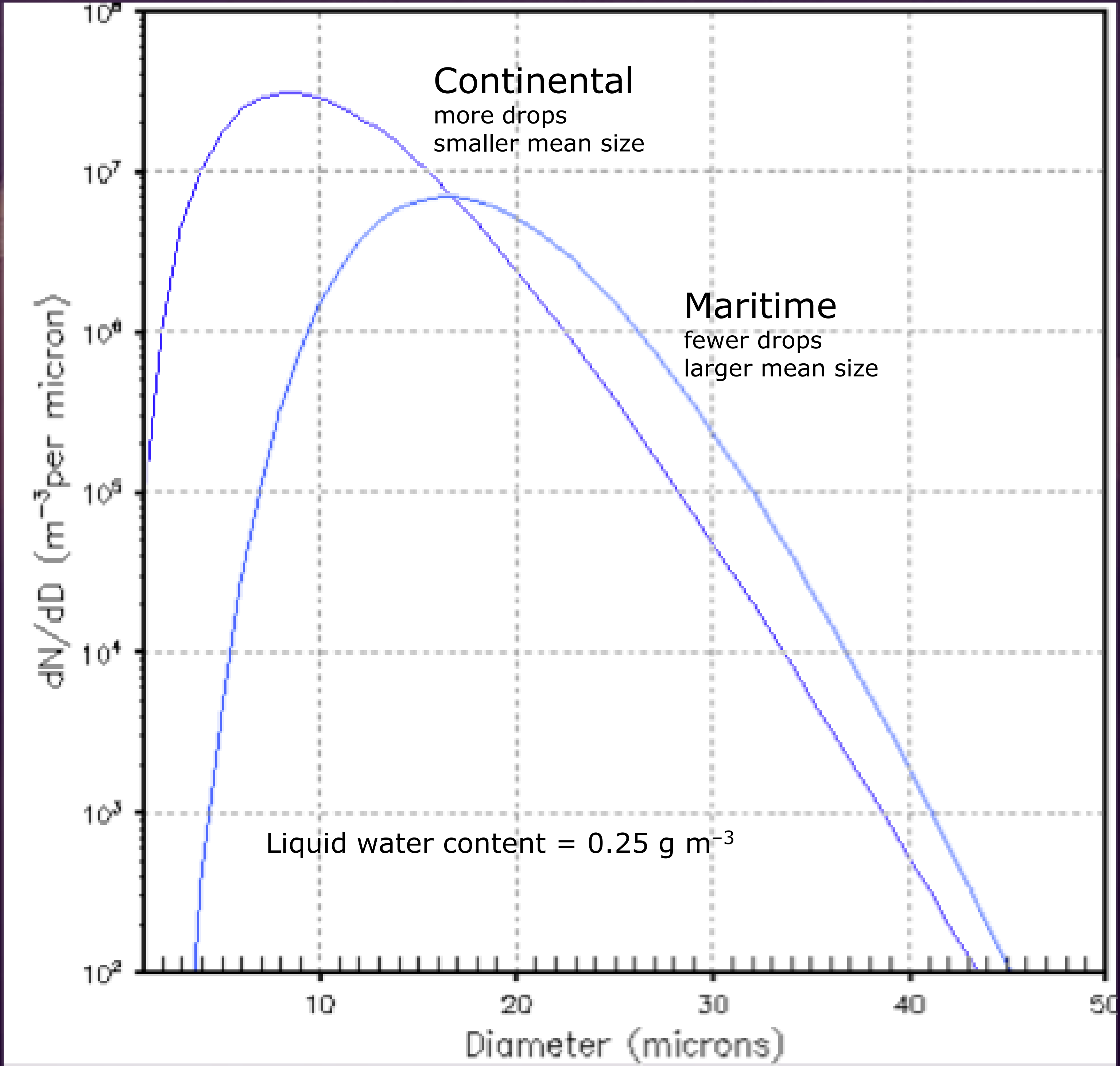
3 characteristic diameters considered when converting cloud water to rain

Affects accretion

due to changes in MVD

Affects droplet freezing

larger drops more likely to freeze than small drops

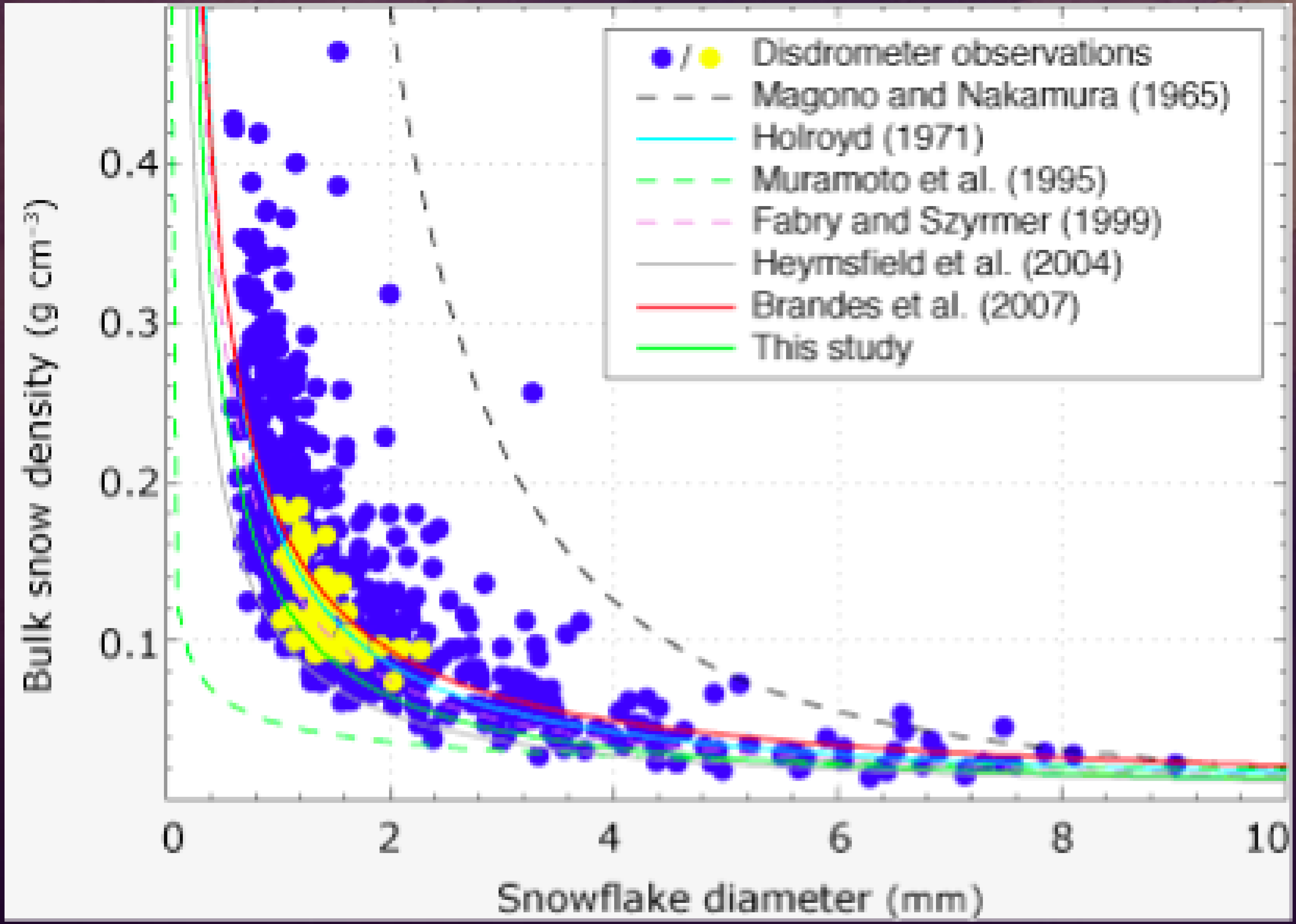


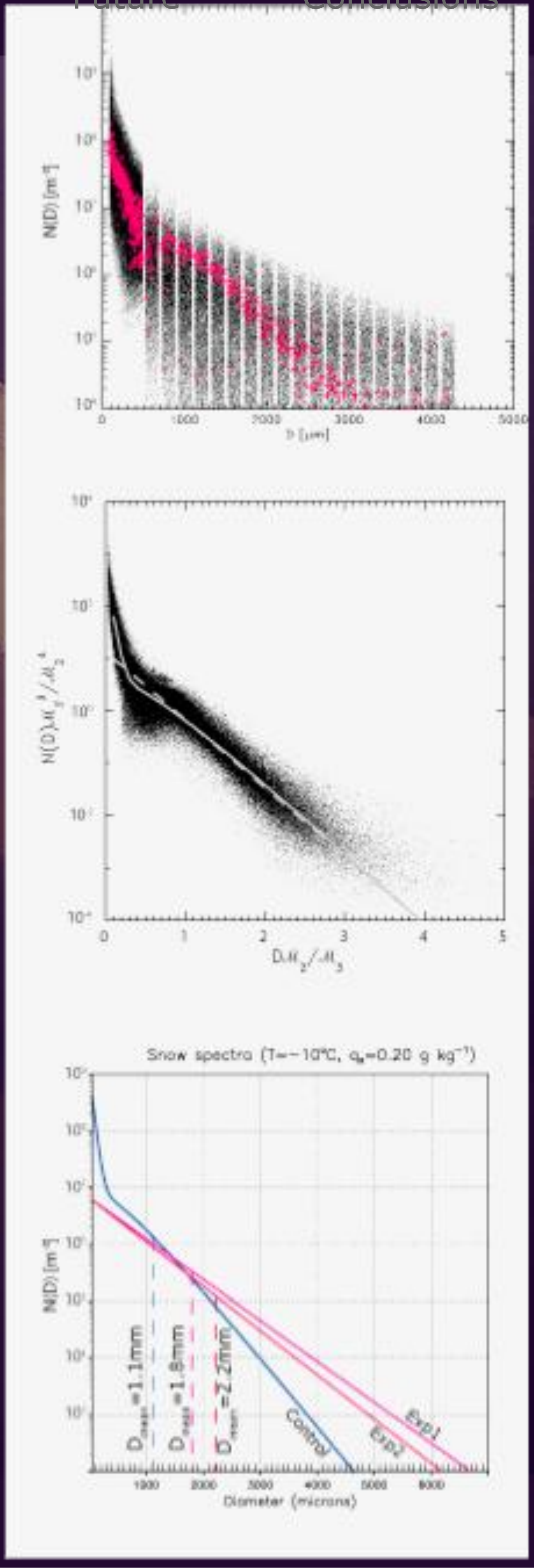
Continental
more drops
smaller mean size

Maritime
fewer drops
larger mean size

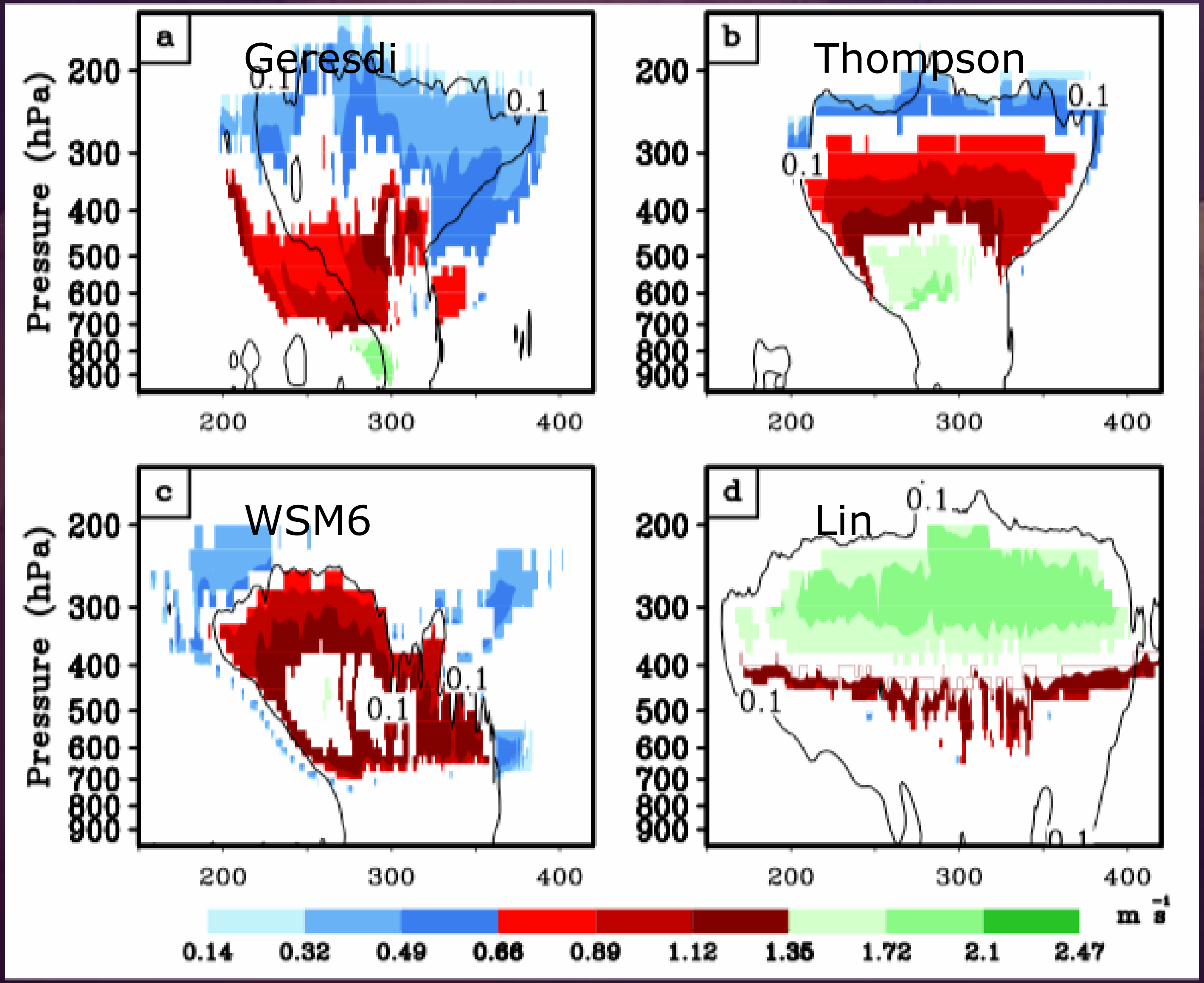
Liquid water content = 0.25 g m^{-3}

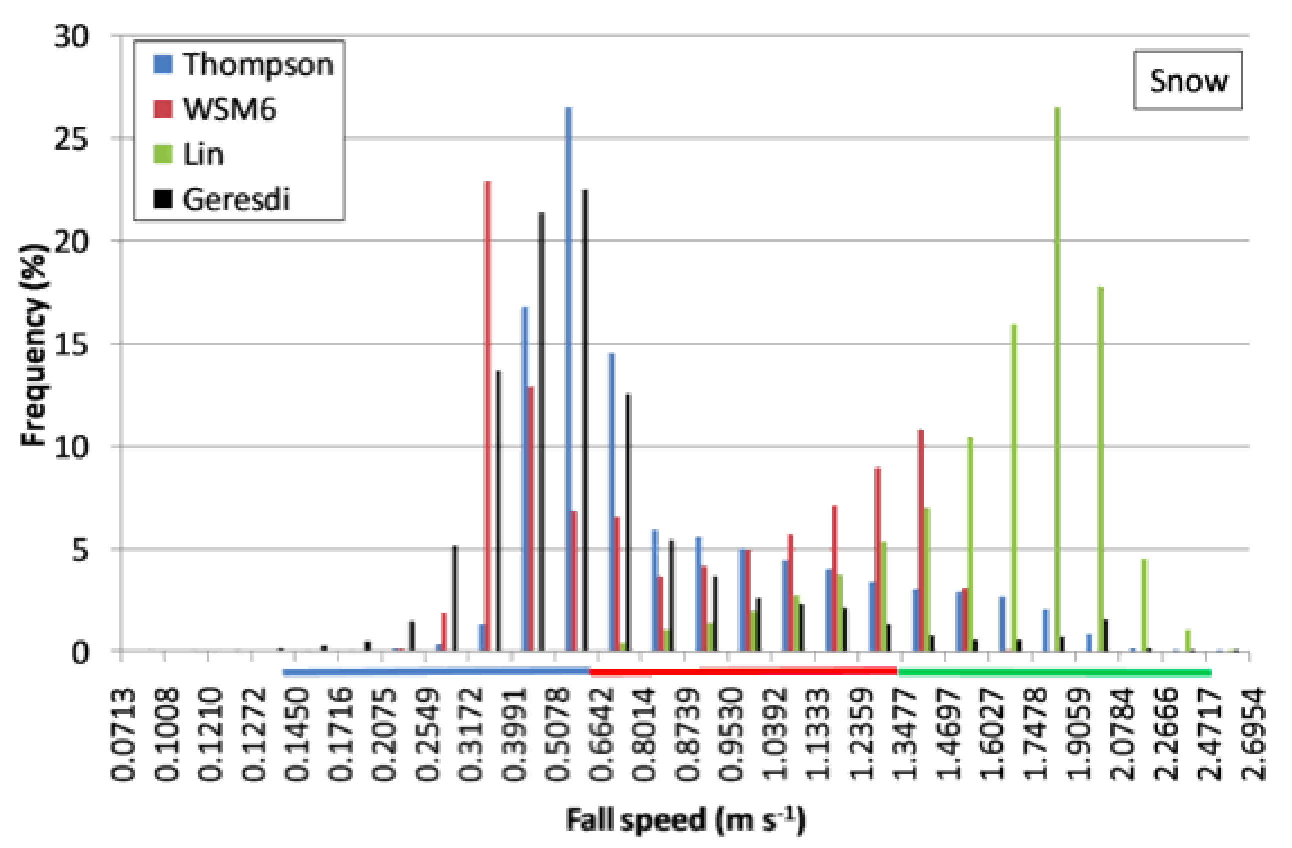
Example: snow density and size distribution



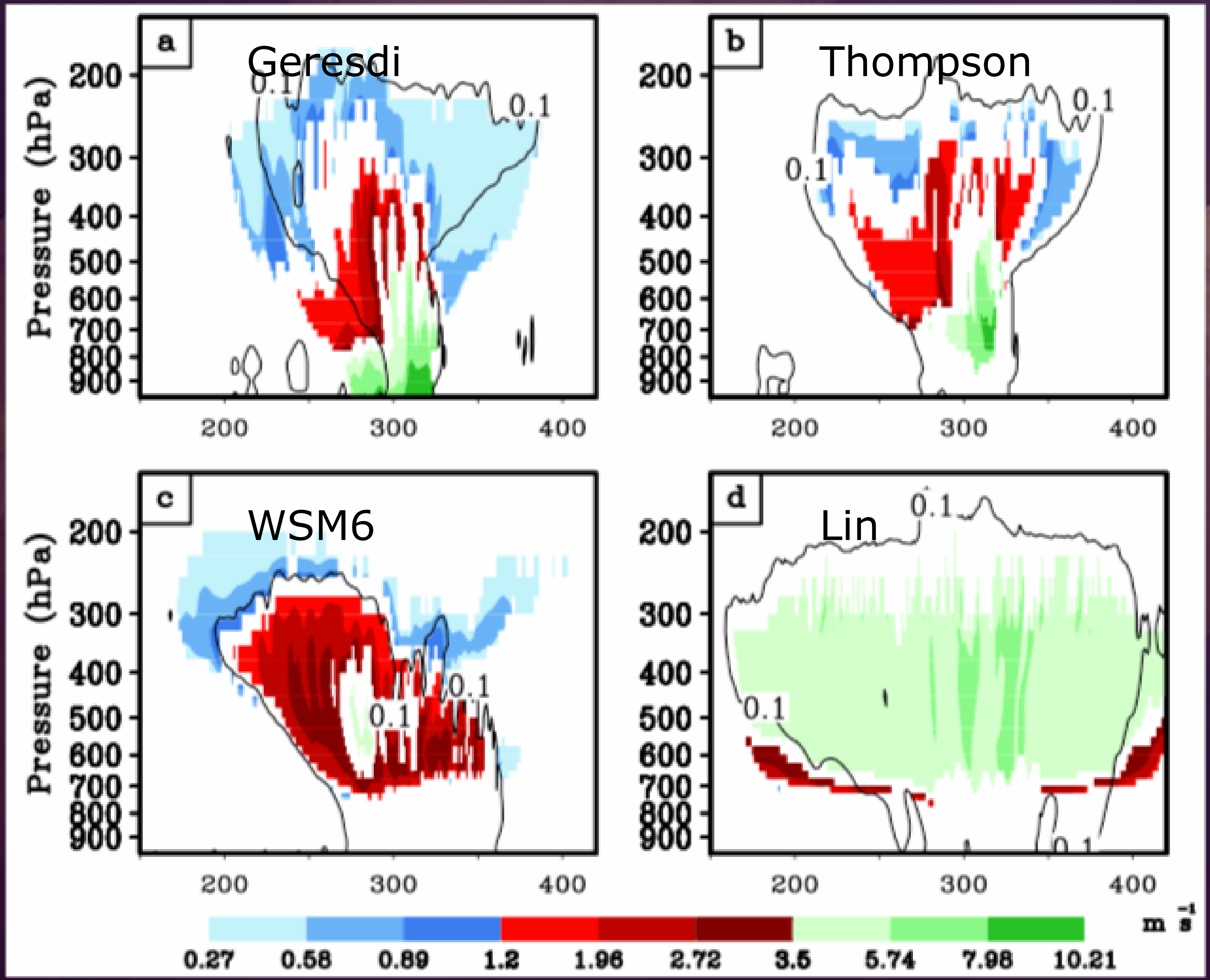


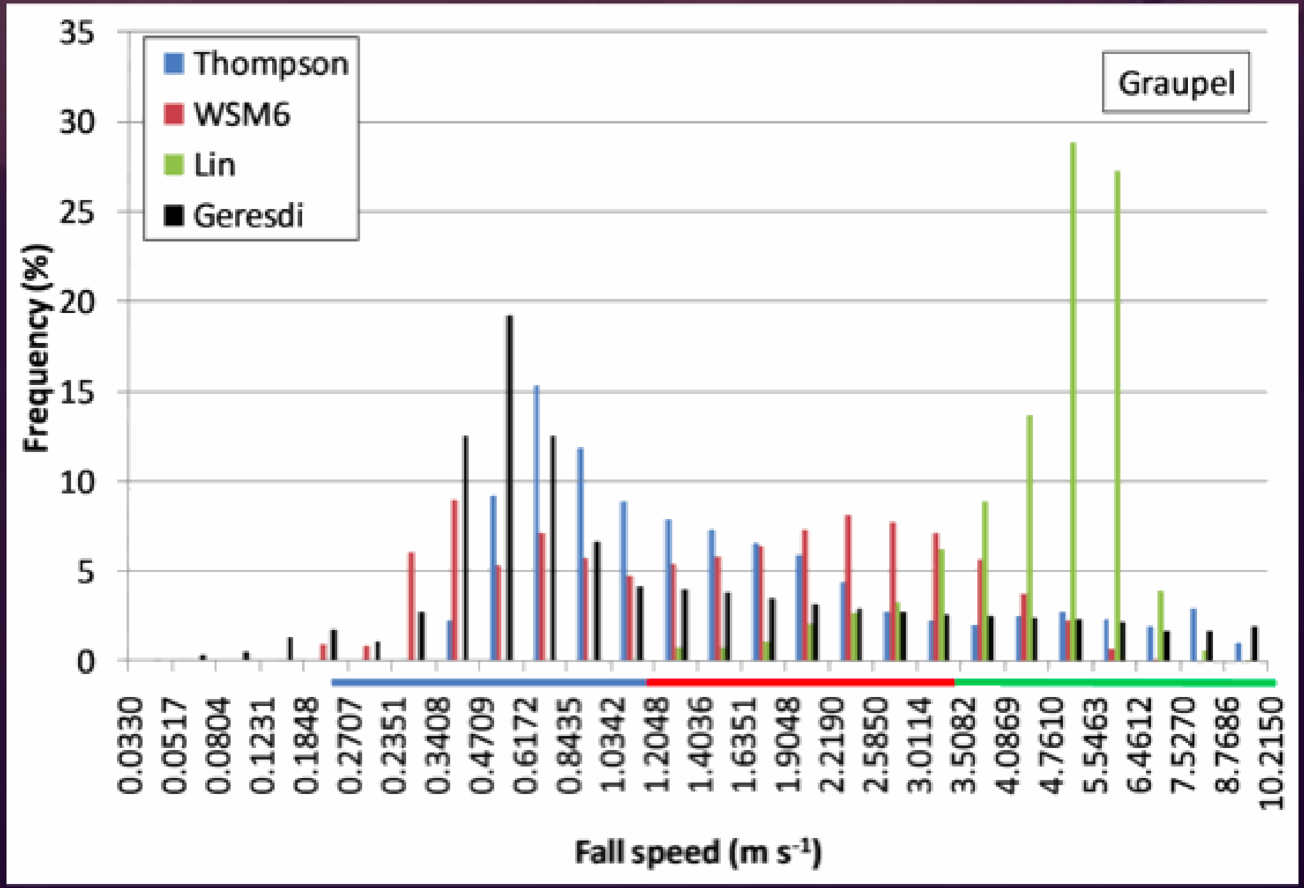
Example: snow sedimenting





Example: graupel sedimenting





Benchmark testing with “ideal” cases

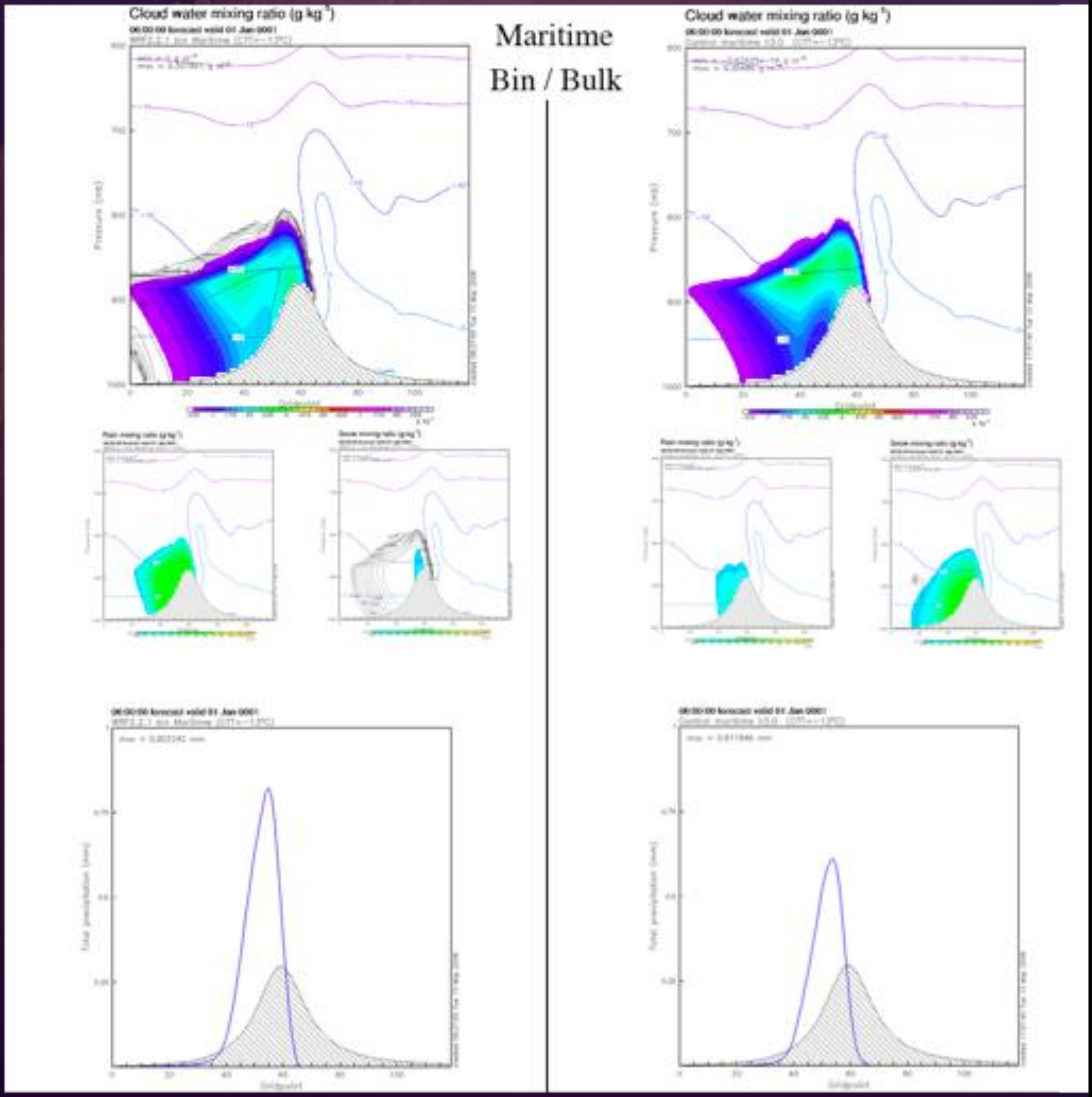
Test case	WRF ideal experiment name	Primary purpose
Simple 2-D bell-shaped hill	em_hill2d_x	Simple and FAST! No complex dynamics. Test all aspects of microphysics sensitivity.
Complex 2-D, Oregon Cascade profile	em_hill2d_x	Realistic topography profile with strong forcing (2-4 m/s) and previous test case related to IMPROVE-2 field project.
Squall line	em_squall2d_x or em_quarter_ss	Moderate to strong convective squall line. Tests sensitivity to cold pool strength from altering microphysics parameters. 3D simulation produces more realistic entrainment mixing.
Supercell	em_quarter_ss	Strong convection test of cold pool strength and attempt to predict hail versus graupel.

Benchmark testing with “real” cases

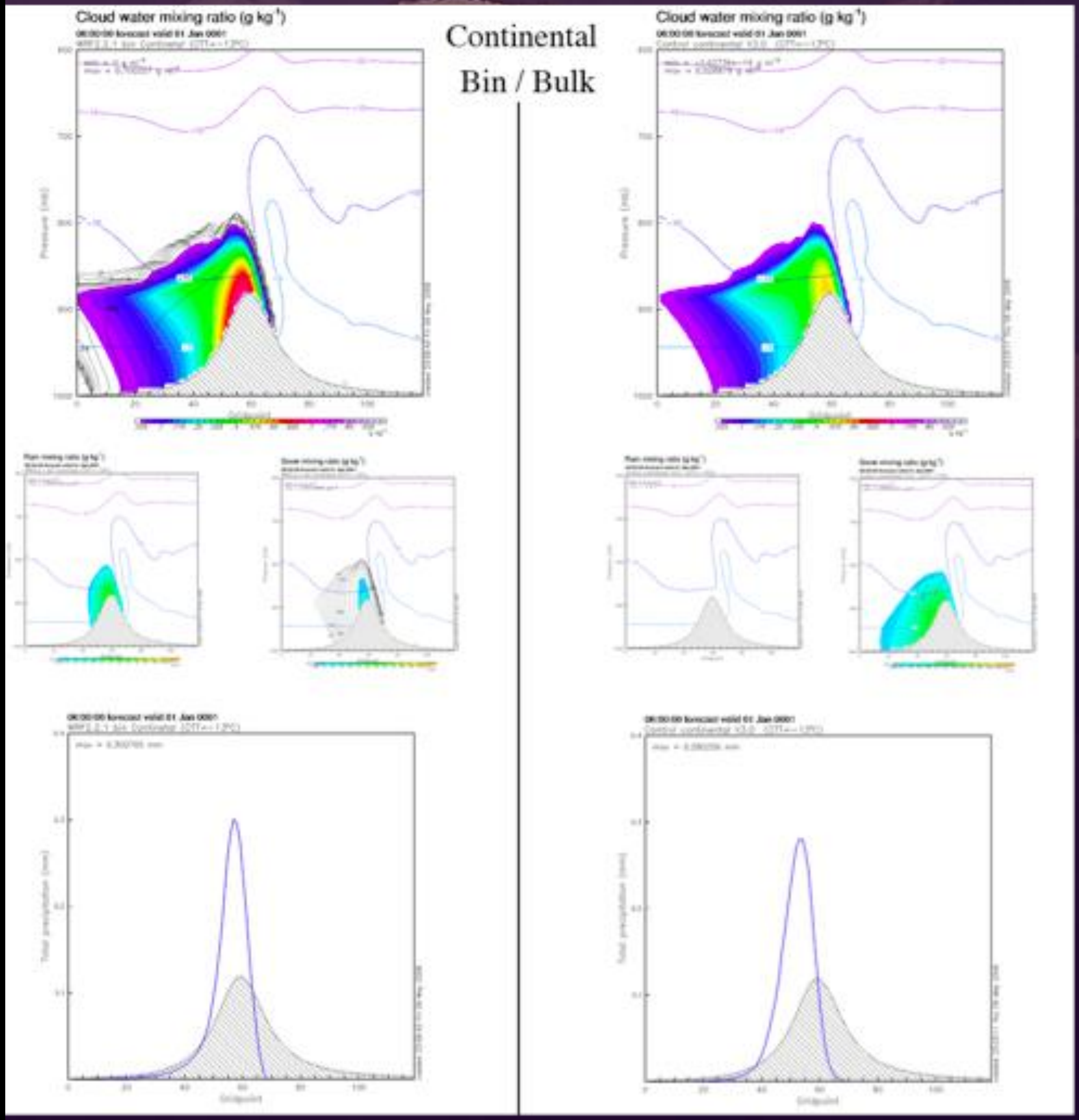
Case study	Primary purpose
1990Feb13	WISP – front range winter upslope event with freezing drizzle and snow and seeder-feeder.
1998Jan30	Shallow stratus cloud, supercooled liquid (no drizzle) observed by NASA Twin Otter.
1998Feb04	Classic “Nor’Easter” with typical freezing rain; observed by NASA Twin Otter.
2001Feb01	Strong Pacific-Northwest, fully occluded low pressure observed during IMPROVE-1. Low liquid water content, lots of ice/snow instead.
2001Nov28 2001Dec13	Two strong Pac-Northwest storms interacting with Oregon Cascades, well observed during IMPROVE-2.
2002Jun12 2005May12 2007Jun12	Three rather typical squall lines starting in northwest OK, first one part of IHOP experiment; other two cases have disdrometer and dual-pol radar data.
2007Nov16 2007Nov18	Two cases of WY wave clouds studied for ICE-L campaign; good tests of ice initiation scheme.

Example: “ideal” bell-hill (2D)

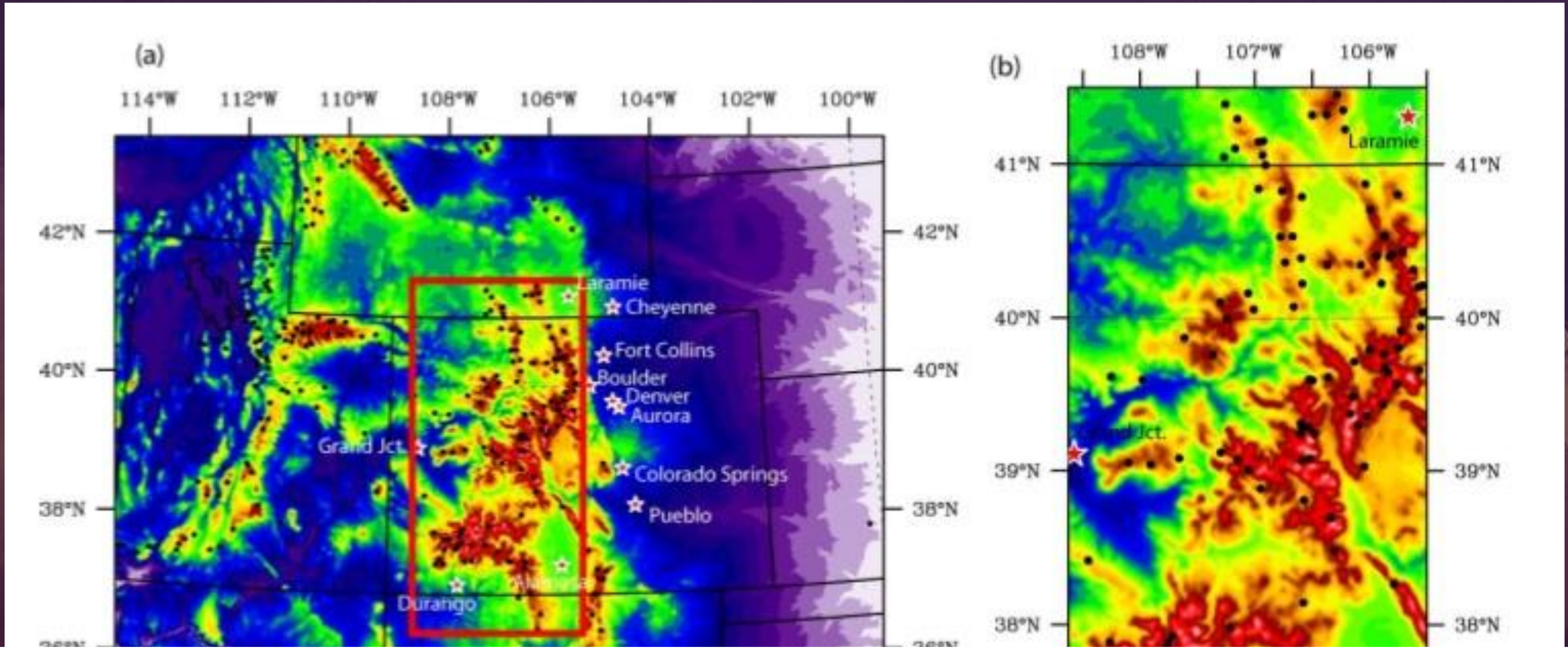
Maritime (25 cm^{-3})

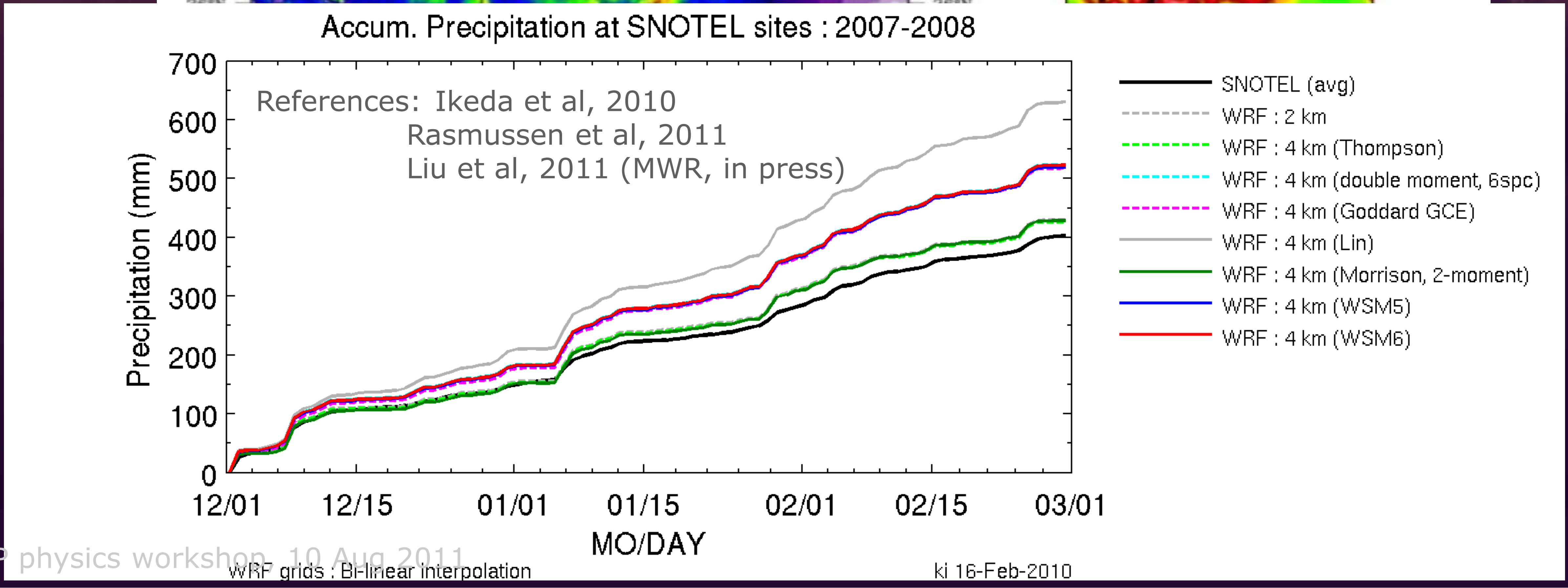


Continental (300 cm^{-3})



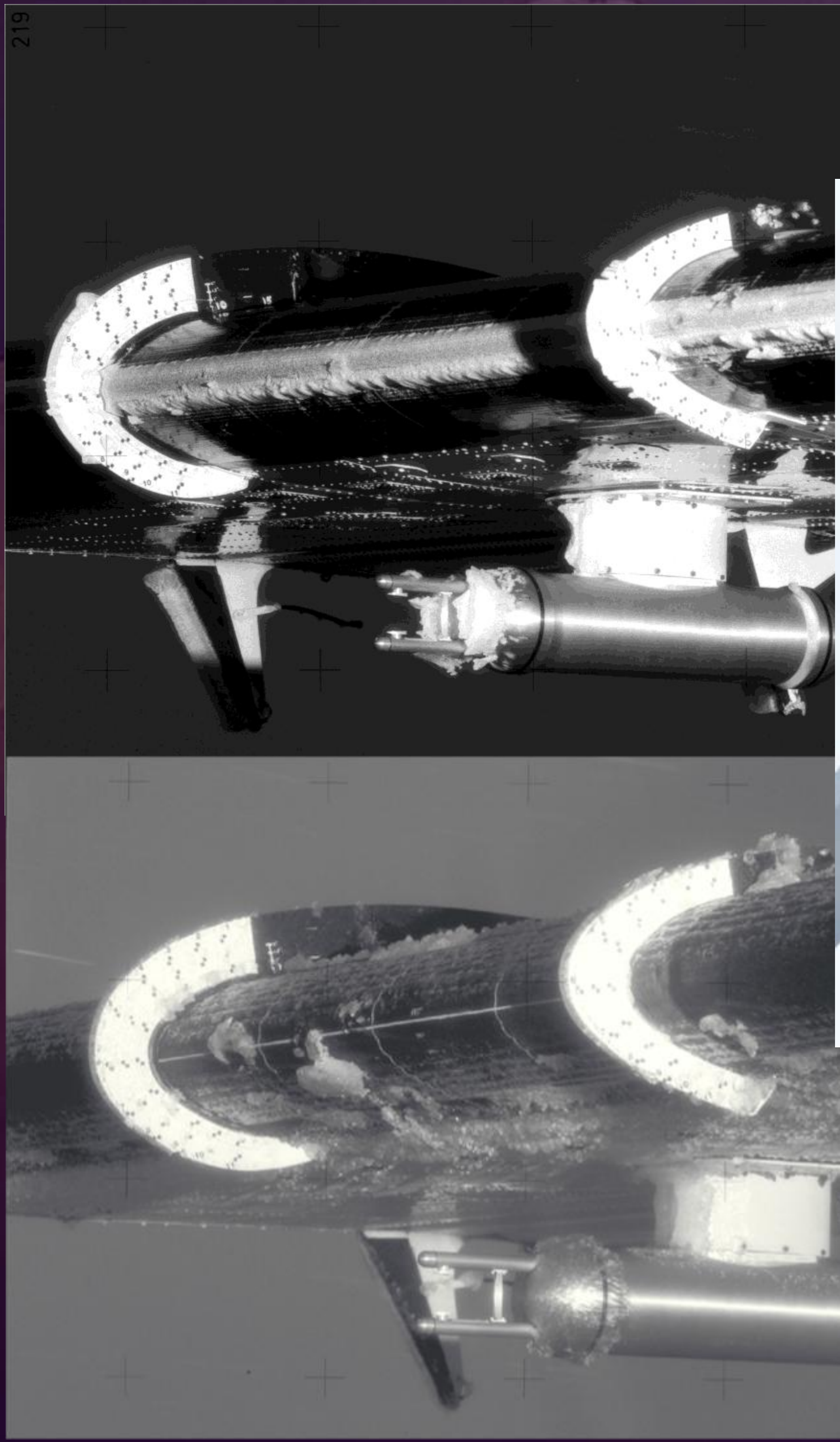
CO Headwaters: microphysics sensitivities





References: Ikeda et al, 2010
Rasmussen et al, 2011
Liu et al, 2011 (MWR, in press)

Applications: aircraft/ground icing



The next frontier: “aerosol awareness”

☑ Crawl:

Constant cloud droplet number that influences precipitation

☐ Walk:

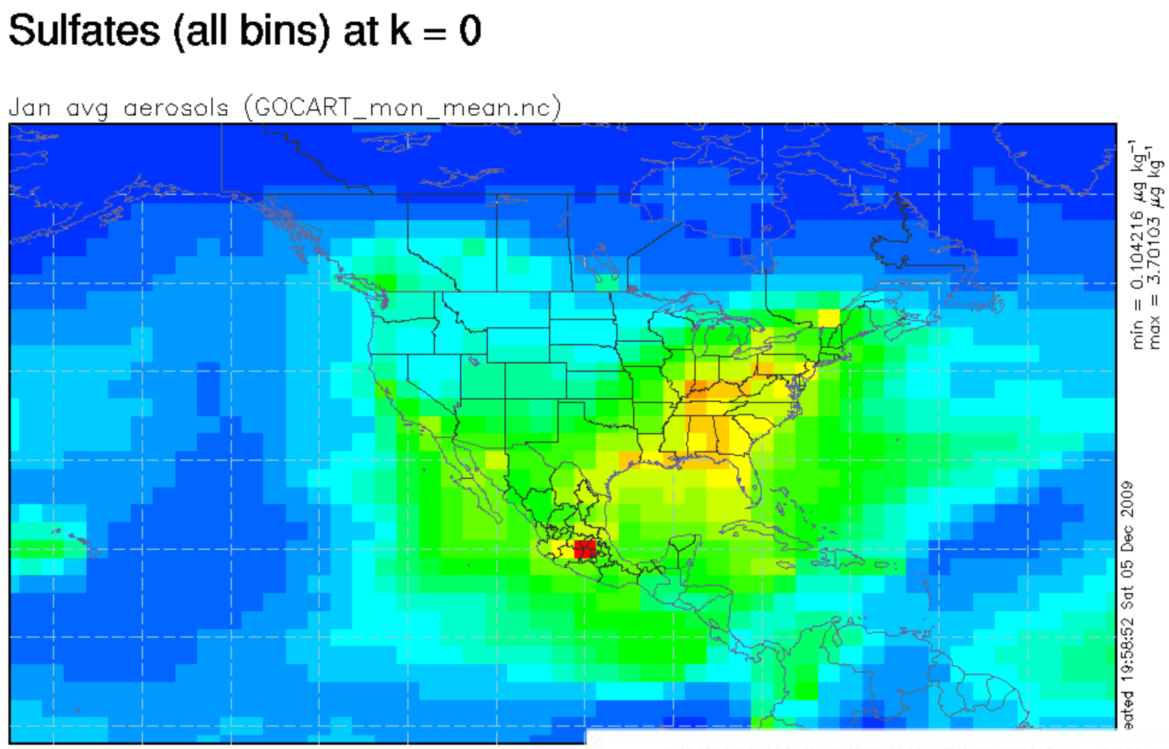
Creating ice and droplet number based on simple, but realistic aerosols

☐ Run:

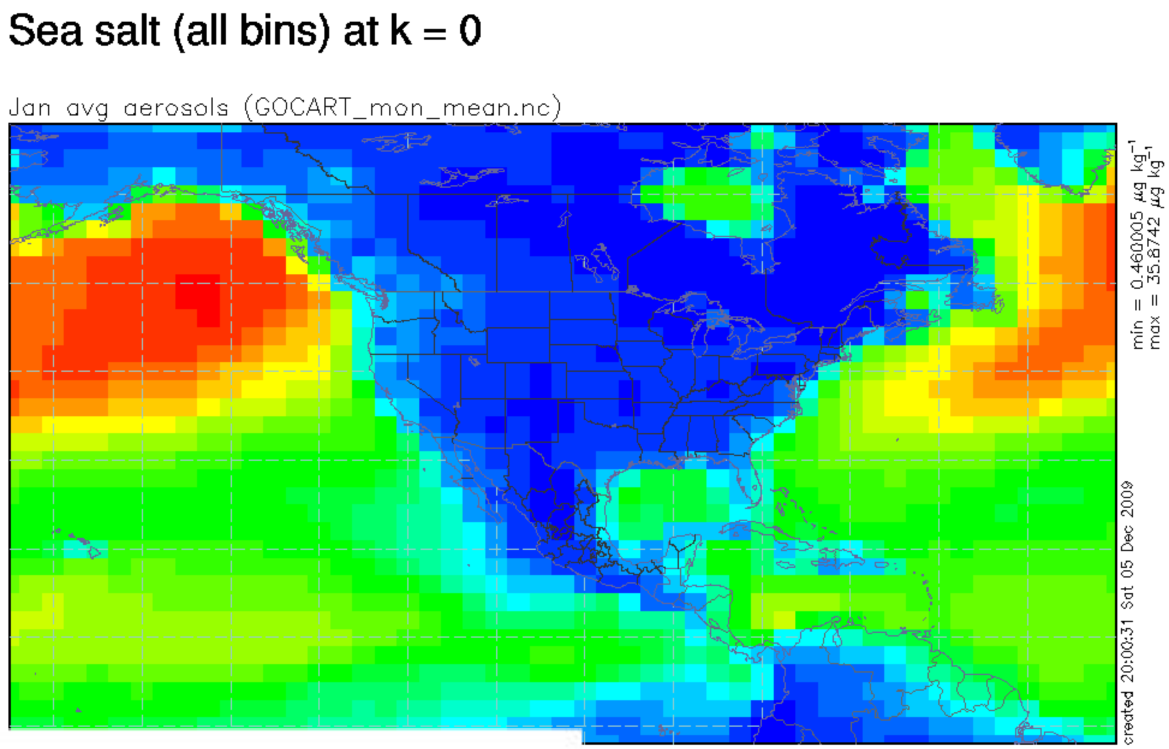
Full integration with WRF-Chem and multiple aerosol species

Input aerosols: sulfates, sea salts and dust

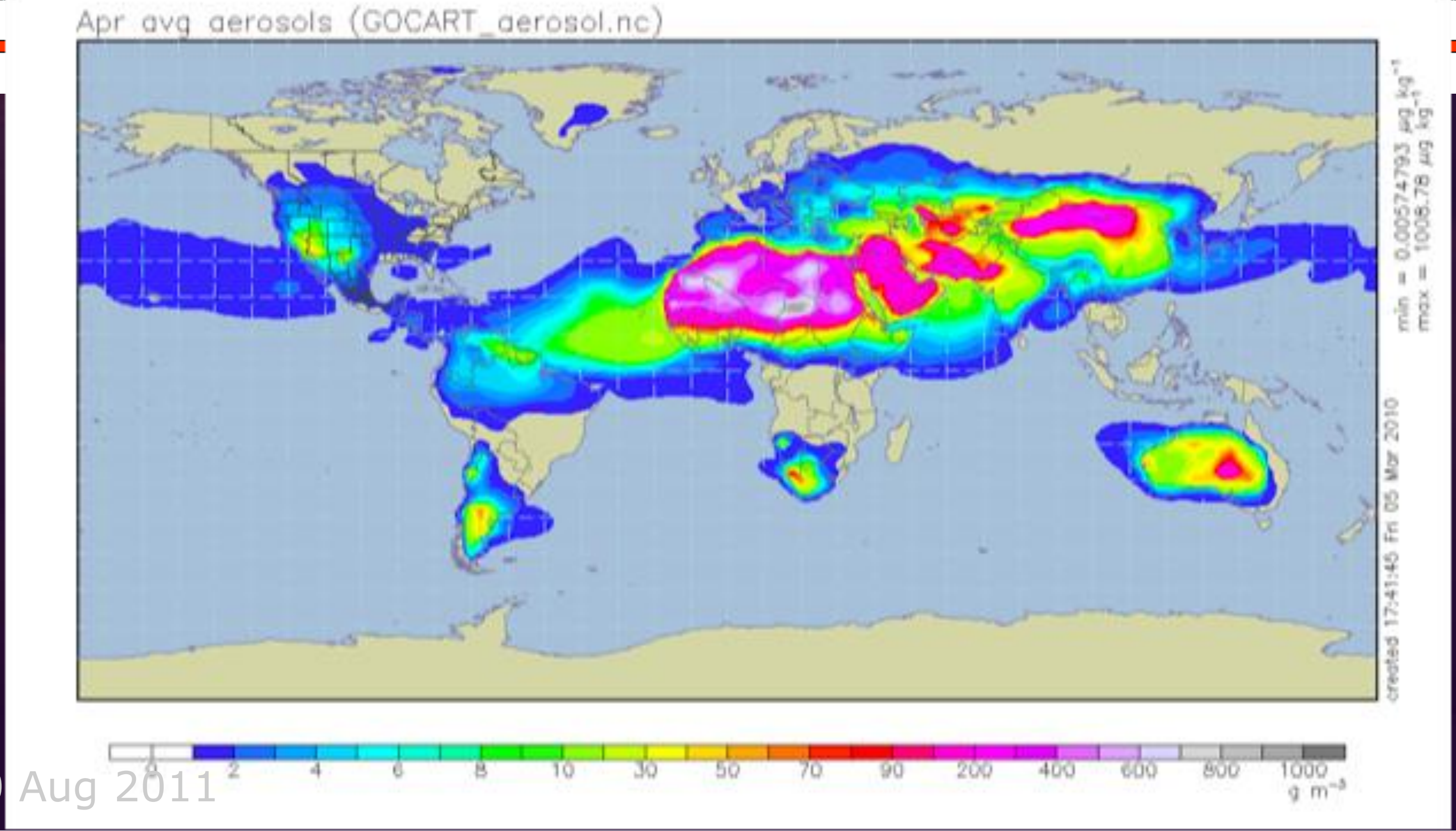
GOCART 2.5º (lon) x 2.0º (lat) global monthly avg data, 20 sigma levels



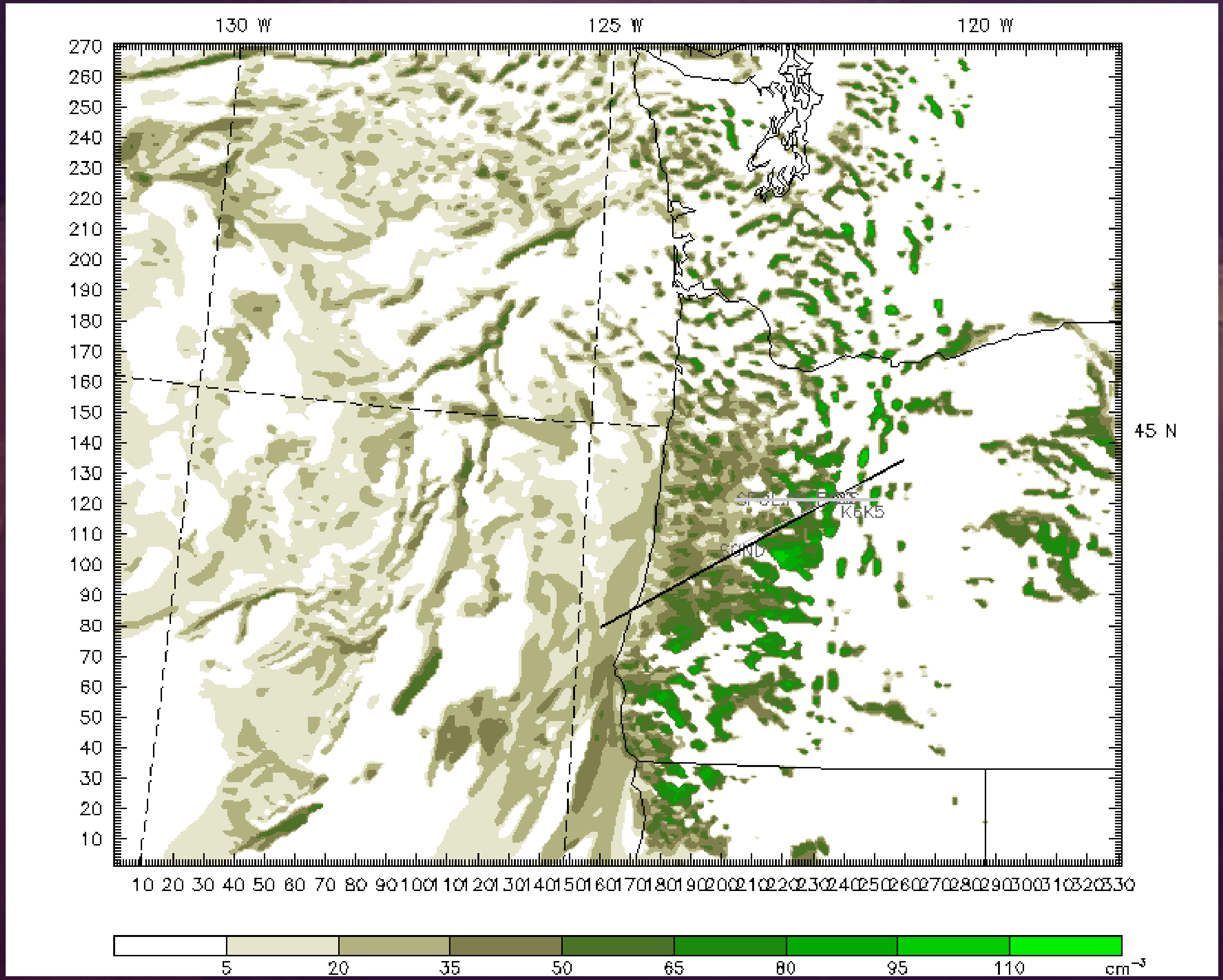
Sulfates (all bins) at k = 0

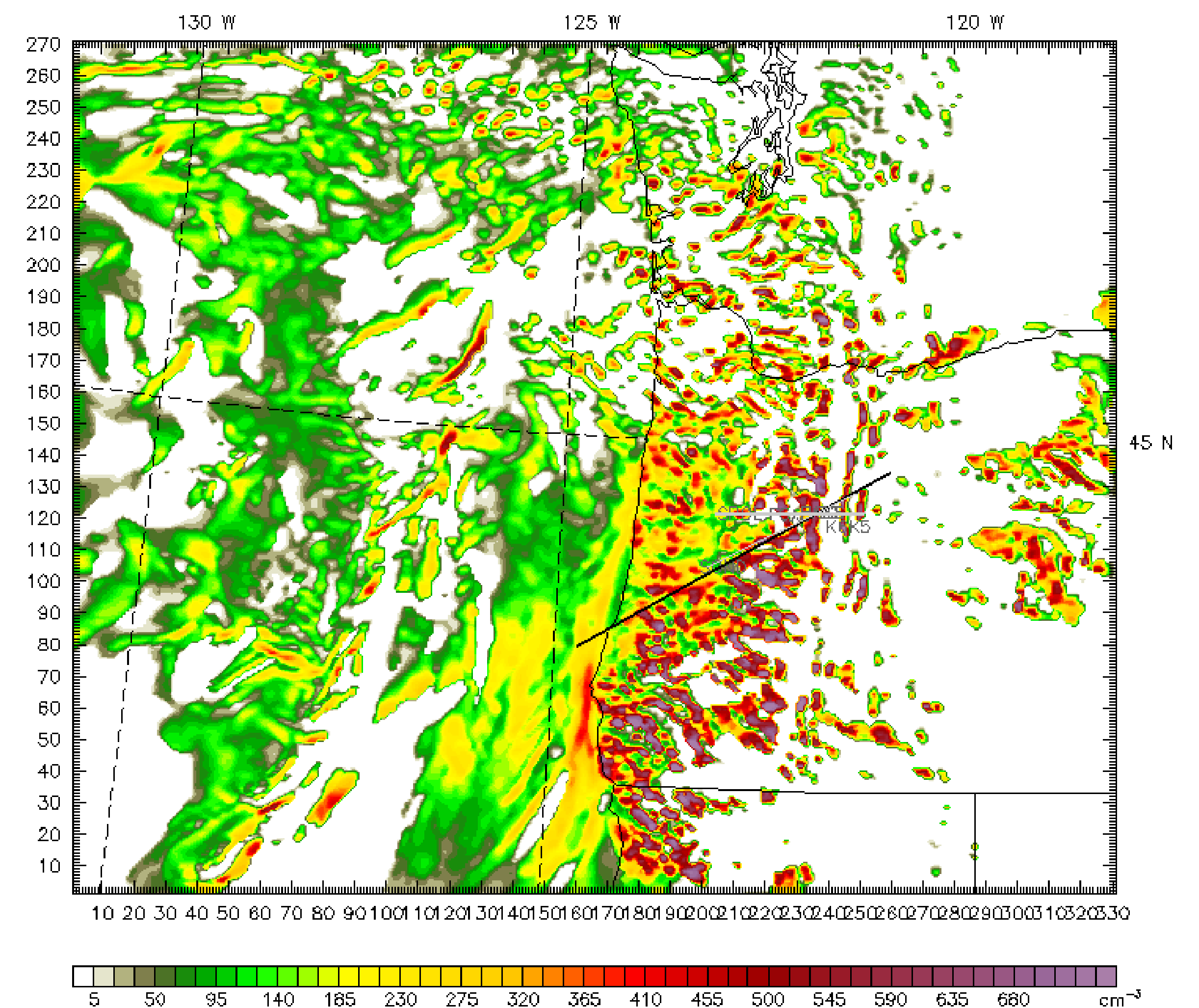


Sea salt (all bins) at k = 0



Aerosol test: clean vs. polluted airmasses

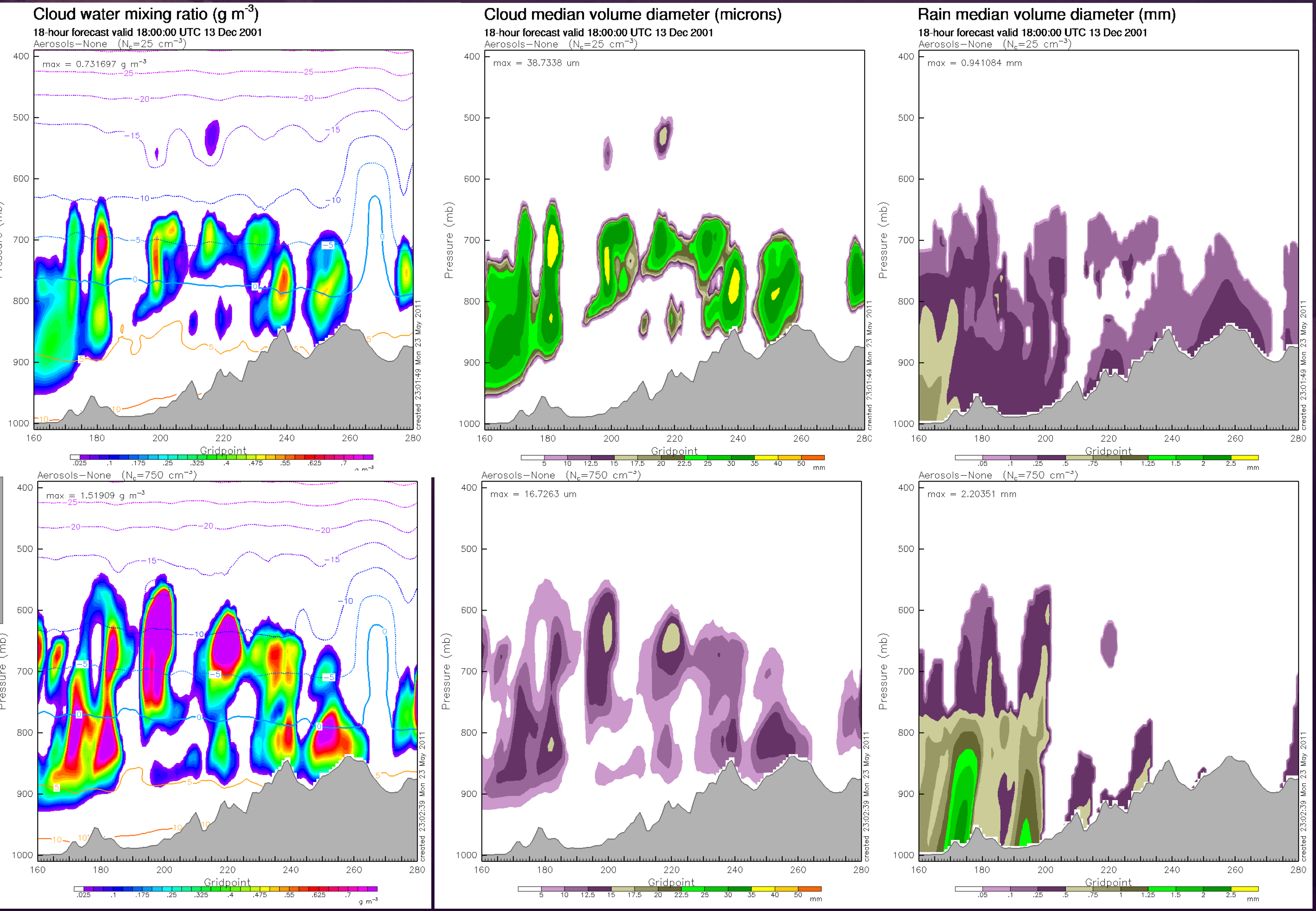




Aerosol test: clean vs. polluted airmasses

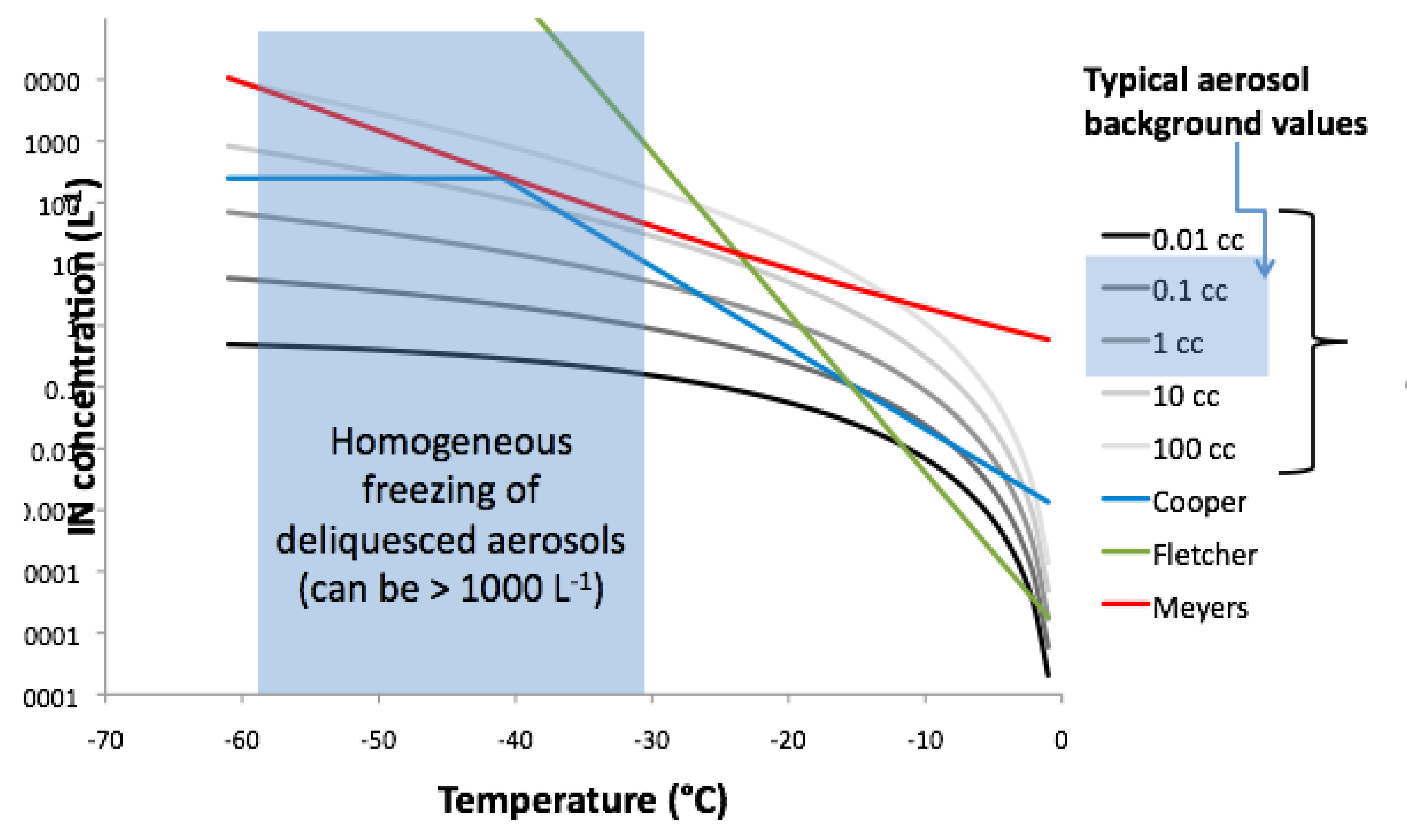
Maritime
fewer drops
much larger mean size
less liquid water content
more drizzle/light rain

Continental
more drops
much smaller mean size
more liquid water
delayed drizzle/rain
alters upper cloud



Dust (> 1μm) as primary ice nuclei

- Primary ice nucleation:
  1) Depends on dust concentration
  2) Based on DeMott et al (2010)
  3) Homogeneous freezing of deliquesced aerosols (T<−30°C)
- Droplet freezing also depends on :
  1) Dust concentration
  2) Temperature and droplet size
- Secondary ice nucleation remains



Biggest challenges ahead

Ice initiation
Input aerosol data
Grid-spacing/resolution dependence
Data assimilation
PBL issues

Biggest challenges ahead

Ice initiation – how many small ice?
Observations of ice in tropical versus mid-lat clouds
Validation of microphysics, especially tropical systems
Diagnostic products for comparison purposes
Physics interactions:

- radiation and microphysics
- PBL and microphysics
- Cumulus and microphysics

Fractional cloudiness?
Operational vs. research, considerations of CPU time/resources
Cloud modeling workshop case with TC? Including idealized setup
Future: aerosols -> Saharan dust, CCN, IN
Bulk scheme tunings from higher order/complex schemes
Recommendations for “reference configurations”

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