Tropical Anvil Characteristics and Water Vapor of the Tropical Tropopause Layer (TTL): Impact of Homogeneous Freezing Parameterizations

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Introduction

- Deep convections over the Tiwi islands during transition season (Nov-Dec, Feb-Mar): Hector

  a) One of the world's tallest thunderstorms (up to 20 km).

  b) Massive anvils and heavy rainfalls.

- Anvil characteristics have a major impact on the radiative balance and hence global climate

- We want to look into the anvil properties predicted from different homogeneous freezing parameterizations and look into the impact of those schemes on TTL compositions in terms of water types.

  Two single-hector cases are selected:

  - Nov 16, 2005 during ACTIVE (polluted)
  - Feb 06, 2006 during TWP-ICE (clean)

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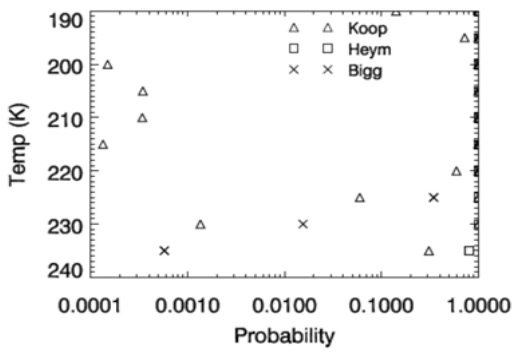
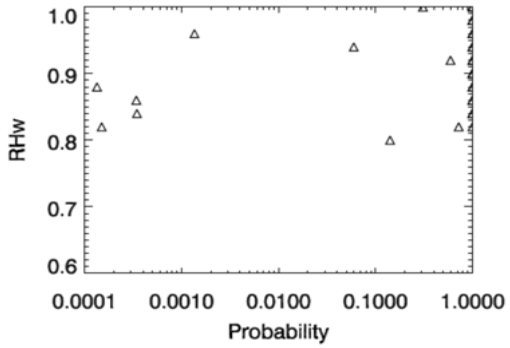
Homogeneous freezing parameterizations

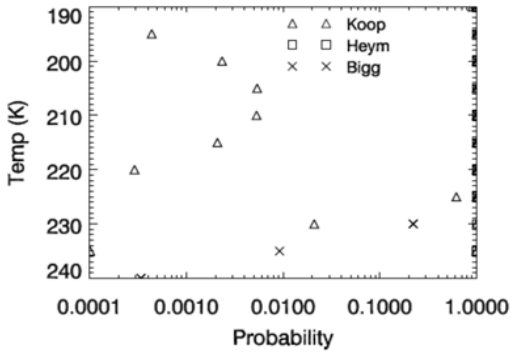
1) Koop et al. (2000): J_r depends on the water activity of the solution and is independent of the nature of solute.
2) Heymsfield and Miloshevich (1993): J_r depends on temperature. Depression of freezing point due to solute and curvature effects is considered but those effects are only significant when droplets are less than 1-2 um.
3) Bigg (1953): J_r depends on temperature. Also function as immersion freezing at the heterogeneous freezing temperatures.
4) ALL_FREEZ (e.g. Khain et al 2005): all droplets are assumed to freeze instantly at the homogeneous freezing level (with probability of 1).

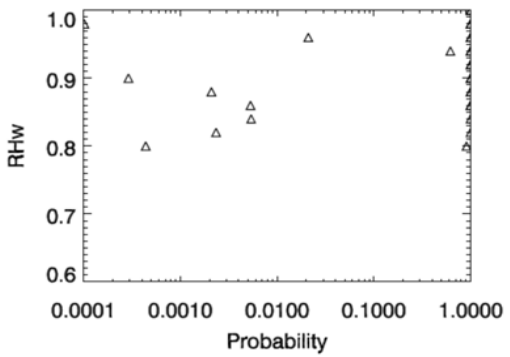
For 2 μm droplets





For 5 μm droplets





- For Koop scheme, over anvil temperature range, freezing is only possible when RHw is over 80% and the probability could be very low even at very low T.
- Heymsfield (square) is close to ALL_FREEZ. When T < 220 K (12.5 km in 0206), both Bigg and Heymsfield have probability of about 1.

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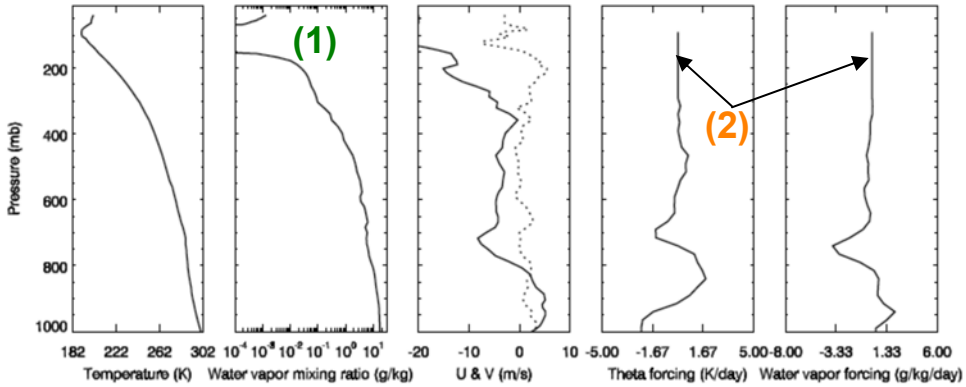
Model Configurations

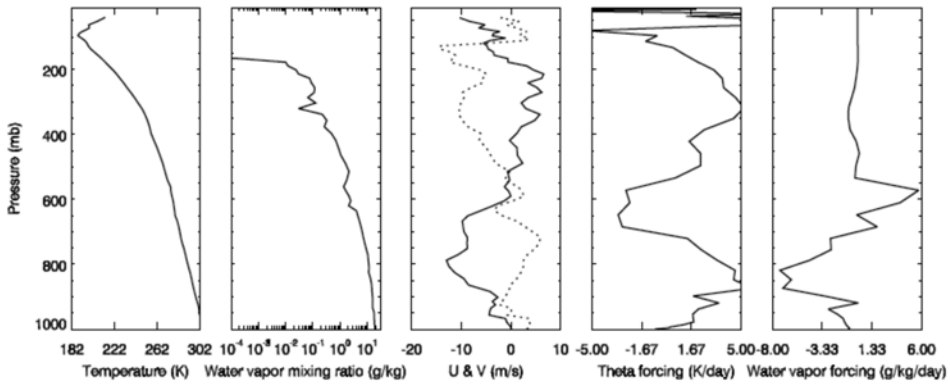
■ Basic setups

- SAM [*Khairoutdinov and Randall*, 2003] coupled with spectral-bin microphysics [*Khain et al.* 2004] and a radar simulator *[Fan et al 2008]*.
- 3D runs: 288×288×73 (grids), 500 m (horizontal) and stretched vertical.
- Periodic lateral boundary conditions
- Heat bubble initialization
- Sounding and LSF:
  Feb 06: Sounding at Garden points and LSF is the updated subdomain forcing for Tiwi islands
  Nov 16: Sounding at Darwin and LSF from ECMWF.
- CAM radiation scheme



(1) Water vapor is set to be very low (10^{-5}) around tropopause.

(2) T and P tendencies are set to be zero at p < 300 mb (~10 km)



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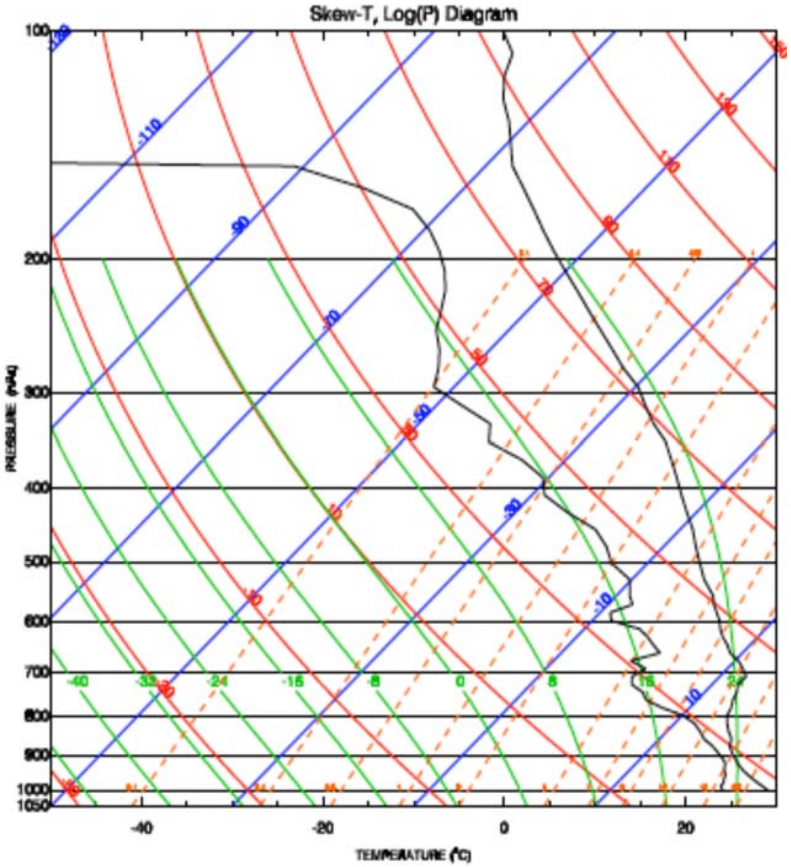
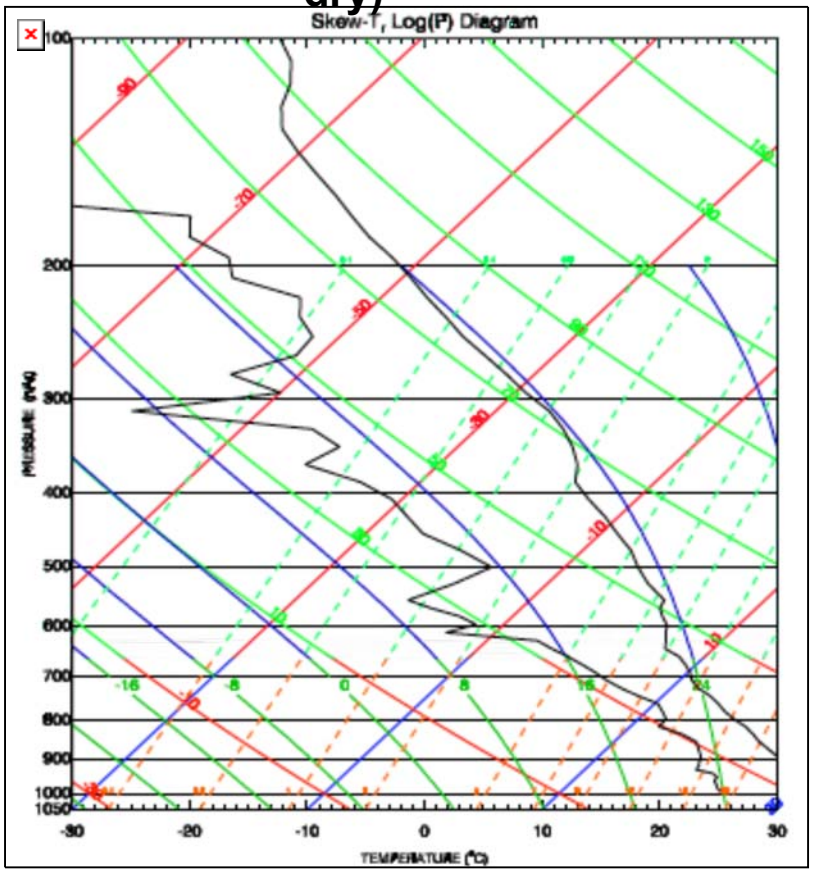
Feb 06 (humid)



Nov 16 (middle-level dry)



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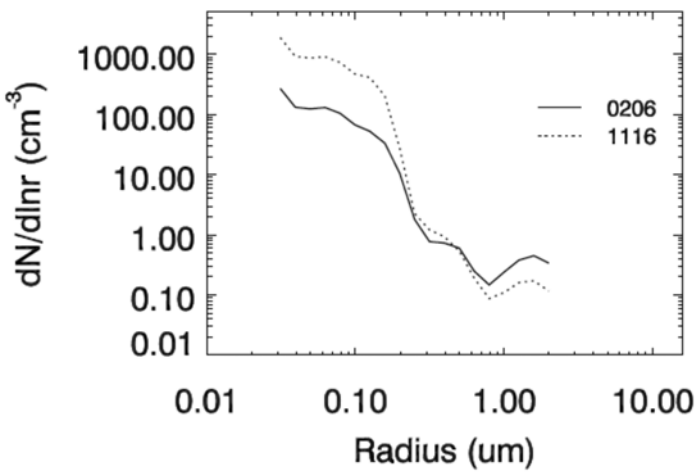
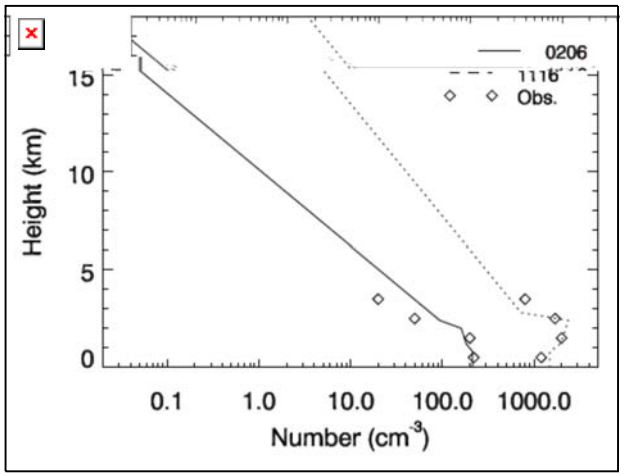
Aerosol size distribution and vertical profiles





Aerosol composition

0206:maritime

Ammonium sulfate: 50%

Organics : 50%

***Density: 1.66 g cm-3**

***MW: 186**

1116: biomass burning

Ammonium sulfate: 30%

Organics : 70%

***Density: 1.62 g cm-3**

***MW: 183**

*** Svenningsson et al (2006): organic components for biomass burning and maritime aerosols.**

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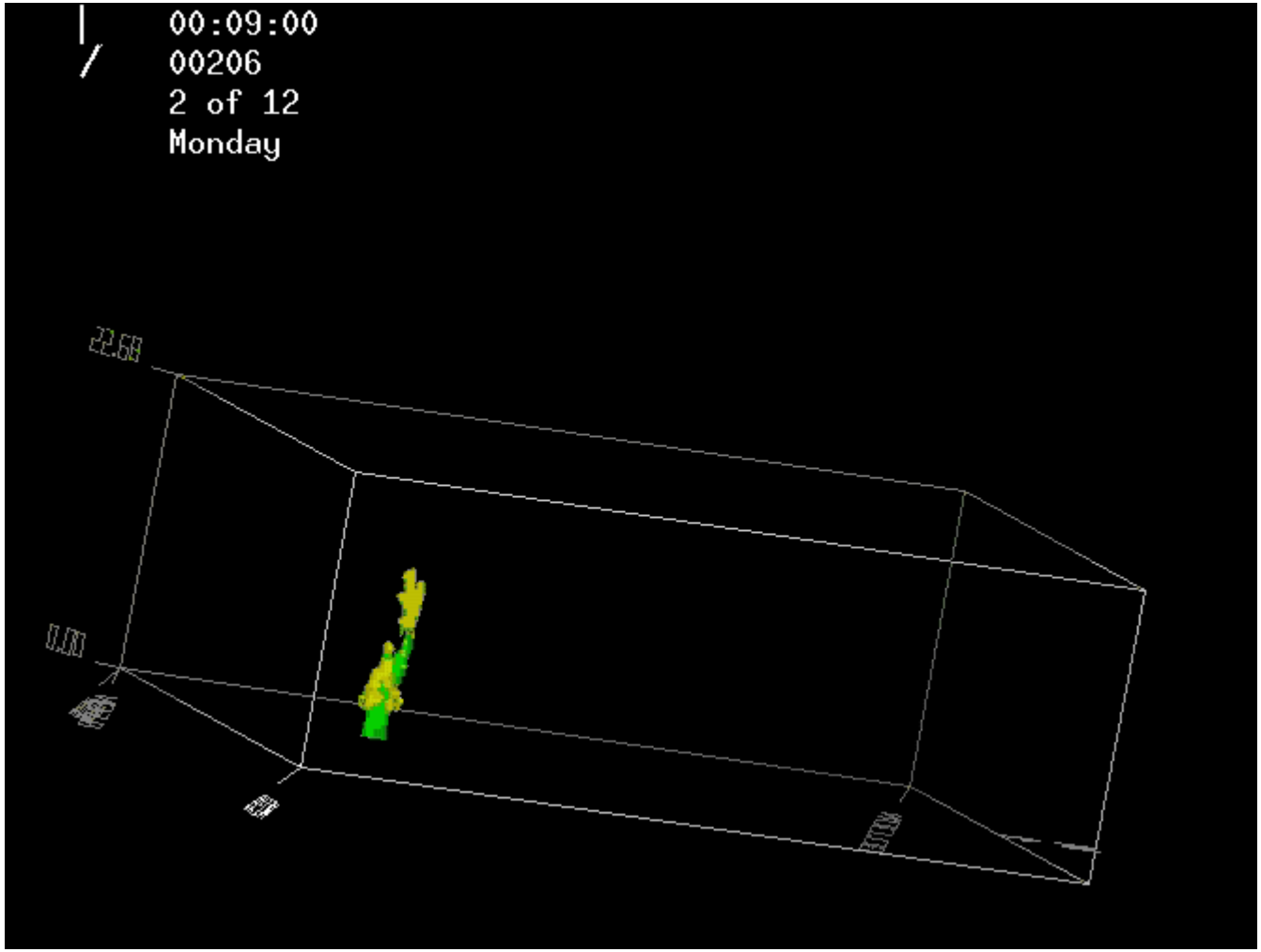
■ Numerical experiments

	Condensation-freezing/deposition	Immersion freezing	Homogeneous freezing
Koop	Meyers et al. (1992)	Vali (1975)	Koop et al. (2000)
Heym	Meyers et al. (1992)	Vali (1975)	Heymsfield and Miloshevich (1993)
Bigg	Meyers et al. (1992)	Bigg (1953)	
All_FREEZ	Meyers et al. (1992)	Vali (1975)	ALL_FREEZ

✦ For ice nucleation, only homogenous freezing is allowed at T < -36 ^{0}C.

Case 0206



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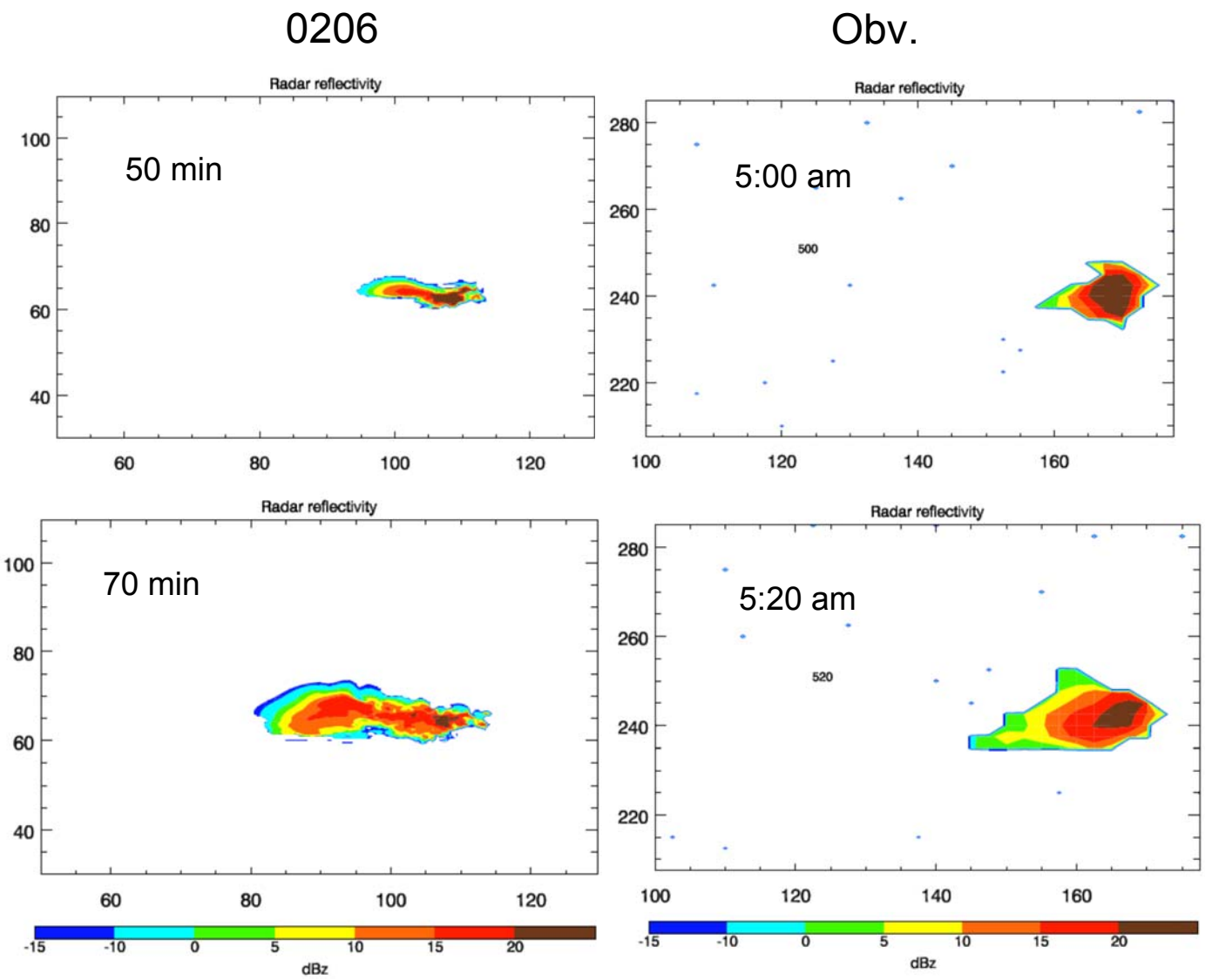
C-POL radar reflectivity at 10 km



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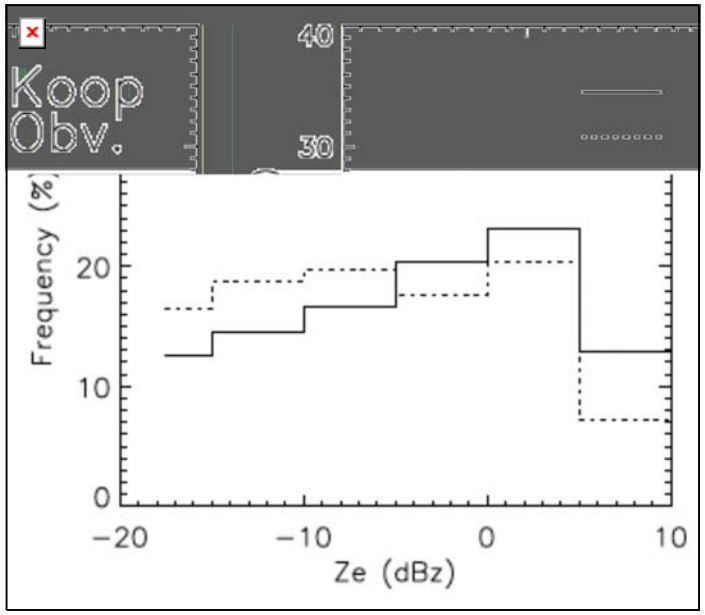
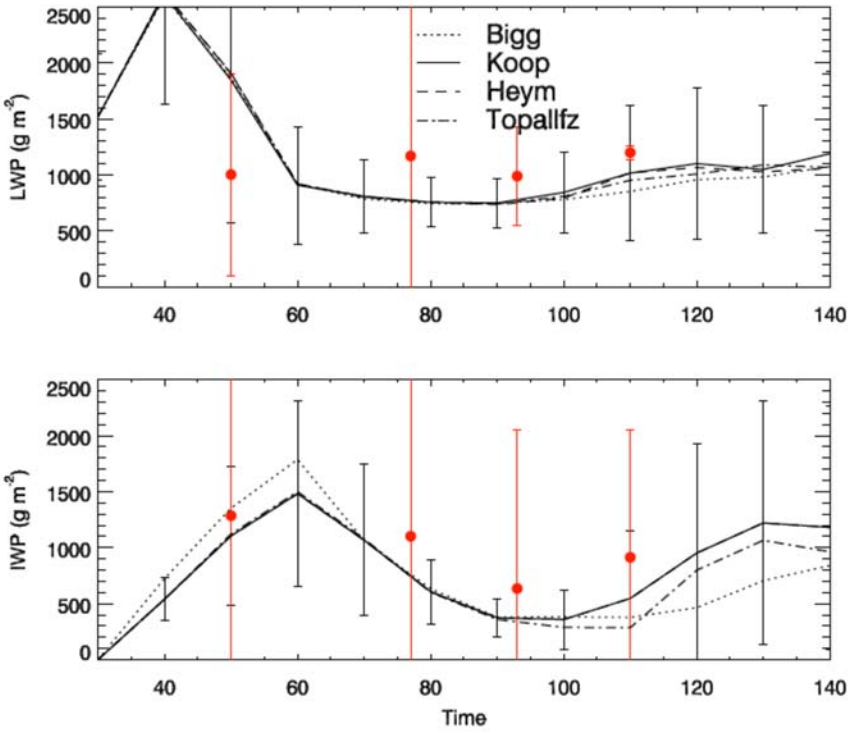
Twin Otter cloud radar (94 GHz) VISST satellite observations





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Anvil properties

Defining anvil

- Developed stage (90-140 min for 0206; 70-140 min for 1116)
- cloud base > 6 km (excluding core area; *Frederick and Achumacher, 2008*)
- Radar reflectivity < 15 dBz (excluding stratiform precipitation regions)

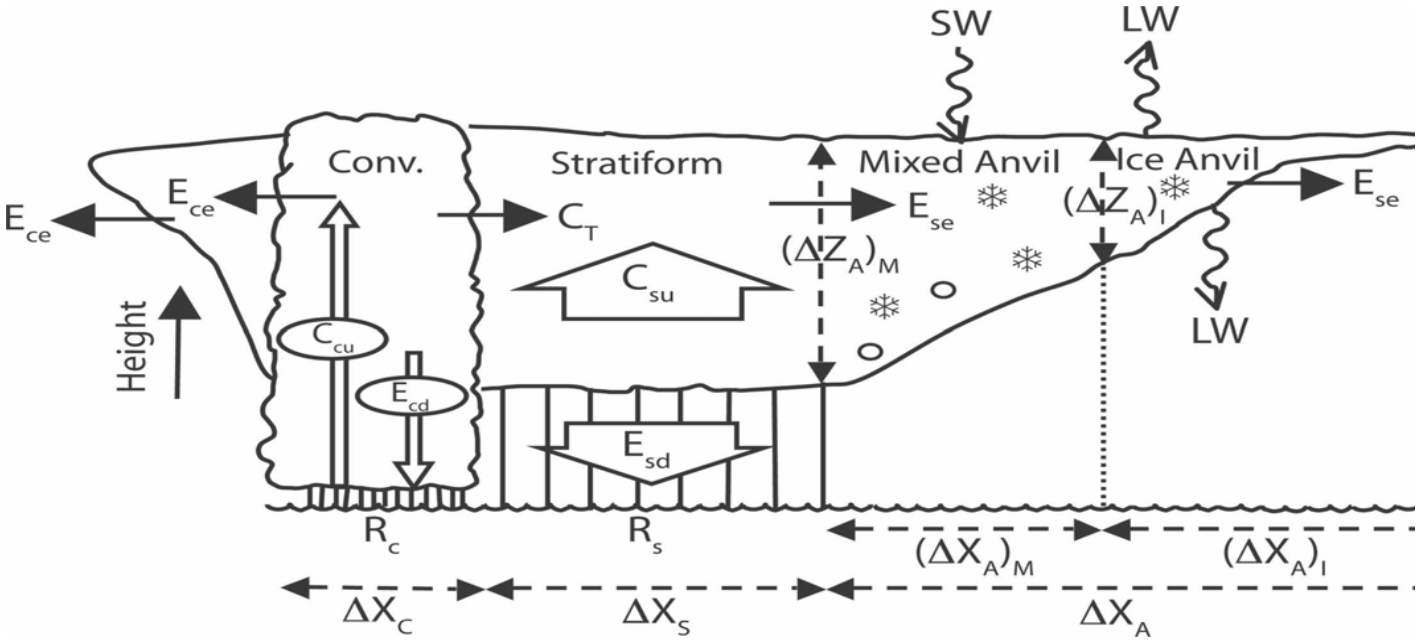

Image from Frederick and Achumacher, 2008

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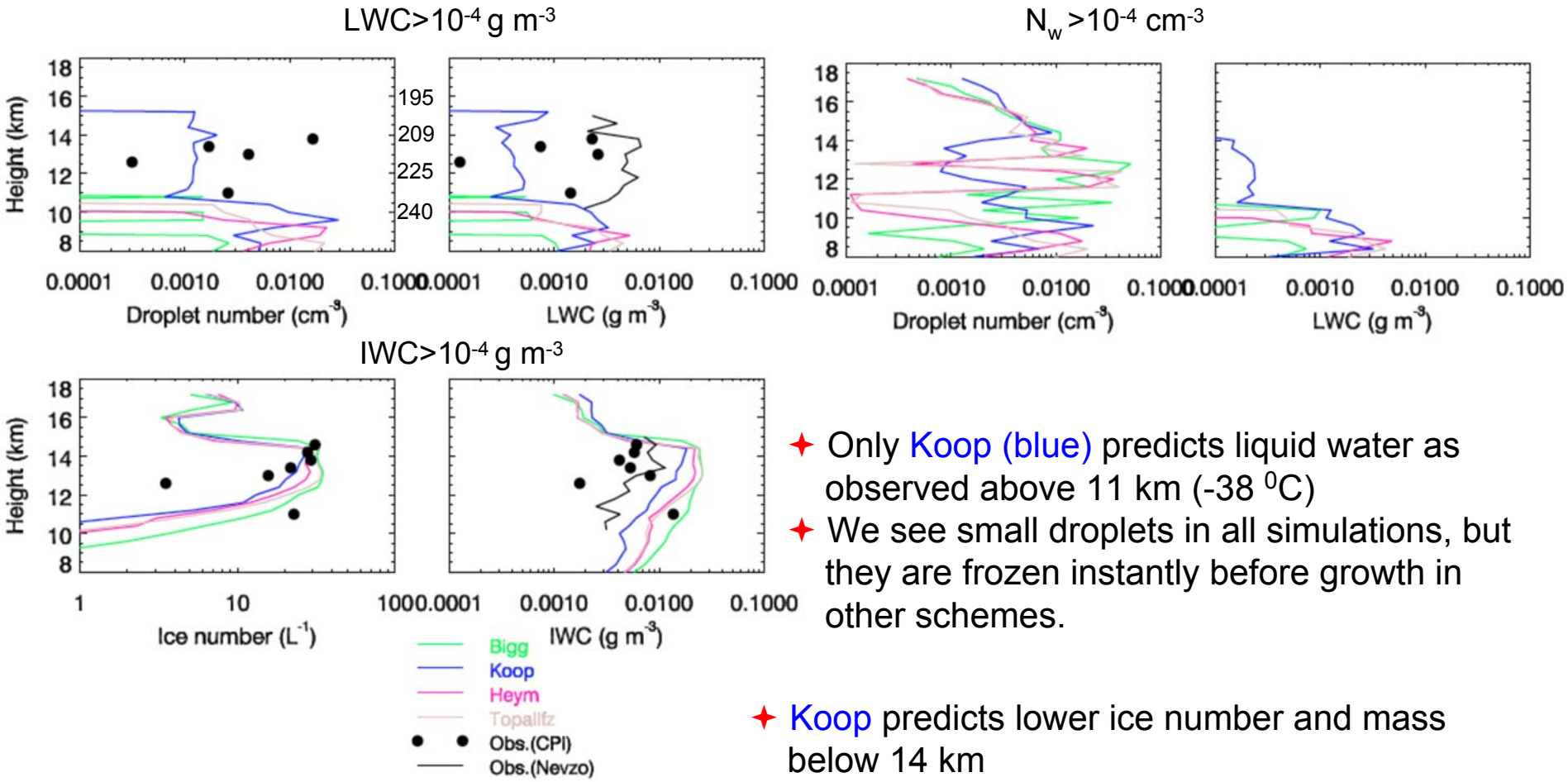
■ Liquid and ice



- Only Koop (blue) predicts liquid water as observed above 11 km (-38 ^{0}C)
- We see small droplets in all simulations, but they are frozen instantly before growth in other schemes.

- Koop predicts lower ice number and mass below 14 km
- Bigg (green) predicts the highest ice number and mass

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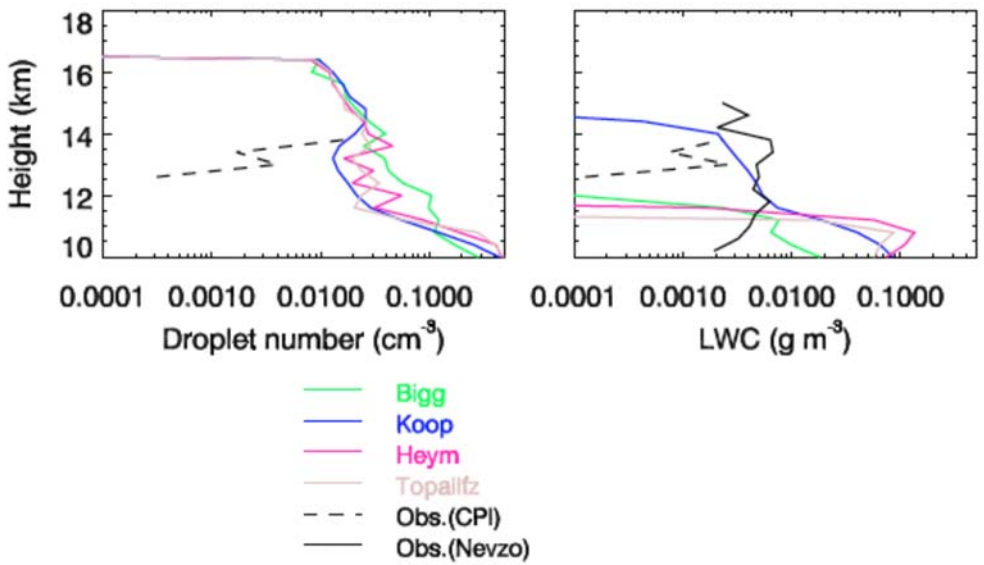
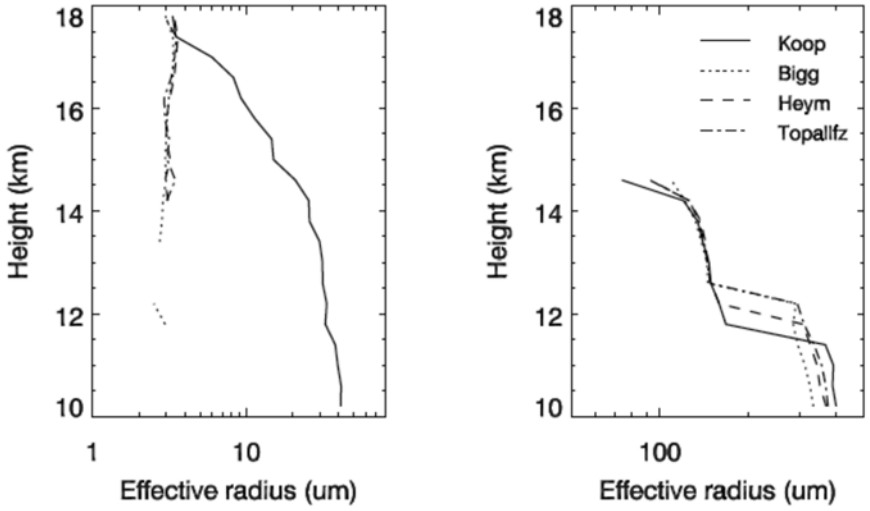
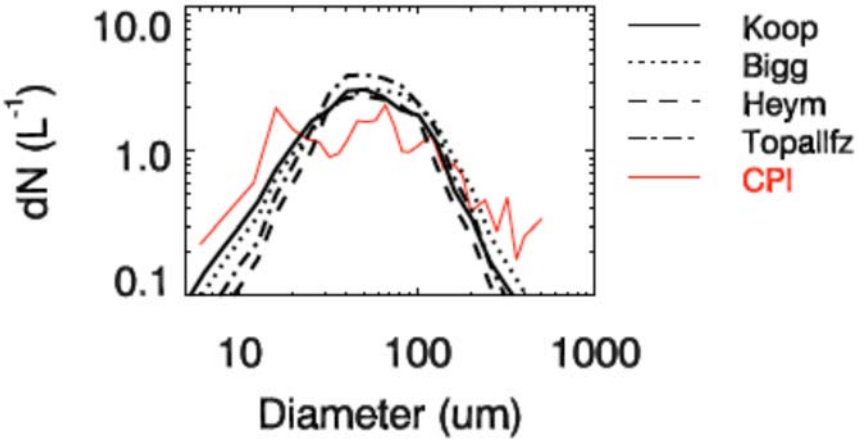
$N_w > 10^{-4}$ cm^{-3}



- Average over all cloudy grids, still no mixed-phase clouds from other simus except Koop.

Particle size





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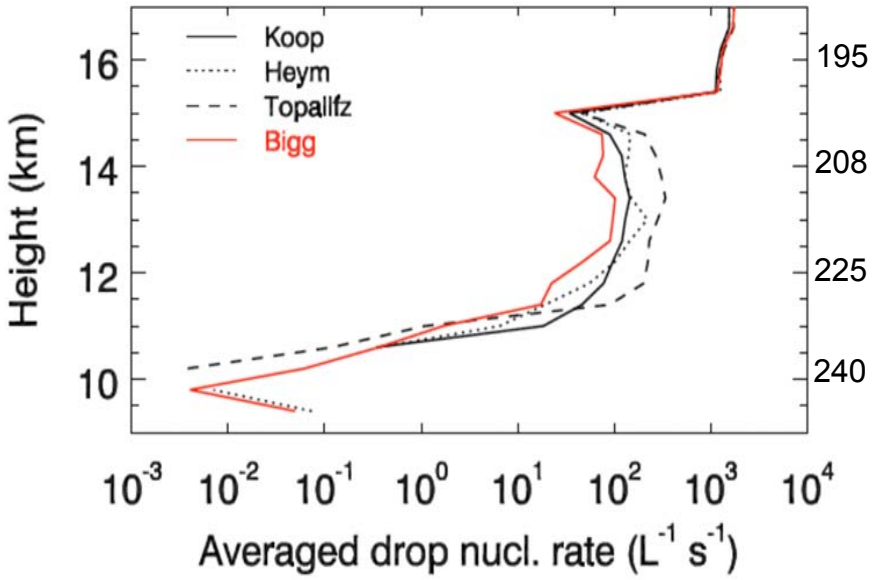
Droplet nucleation



- Significant droplet nucleation rate is seen in the anvils from all simulations, implying that droplets are mostly formed there. Koop scheme has lower freezing, allowing some droplets have time to grow and form mixed anvil.

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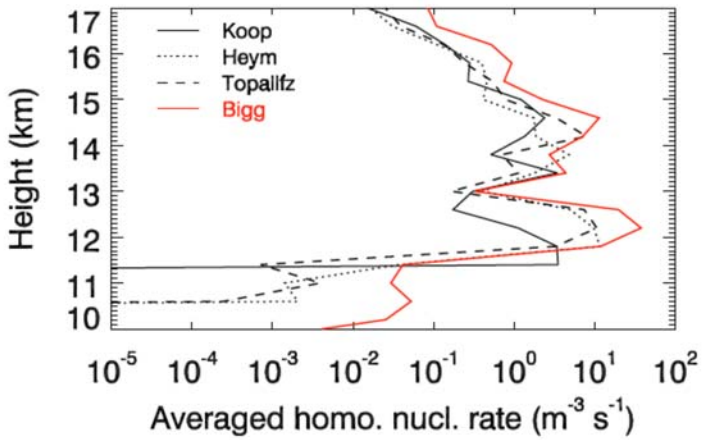

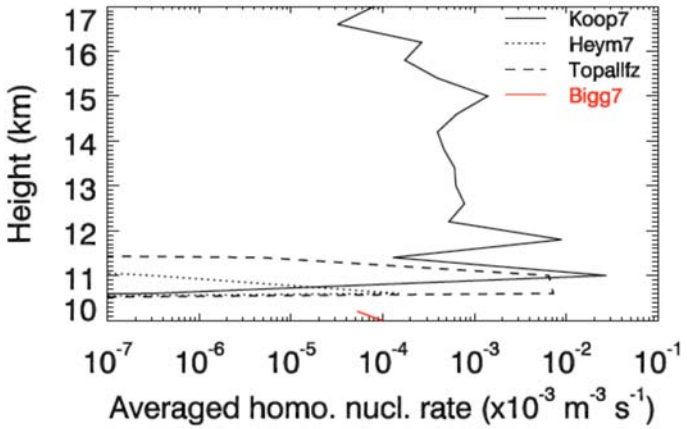

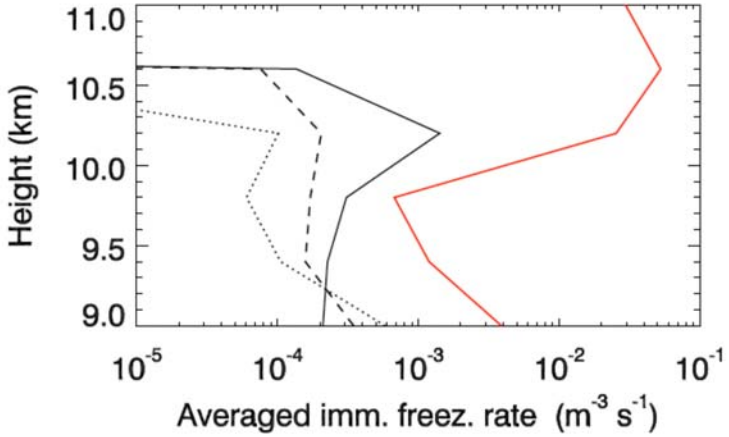

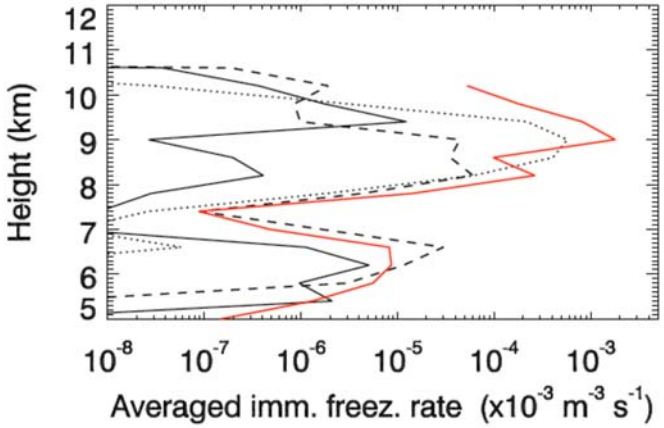

- Generally, **Koop (solid)** predicts lower freezing rate (2 times lower) than Heym and Topallfz. Bigg (red) predicts the highest rate, resulting in the highest ice number and mass.
- We do not see significant competition between homo and immersion freezing (because droplets are mainly formed locally (not transported from lower levels).
- In the cases without any droplet nucleation above 10 km, significant competition between homo freezing and immersion freezing.

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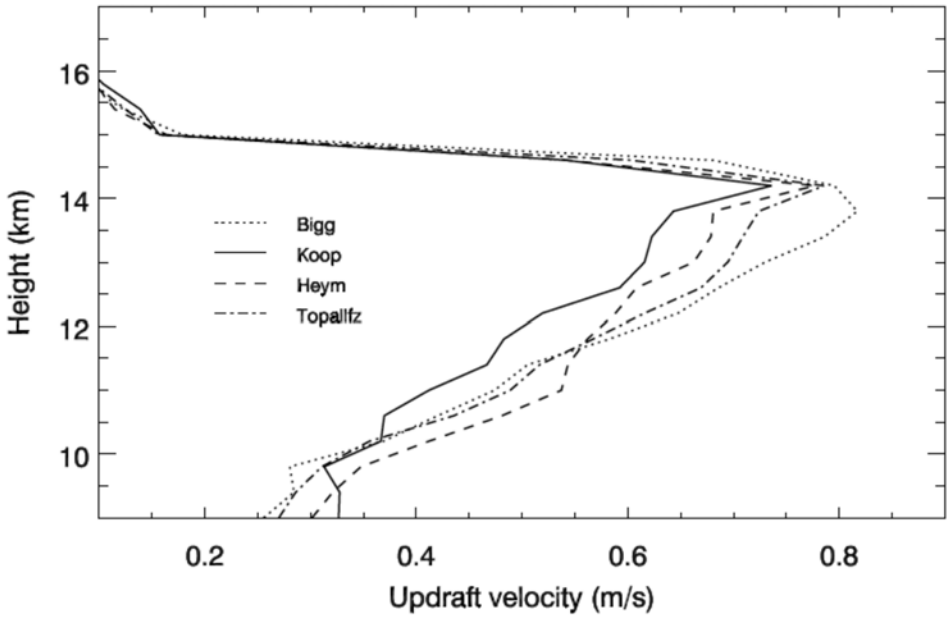
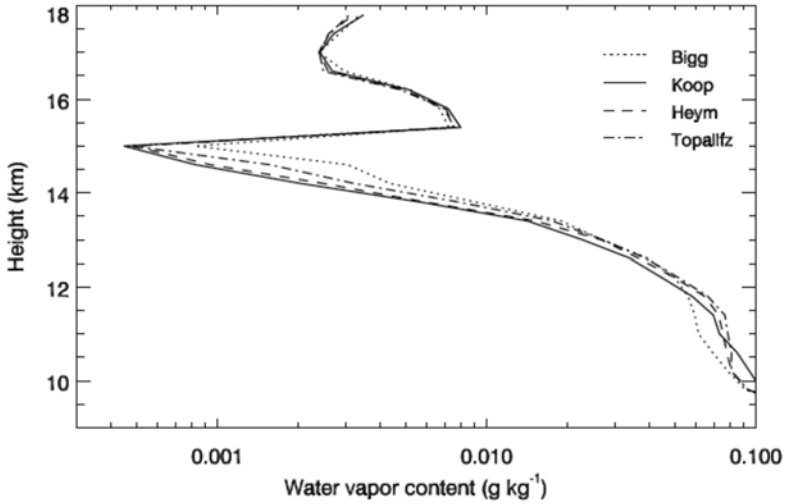
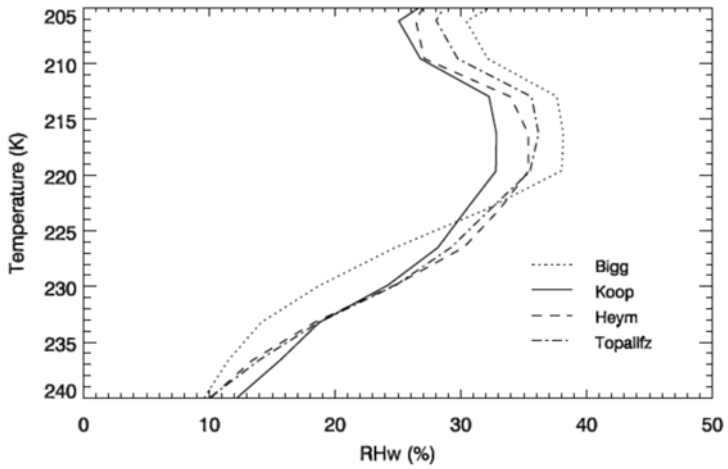
Anvil convection

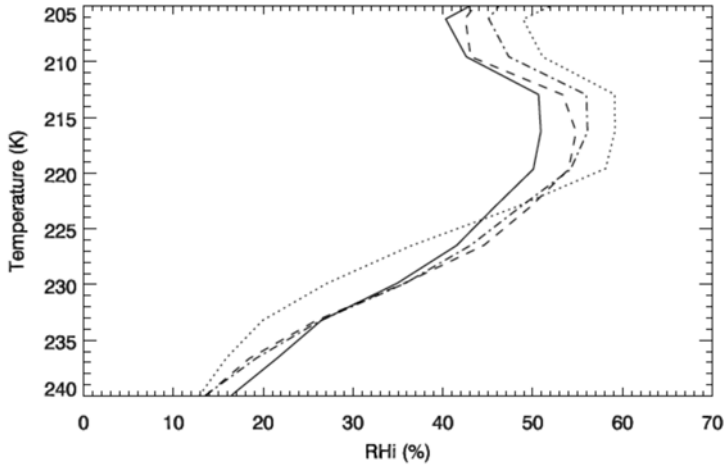


- Bigg (dotted) predicts the strongest anvil convection, resulting from larger latent heat release due to higher freezing rate.
- Koop (solid) predicts the weakest convection because of lower freezing rate.

Water vapor







- The differences in water vapor are small but significant in SS.
- Koop predicts the lowest SS and Bigg predicts the highest SS at the upper levels (> 12 km), corresponding to weakest and strongest convections.

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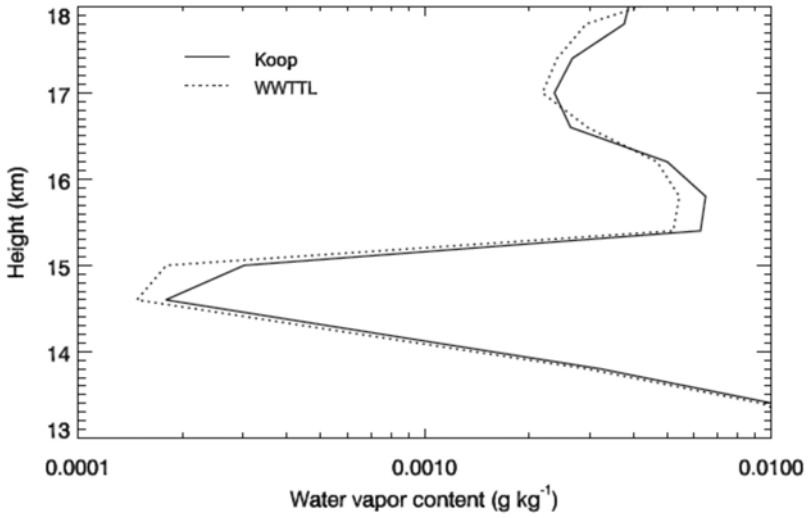

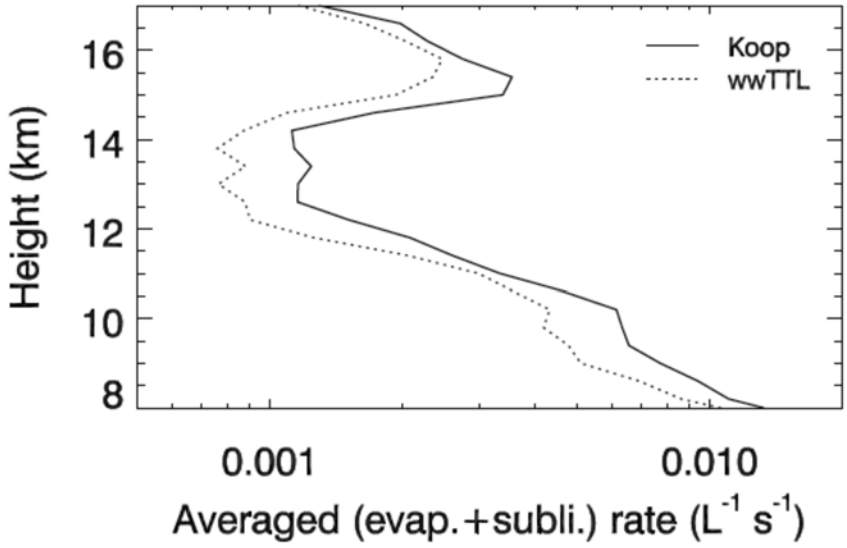

- Weaker horizontal wind speed above 10 km predicts much less water vapor mixing ratio (up to 60% less), due to much weaker evaporation and sublimation rate.

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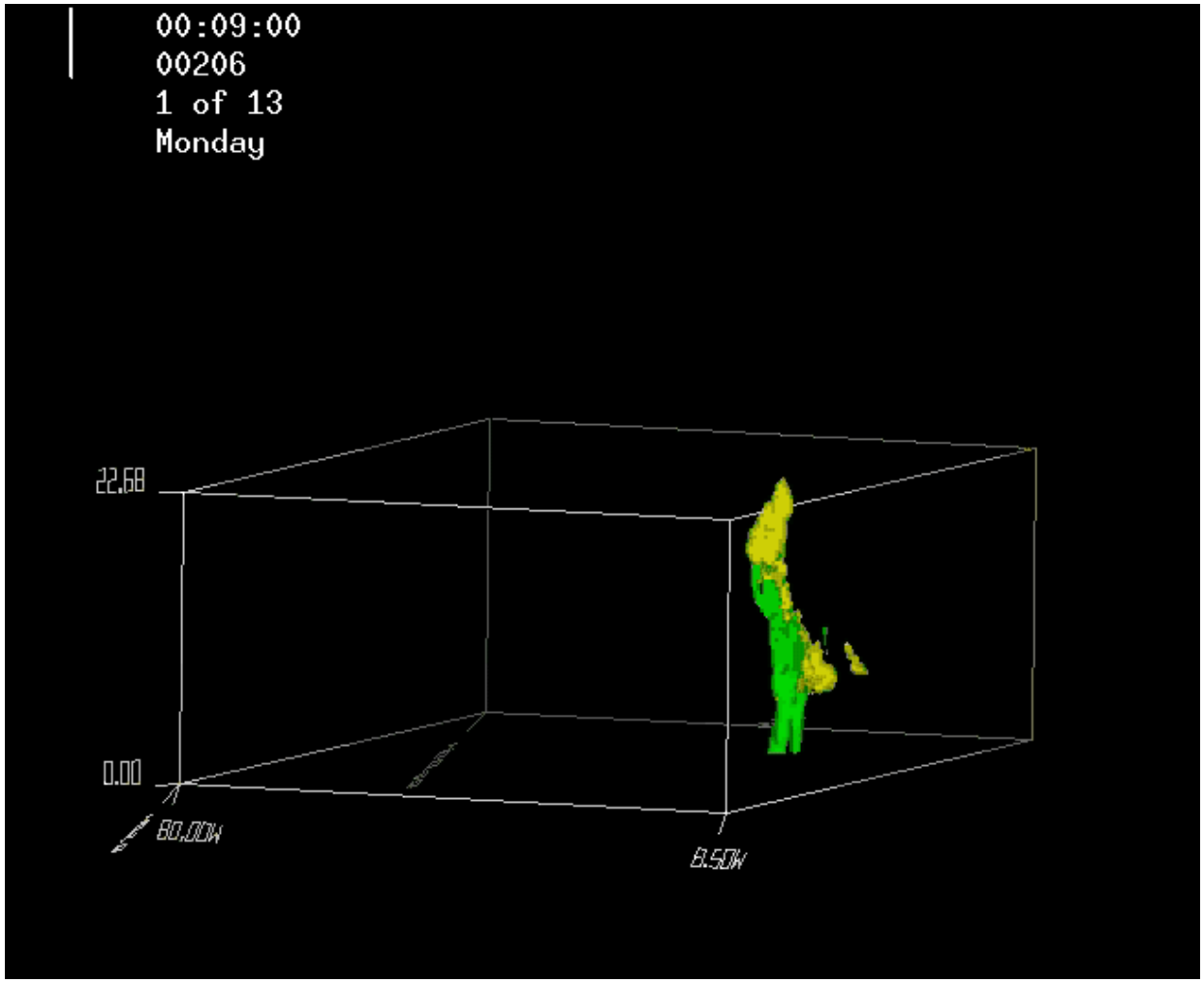
Case 1116



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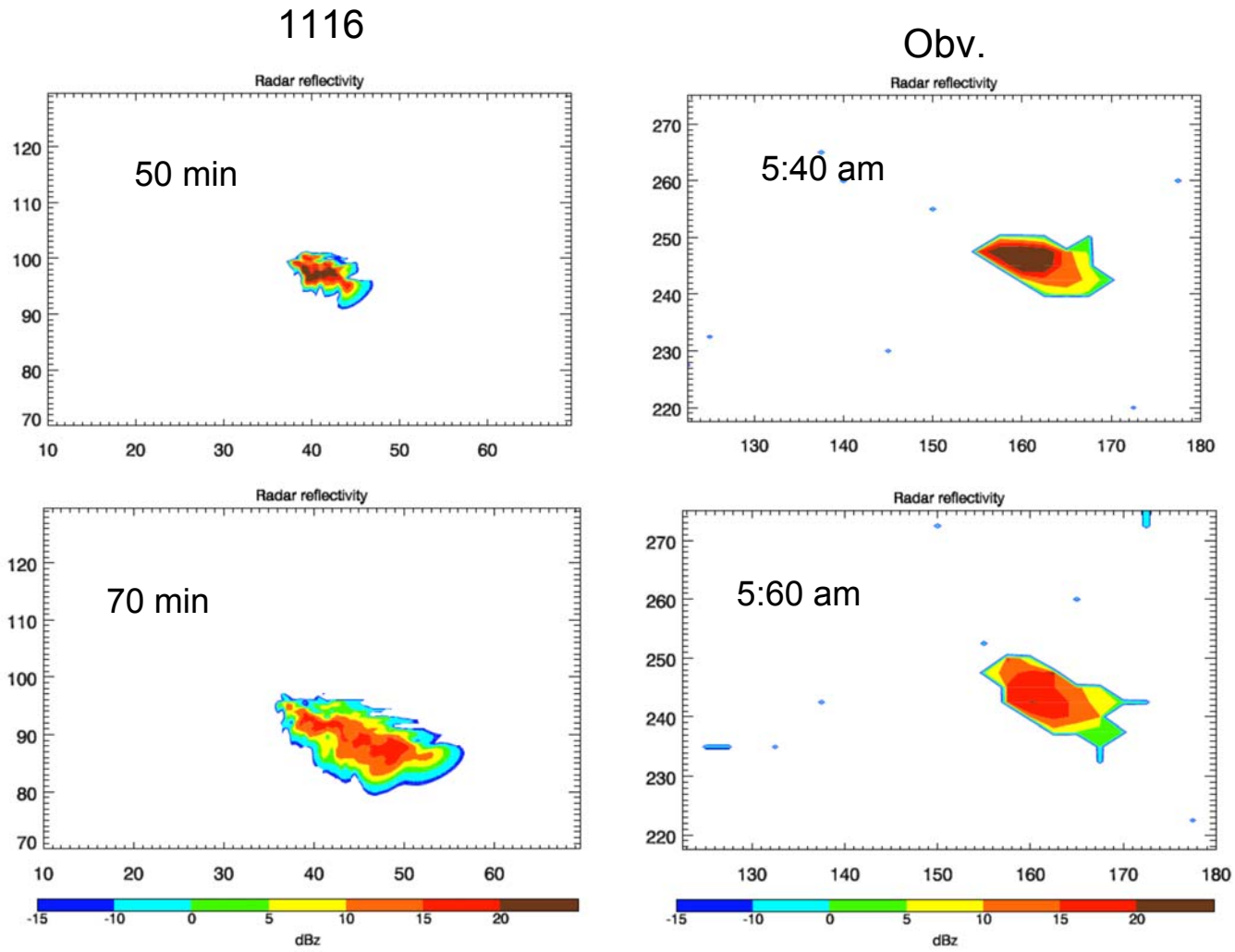
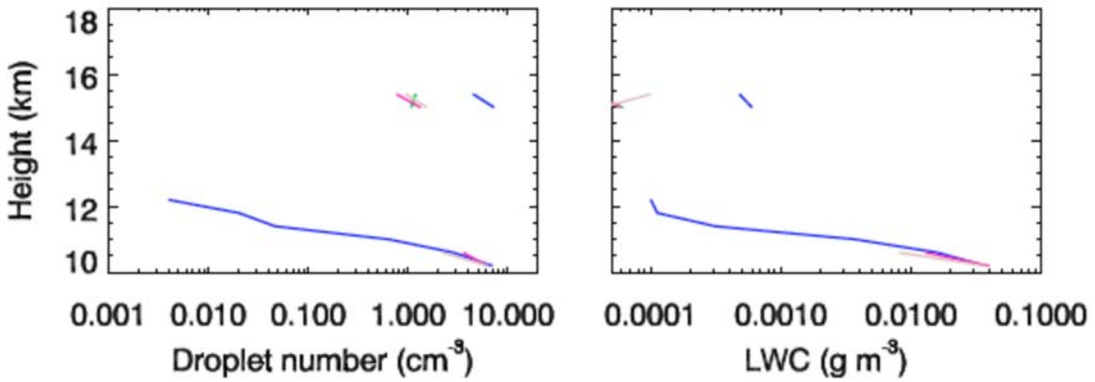
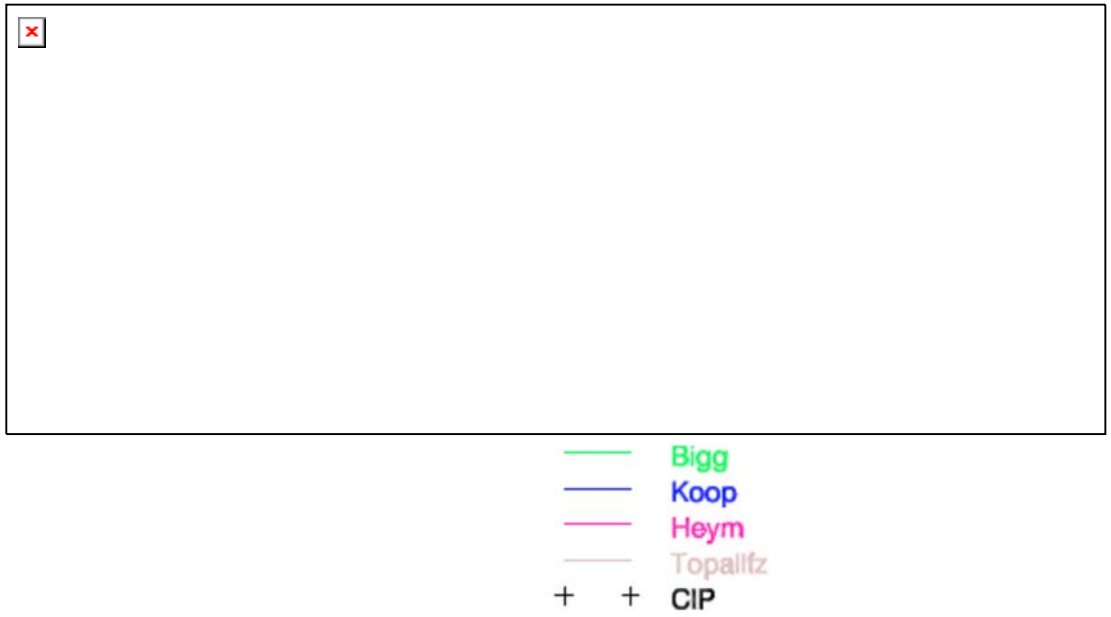
C-POL radar reflectivity at 10 km



■ Liquid and ice





- Only Koop (blue) predicts the liquid water above homogeneous level.
- No much cloud between 13-15 km because the clouds below and above drift away in the opposite direction.

- To compare with CIP measurements, only ice particles with d> 100 um are included for model results. Koop (blue) predicts lower ice number and mass, similar to the TWP-ICE case.

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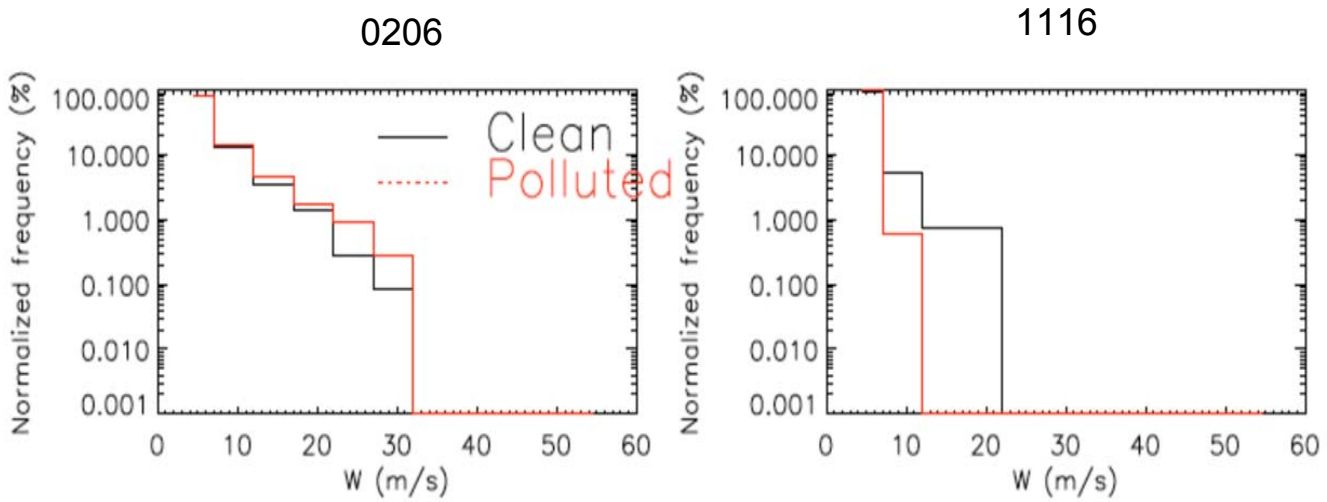
Conclusion

- Only Koop parameterization can predicts mixed anvils at homo freezing levels. Liquid water is not able to form by Heymsfield and Bigg schemes. Heymsfield parameterization predicts similar ice nucleation and anvil properties with the simulation in which all droplets are assumed to freeze instantly.
- Koop parameterization predicts weaker anvil convection, lower supersaturation, larger droplet size and smaller ice particle size, and lower ice number and mass concentrations which agree better with observations.
- No significant competition between immersion and homo freezing in the case that significant droplet nucleation occurs at homo freezing level.
- TTL wind speeds is an important factor to affect water vapor mixing ratio in TTL

Futhure Work

- Aerosol effects on the deep convections in both cases



Acknowledgements

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