Controls on phase composition and ice water content in a convection permitting operational model

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Aims

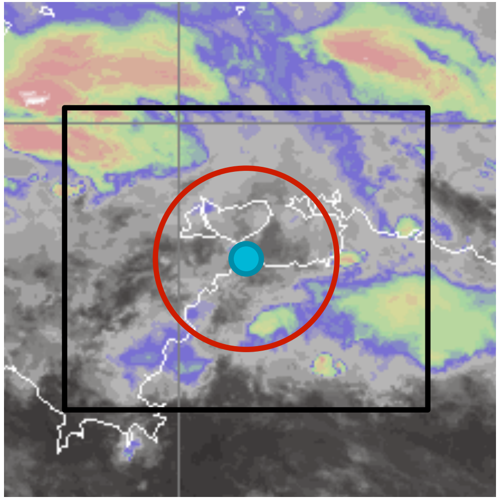
- Evaluate UM 1km simulations of tropical convection (8.5 PS32 L80)
- Investigate the controls on phase composition in the model
- Examine the effects of dynamics, turbulence and microphysical parameterisations

nd	——————	= control, PS32 using new dynamics
eg	——————	= ENDGame even newer dynamics
3d	△————△	= 3d Smagorinsky rather than blended vertical diffusion
nopsd	——————	= no generic ice size distribution parameterisation
qcf2	···················	= nopsd but with additional ice prognostic
qcf2hm	- - - - - -	= qcf2 but with Hallett-Mossop ice splintering parameterisation
qcf2ndrop500	◇————◇	= qcf2 but with cloud droplet number of 500 not 100
qcf2sr2graupel	-·-·-·-·-·-	= qcf2 but without snow-rain collisions producing graupel
qcf2noqgr	✳————✳	= qcf2 but without graupel
qcf2rainfreeze	+ - - - - - +	= qcf2 but with heterogeneous freezing rain parameterisation
qcf2raindsd	□ - - - - □	= qcf2 but with Marshall-Palmer rain drop size distribution

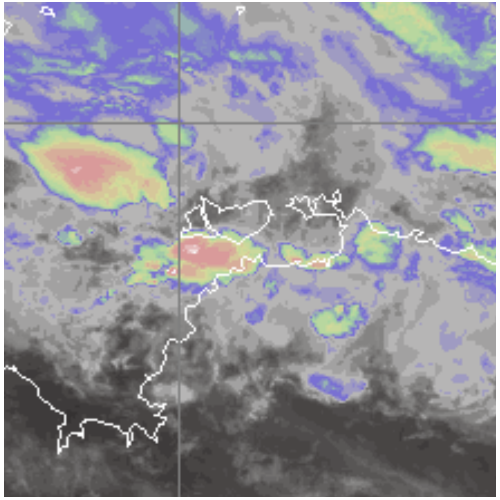
- Darwin mesoscale convective system case study February 18 2014
- Evaluation using CPOL radar, radiosonde, satellite and aircraft obs

MCS lifecycle

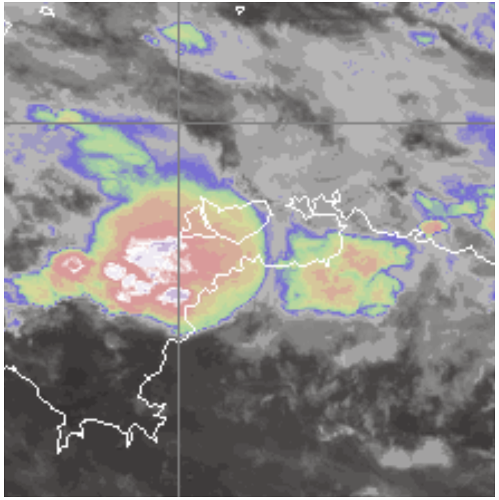
12 UTC = 21:30 local



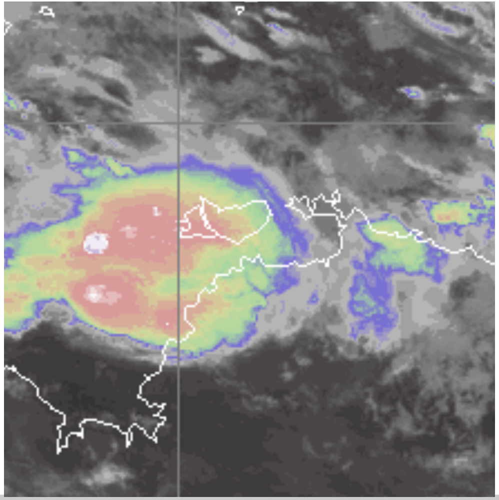
15 UTC



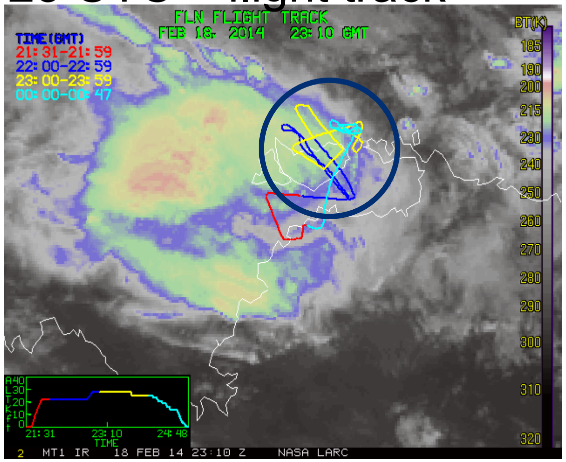
18 UTC



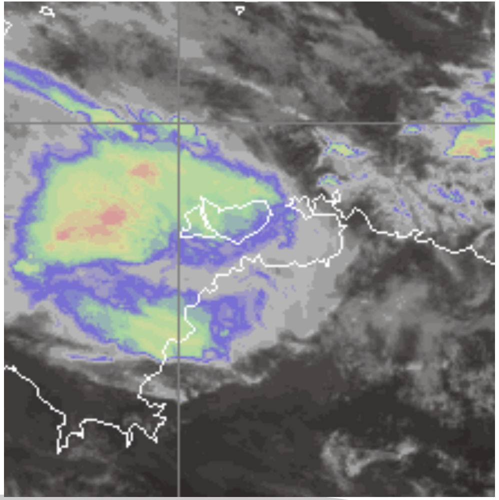
21 UTC



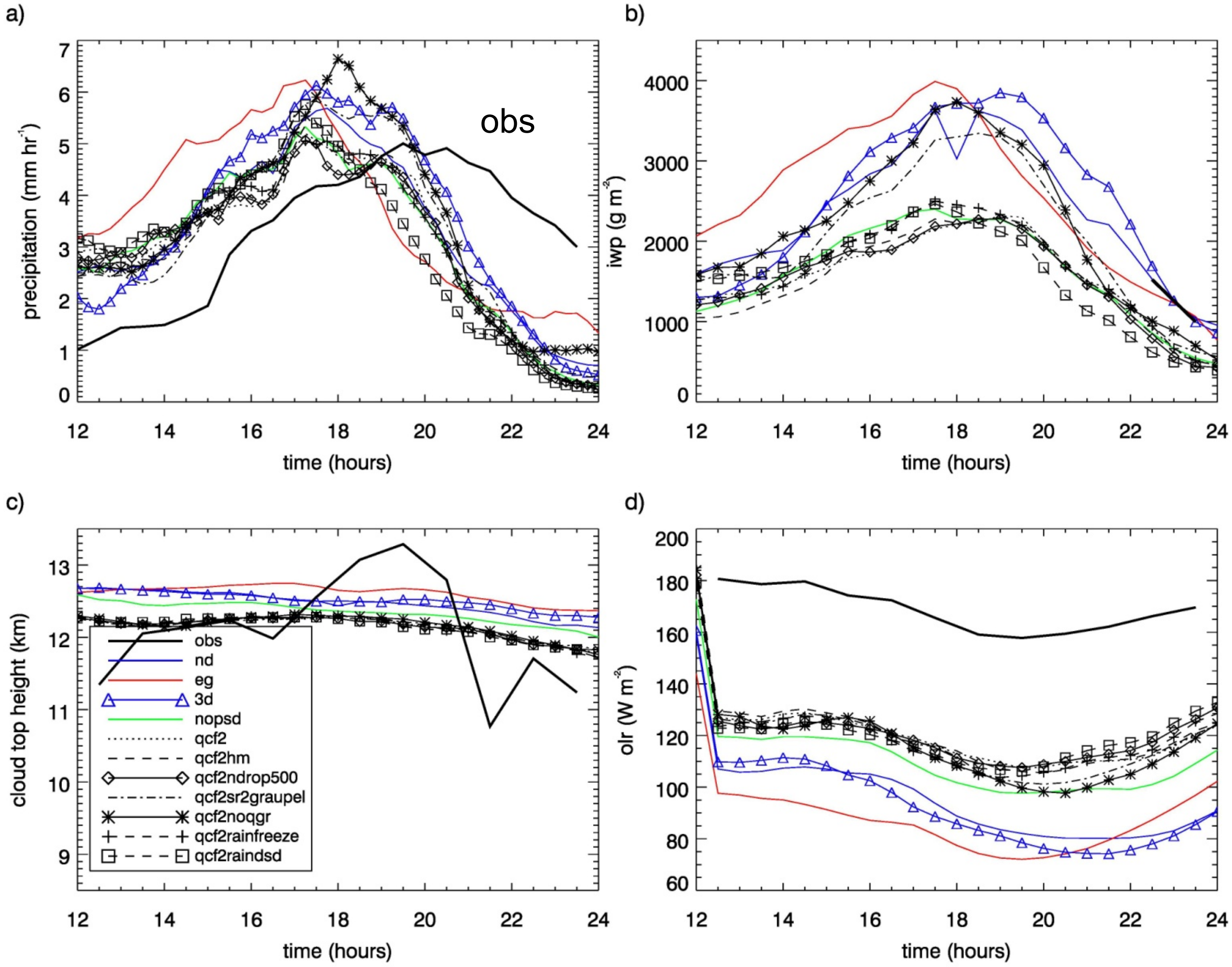
23 UTC – flight track



24 UTC = 9:30 local

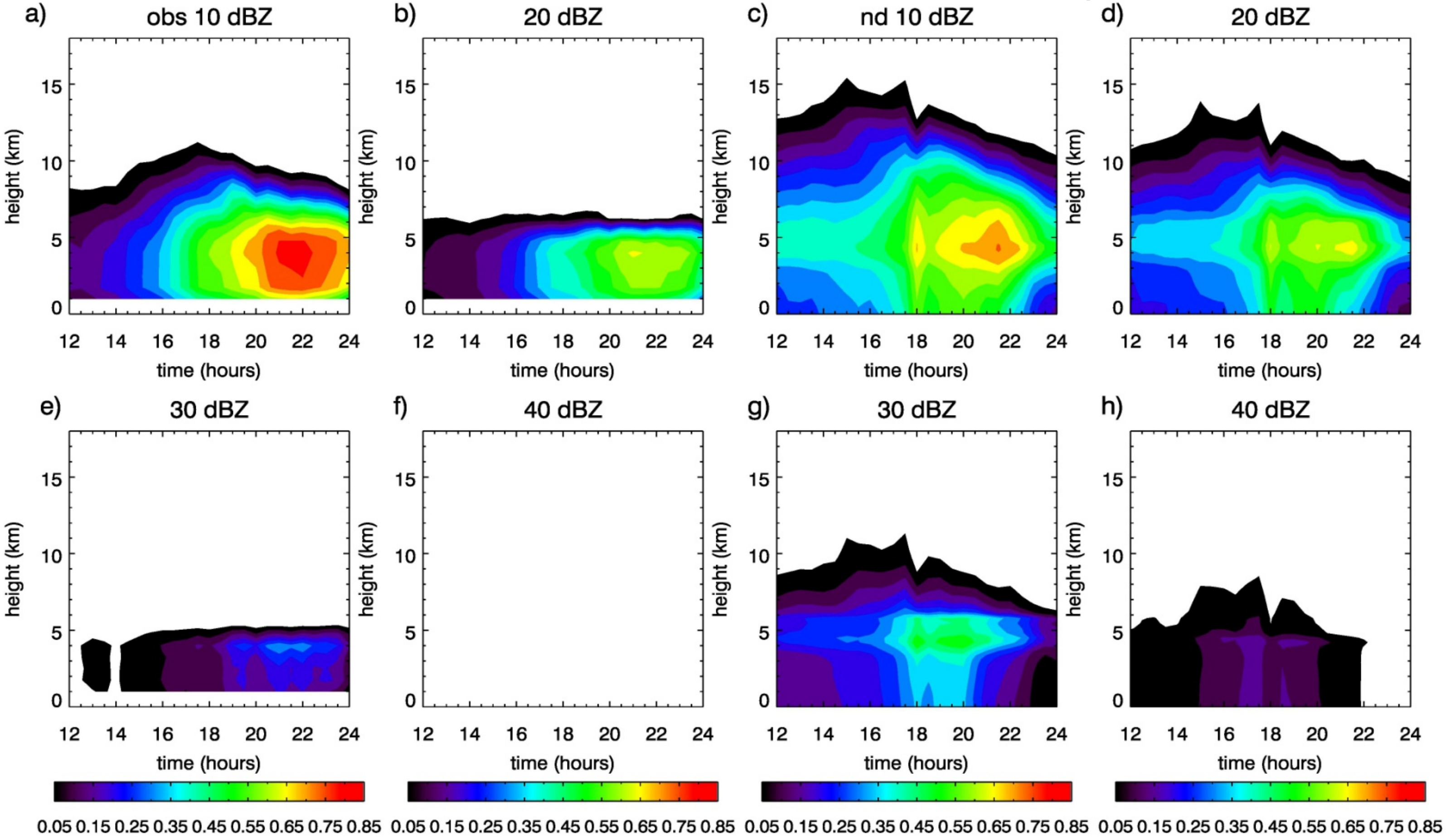


Time series comparison with obs



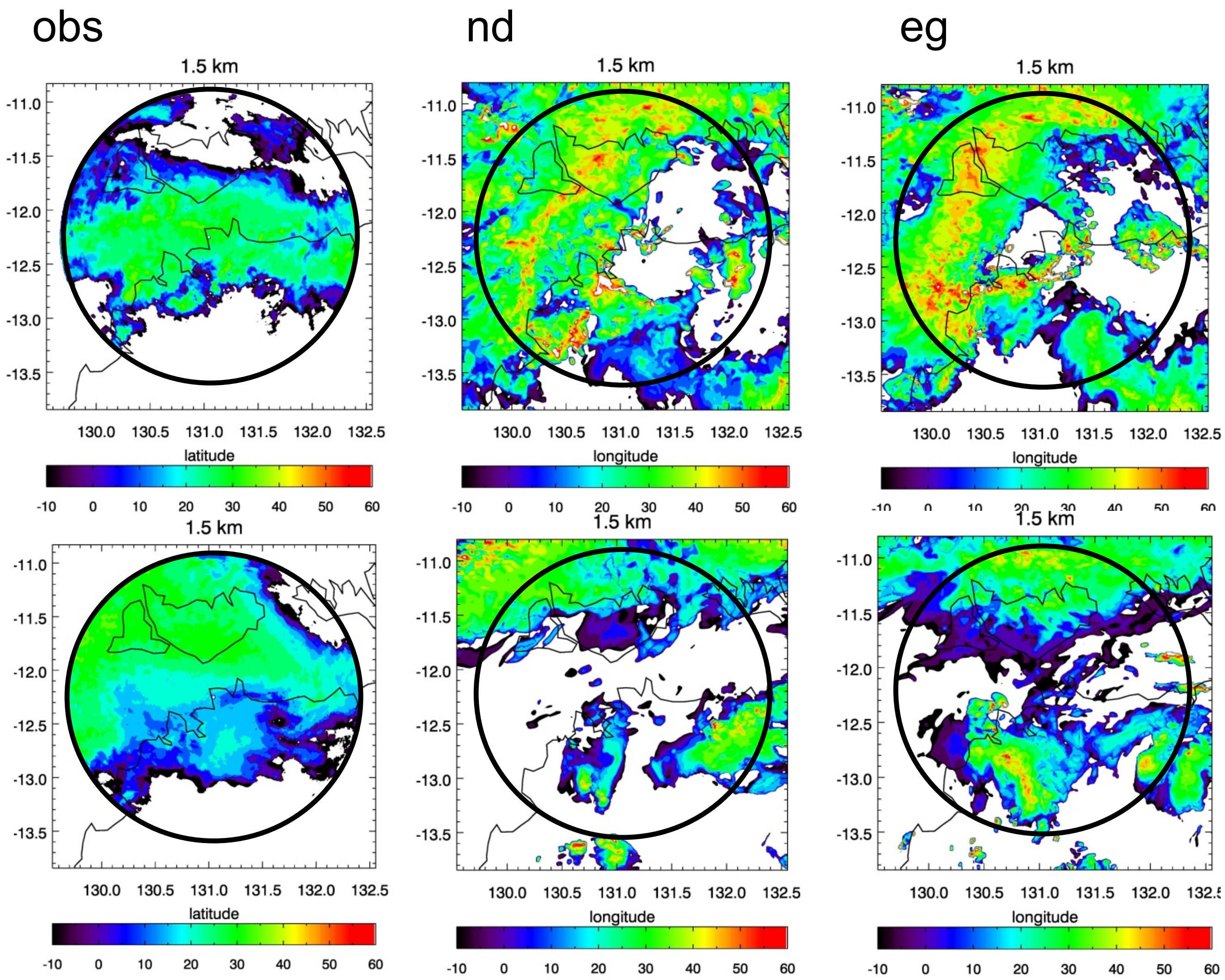
- Generic PSD has larger IWP, due to higher RH and greater vertical extent, compares better with obs at later times
- Avg cloud top heights reasonable but less variable
- Cloud top temps too cold and OLR too low

Evolution of MCS radar reflectivity



- Intensification and decay of convective strength reasonably well simulated
- Greater variability in area coverage with height – lack of stratiform rain area
- Too much rain advected above freezing level and areas > 30 dBZ overestimated

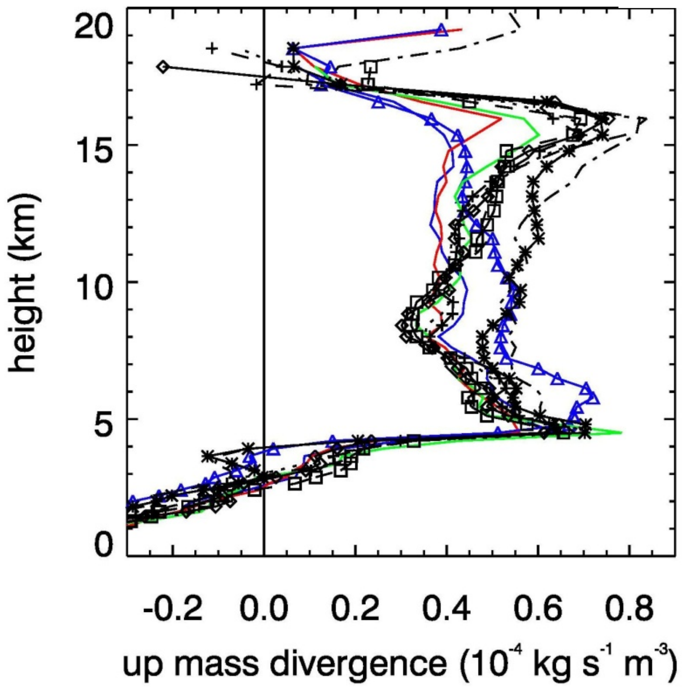
Rainfall dBZ@17-18 and 23-24 UTC

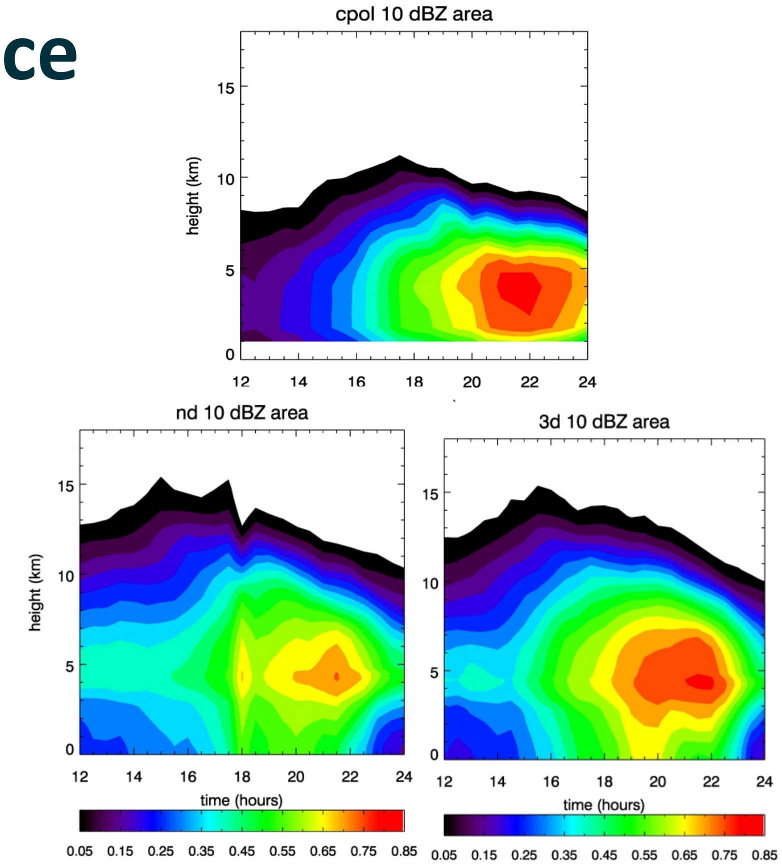


- Model produces too many high dBZ areas
- Simulations capture reduction in high dBZ areas at the later time
- Model area coverage of rain too small at later times

Horizontal mass divergence

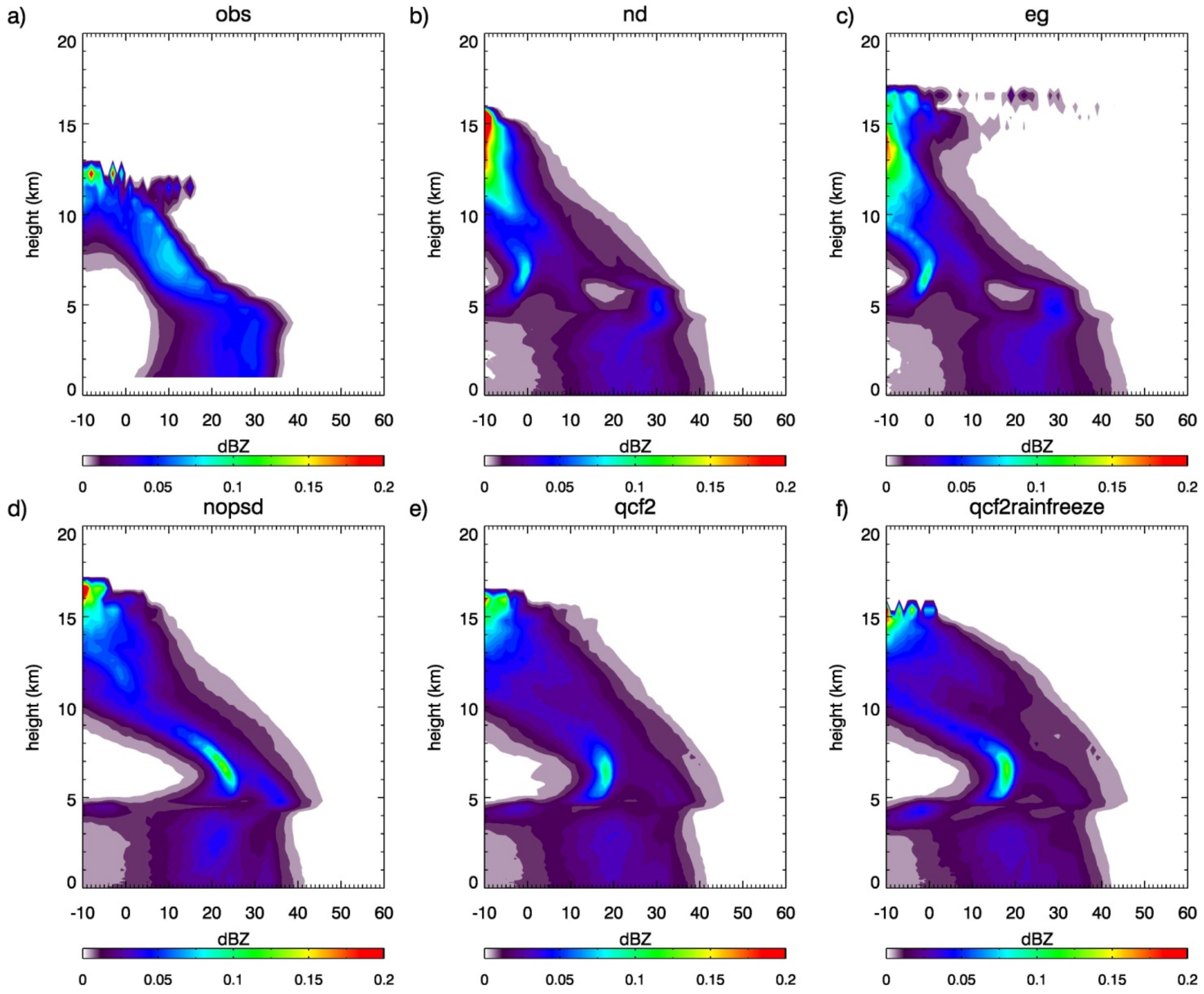
18 UTC





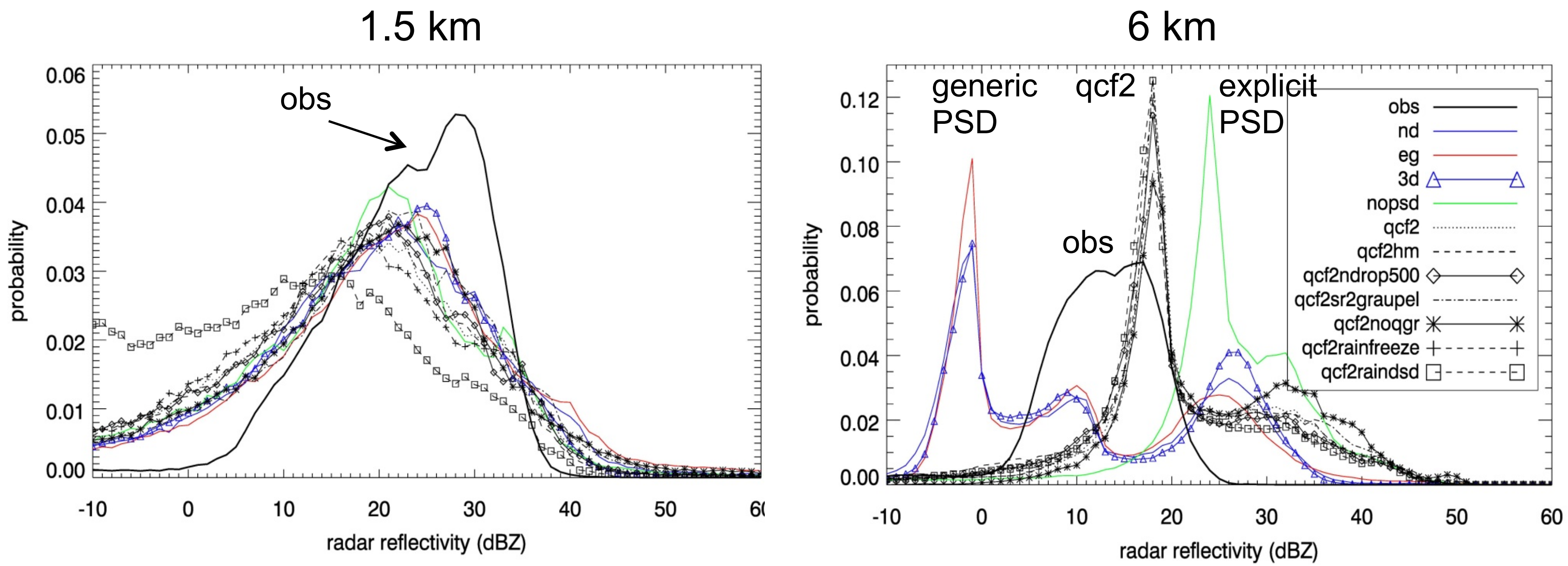
- Decelerating updrafts due to reduced buoyancy is where divergence occurs
- In the mixed-phase zone (5 – 8 km) turbulent mixing has the greatest effect on entrainment and mass divergence
- In the ice-only regions the ice sizes have the greatest effect on reducing buoyancy

Radar reflectivity histogram 23-24 UTC



- Models show broader, more convective profile with many high dBZ outliers
- Evidence of large particles being lofted
- Heterogeneous rain freezing parameterisation reduces occurrences of high dBZ and cloud tops

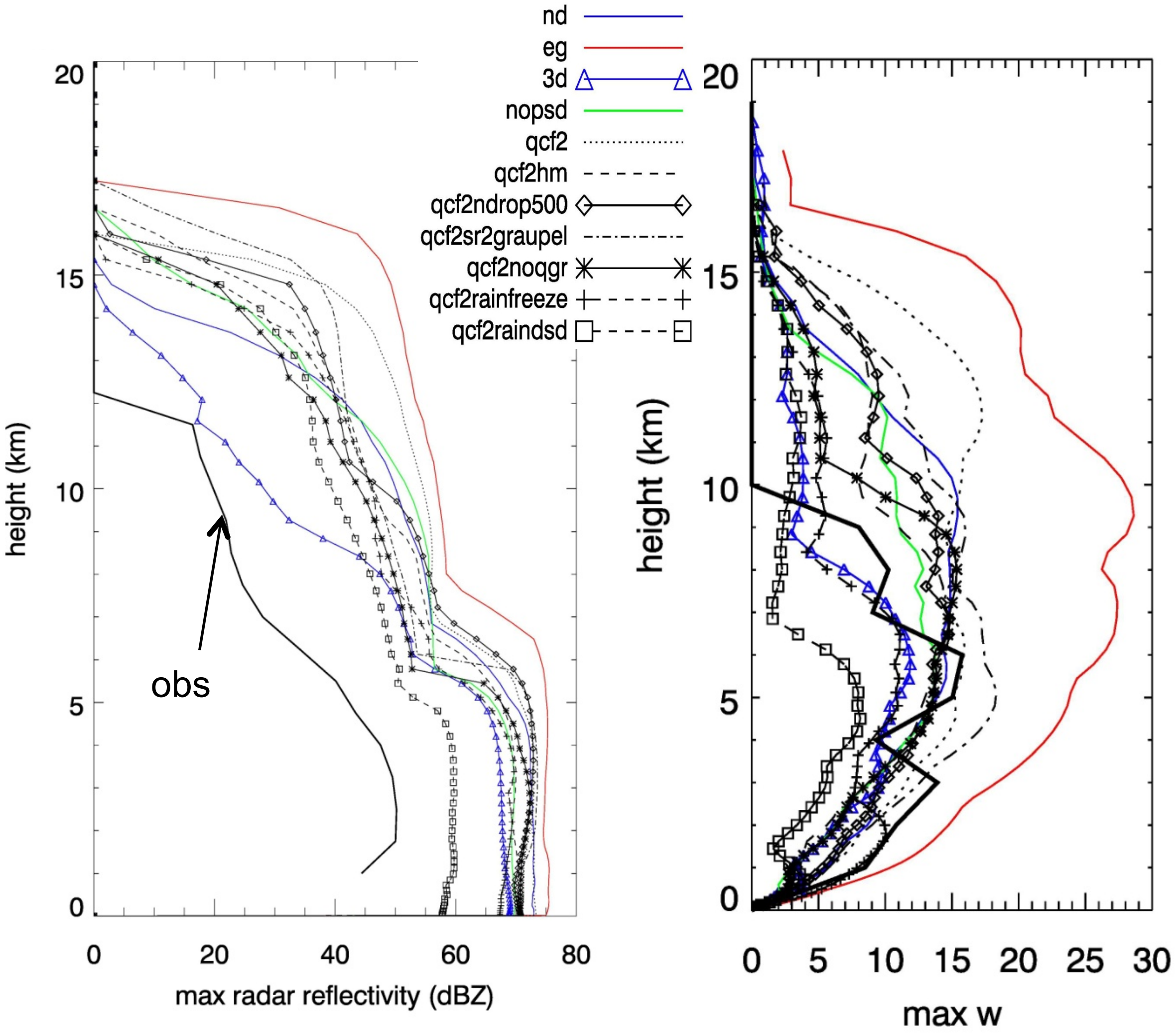
Radar reflectivity PDFs


1.5 km

6 km

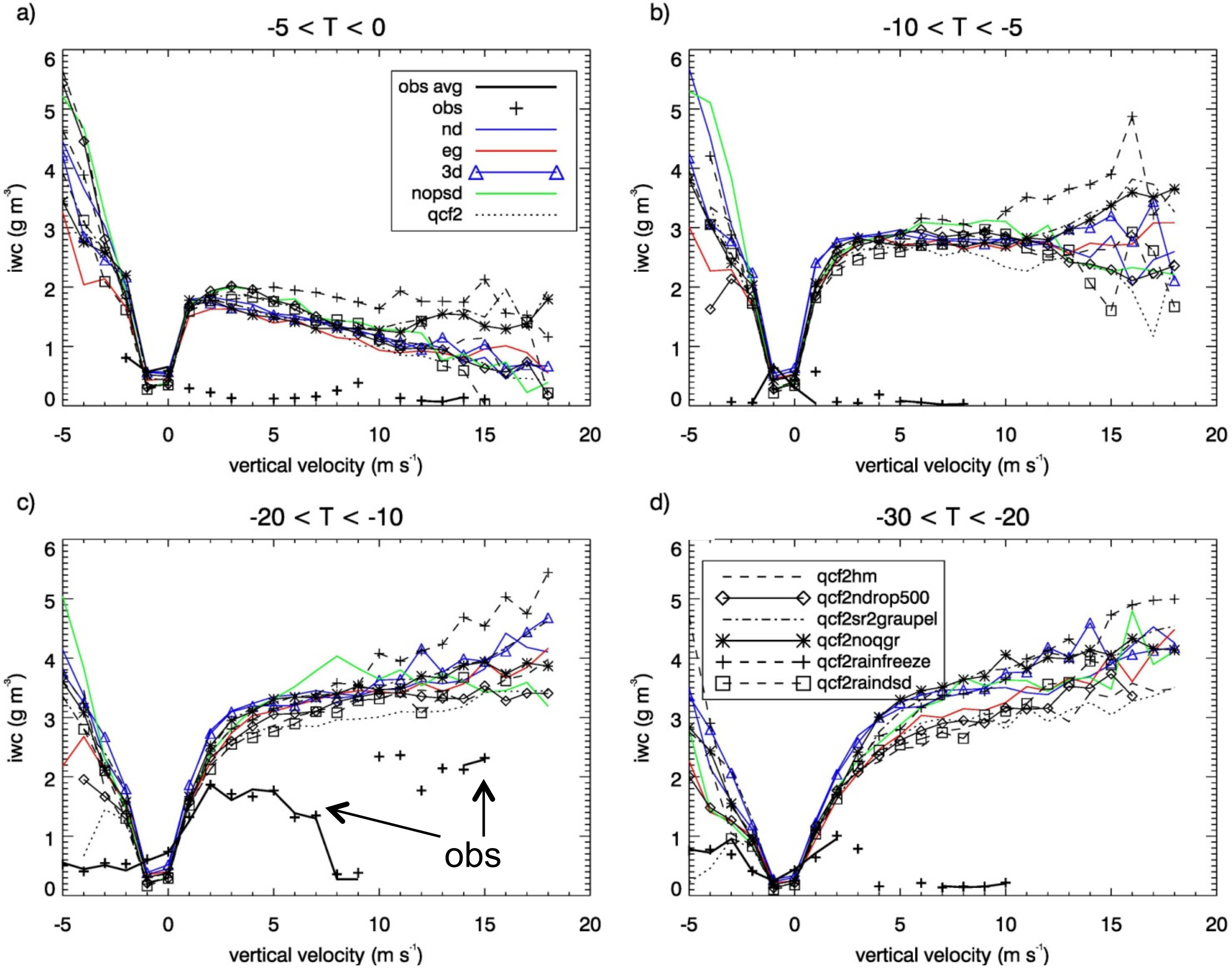
- Abel and Boutle rain DSD quite good but too many occurrences in tails
- ENDGame simulates more occurrences in the high dBZ tail
- At 6 km the obs have a single mode with peak centered on ~ 15 dBZ, simulations produce multiple modes, the generic PSD simulations produce peak around -1 dBZ, 2 separate ice prognostics produces peak at 18 dBZ

Convective updraft reflectivity and velocity



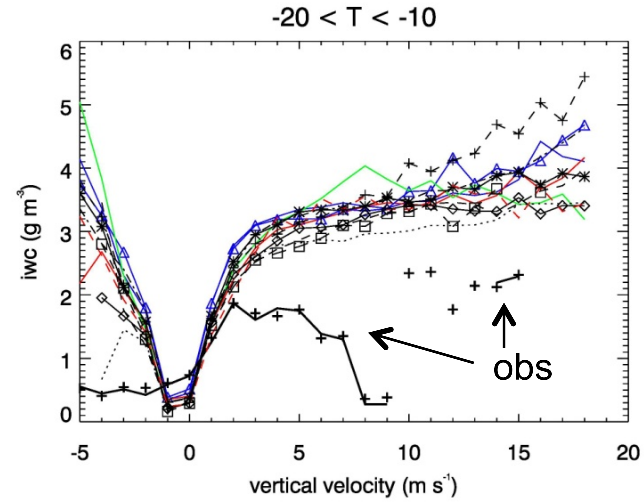
- Strong updrafts loft large particles producing profile of constant max dBZ
- Large sensitivity in updrafts from dynamics, turbulence and microphysics
- Effect of turbulence change on max w the same as rain freezing parameterisation

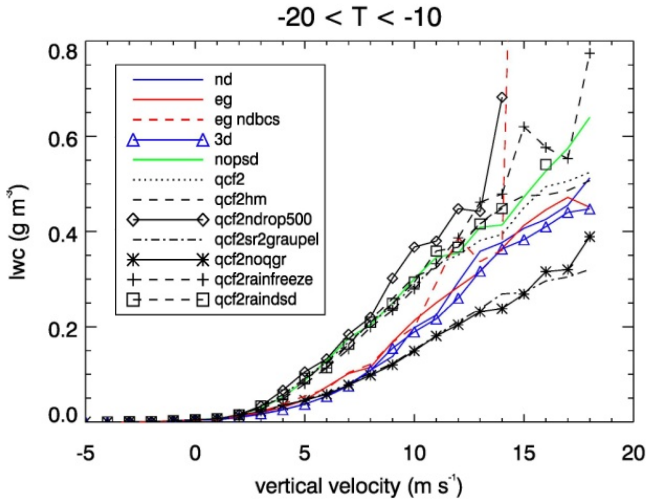
Ice water content

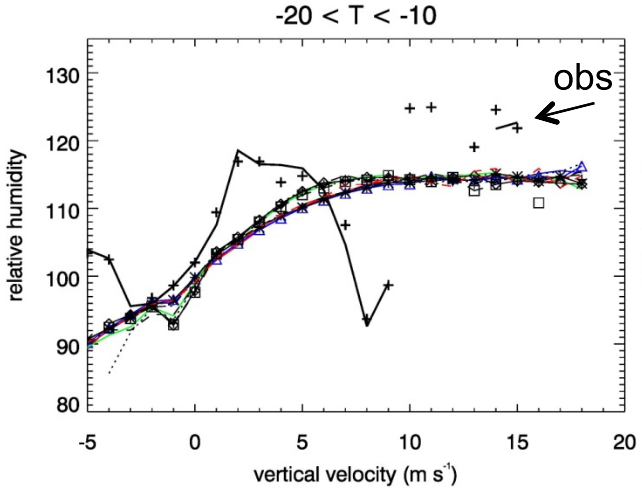


- IWC does not increase with w until the temp regimes cools to where ice nucleation occurs
- Inclusion of freezing rain produces more ice at high w
- IWC decreases at the colder temp regime due to lower supercooled water contents

Phase composition

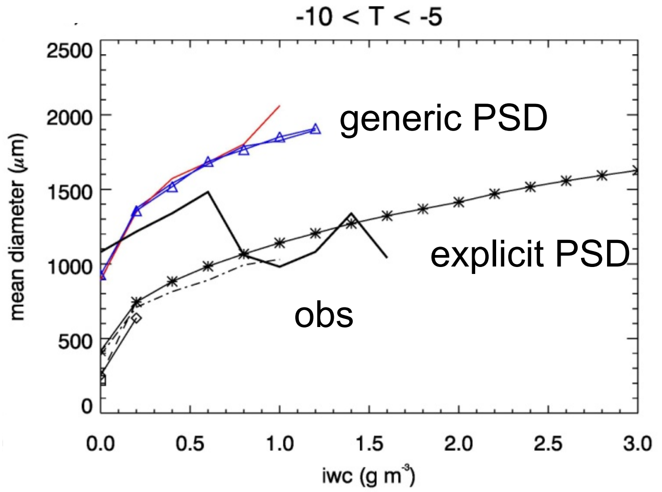




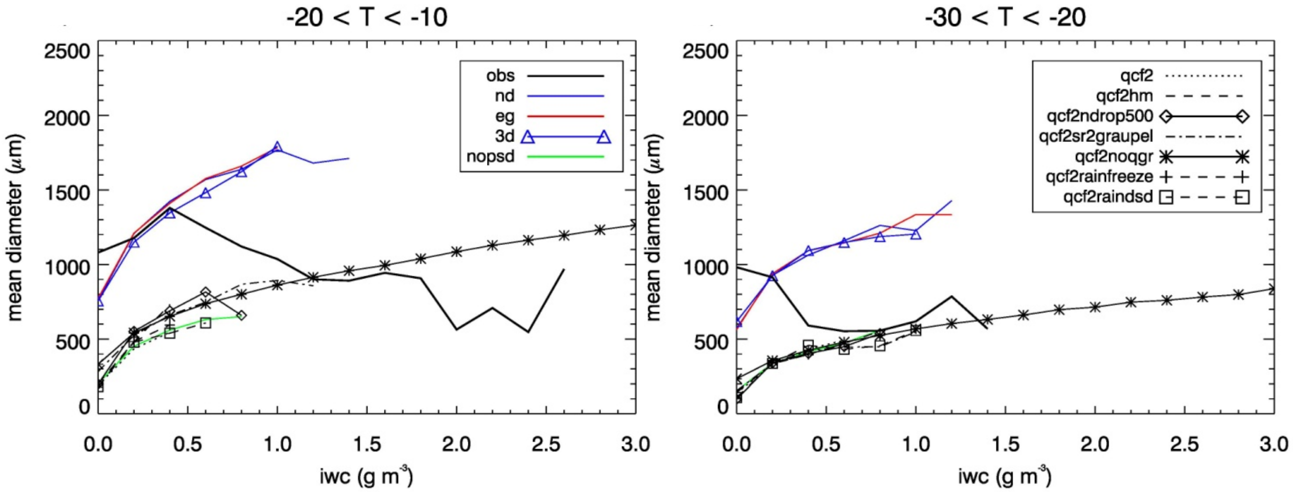


- Growth of ice less dependent on vertical velocity than liquid
- Control on LWC is updraft strength and ice size: stronger updrafts have minimal entrainment; larger ice remove more LWC via accretion
- Control on IWC is ice size and available LWC
- Lower RH & higher IWC in updrafts suggests ice depositional growth too efficient in the model

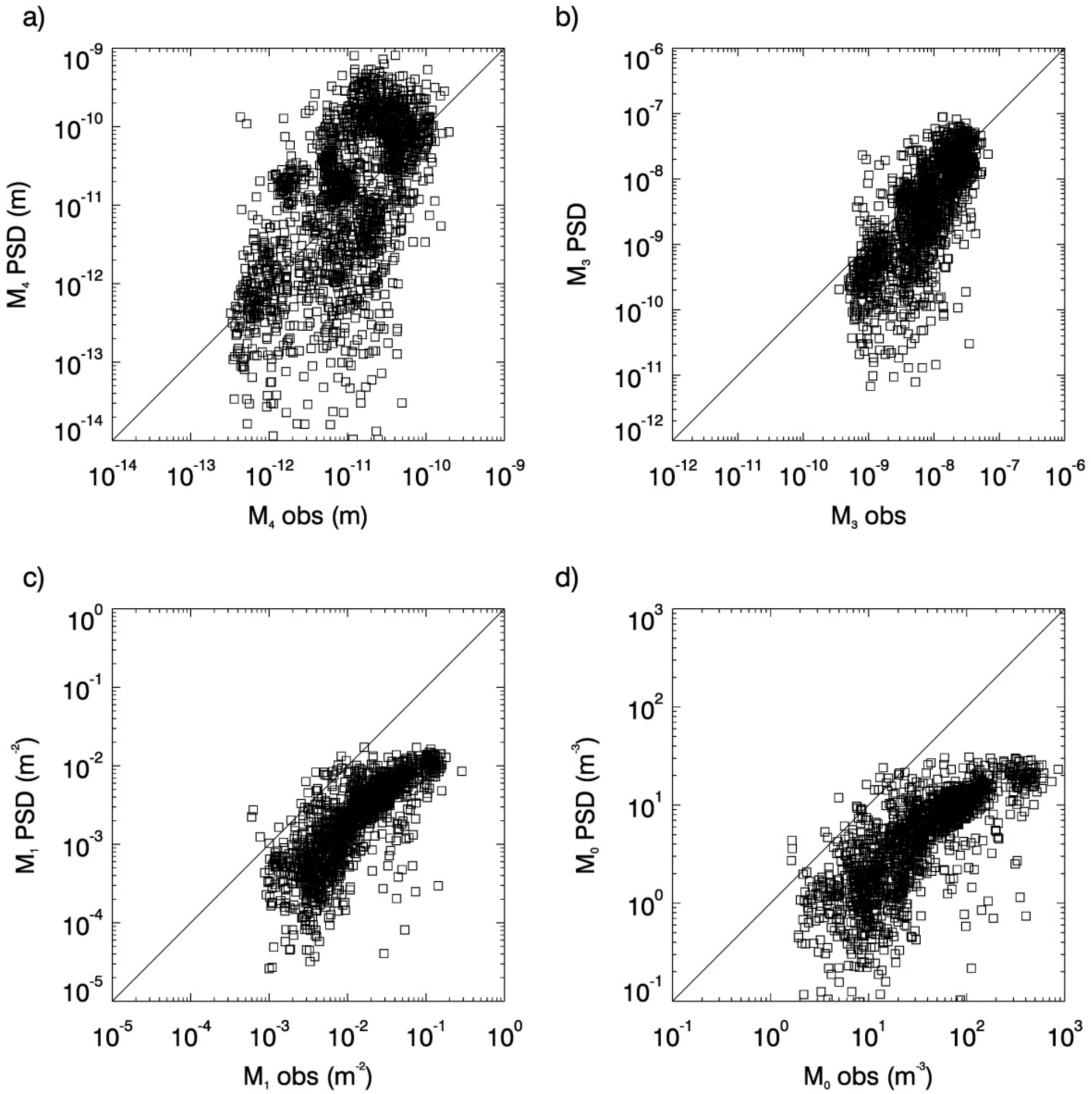
Ice particle sizes



- Obs show a reduction in mean size with increasing IWC – dominance of smaller particles for high IWC
- Generic PSD mean snow sizes larger than explicit PSD and obs for IWC > 0.5 g m^{-3}
- Explicit PSD mean snow sizes too small for low IWC



Moments of the particle size distribution



- Field et al. (2007) moment estimation parameterisation

$$M_n = a\exp(bT)M_2^{\,c}$$

- 0th moment (ice number concentration) is underestimated by the parameterisation
- 4th moment (radar reflectivity) tends to be overestimated

Reducing model biases

Bias	Development
Excessive areas with high reflectivities	Reduced ice sizes, freezing rain, additional ice prognostic variable, 3D Smagorinsky turbulence
Too much rain above the freezing level	Heterogeneous rain freezing parameterisation
Too little entrainment with too much detrainment in the upper troposphere	Change turbulence parameterisation, smaller ice sizes
Too little stratiform rain area	Increased turbulent mixing
Too efficient depositional growth of ice	Reduced vapour deposition

Summary

- Intensification and decay of convective strength associated with the MCS life cycle is well simulated, but > 30 dBZ areas overestimated due to larger particle sizes and rain above the freezing level
- Reflectivity distributions and large scale environment better simulated when using smaller ice sizes and when a heterogeneous freezing rain parameterisation is included
- Entrainment in mixed-phase regions of convective updrafts is controlled by turbulent mixing. In the ice-only regions ice sizes determine the updraft buoyancy and entrainment.
- Control on IWC is determined in the model by ice size and available liquid: larger ice grow more efficiently via accretion and riming, reducing the efficiency of the warm rain processes increases liquid water content and consequently ice.

Thank you

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