Impact of Heterogeneous and Homogeneous Freezing Parameterizations on Tropical Anvil Characteristics and Water Vapor Content of the TTL

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OBJECTIVES

- Look into the effects of the commonly used heterogeneous and homogeneous freezing parameterizations on anvil properties and water vapor content in the TTL for the deep convective clouds developed in the contrasting environments.
- Examine the impact of the immersion-freezing on homogeneous freezing process.

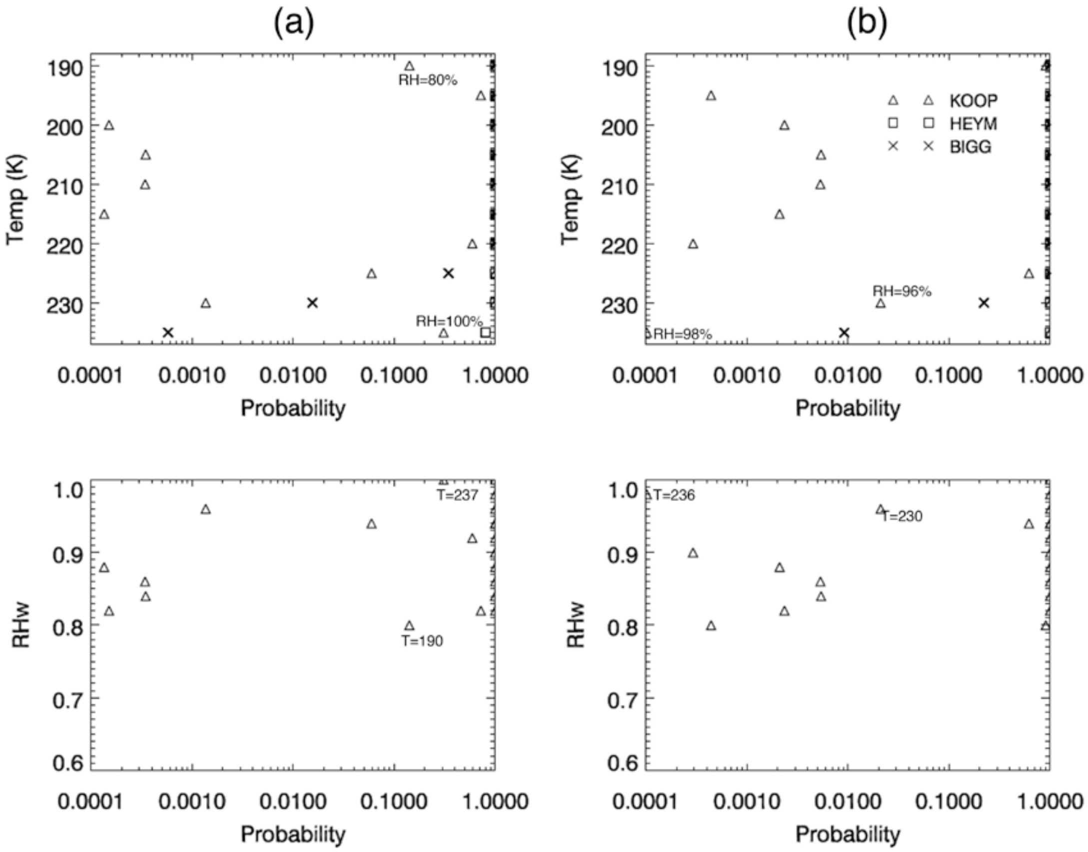
Homogeneous freezing parameterizations (HFPs)

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 T. Depression of freezing point due to solute and curvature effects is considered but those effects only significant when droplets are less than 1-2 um.
3) Bigg (1953): J_r depends on T. Serve as immersion-freezing at relatively warmer temperatures.
4) TOPFZ (Khain et al. 2004): Assume all droplets freeze instantly at the homogeneous freezing level.

Immersion-freezing parameterizations

1) Bigg (1953): J_r depends on T. Notorious for it's high nucleation rates.
2) Vali (1975): much lower temperature dependence of active immersion IN relative to Bigg (1953).

For 4 µm droplets For 10 µm droplets

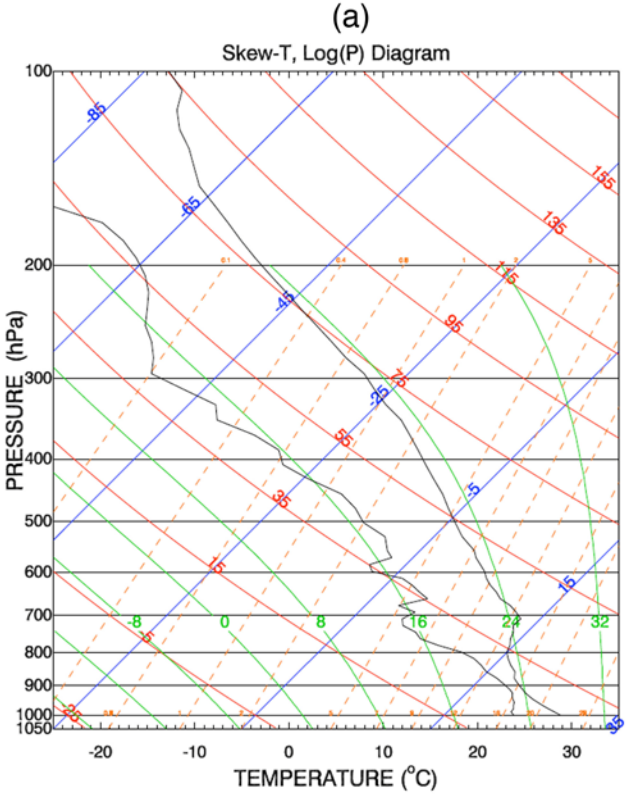


- ✦ KOOP and BIGG have very low freezing probability at relatively warmer *T*.
- ✦ KOOP has very low freezing probability at RH < 100%.

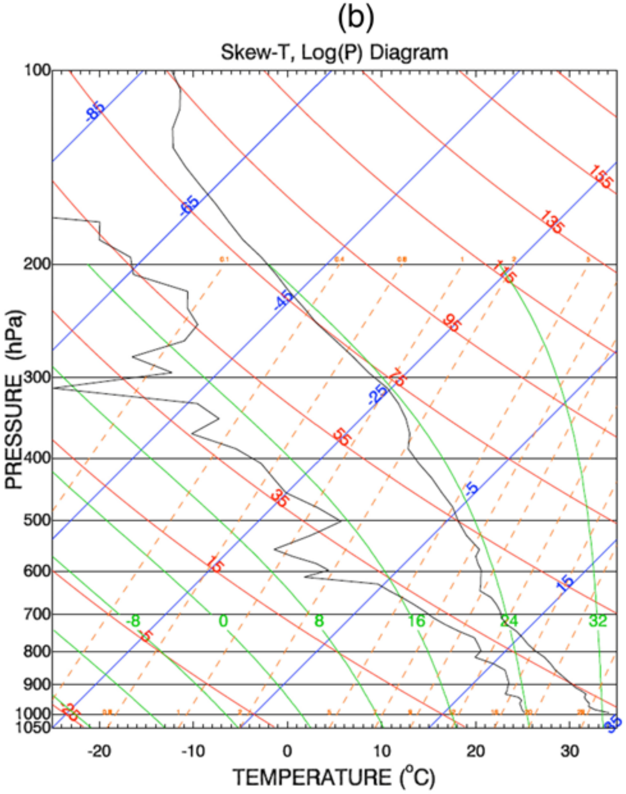
STUDIED CASES

- **TWP-ICE Case FEB06**: Clean and humid, with N_{ccn} of 220 cm^{-3}
- **ACTIVE Case NOV16**: Polluted and dry, with N_{ccn} of 1500 cm^{-3}

FEB06 (humid)



NOV16 (middle-level dry)



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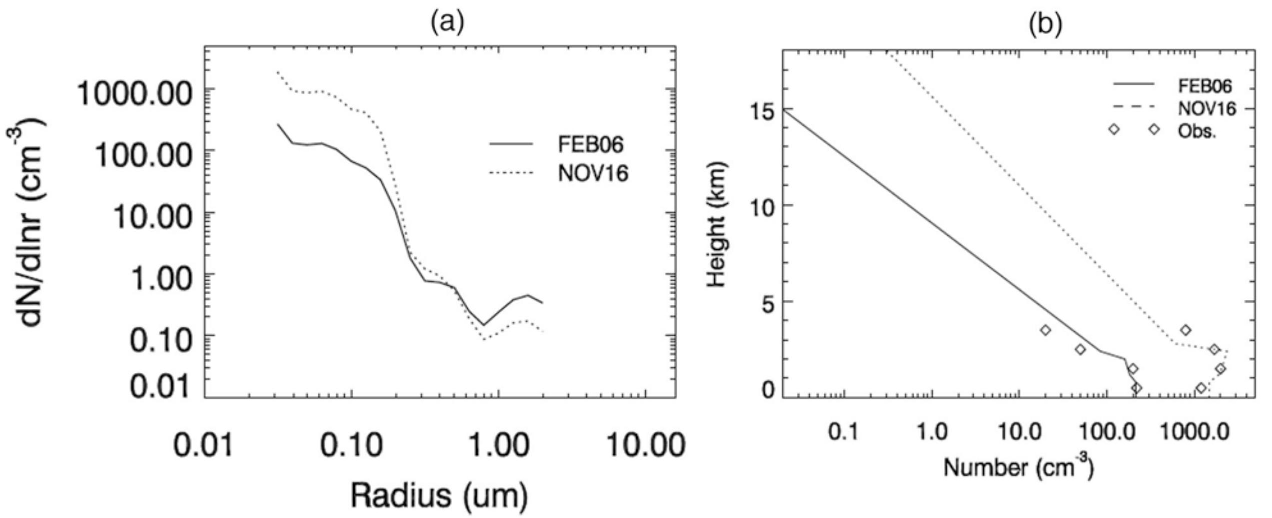
Aerosol size distribution and vertical profiles



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 compositions for biomass burning and maritime aerosols.**

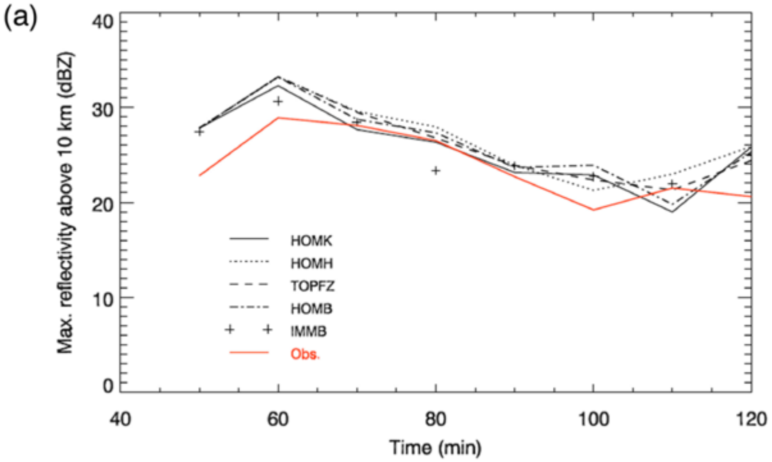
■ Numerical Experiments

Simulations	Condensation-freezing/deposition	Immersion-freezing	Homogeneous freezing
HOMK	Meyers et al. (1992)	Vali (1975)	Koop et al. (2000)
HOMH	Meyers et al. (1992)	Vali (1975)	Heymsfield and Miloshevich (1993)
TOPFZ	Meyers et al. (1992)	Vali (1975)	Freezing probability of 1.0
HOMB	Meyers et al. (1992)	Vali (1975)	Bigg (1953)
IMMB	Meyers et al. (1992)	Bigg (1953)	Bigg (1953)

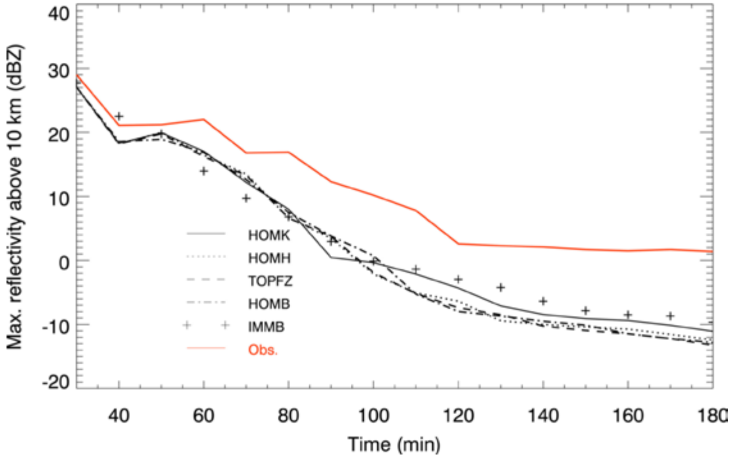
RESULTS

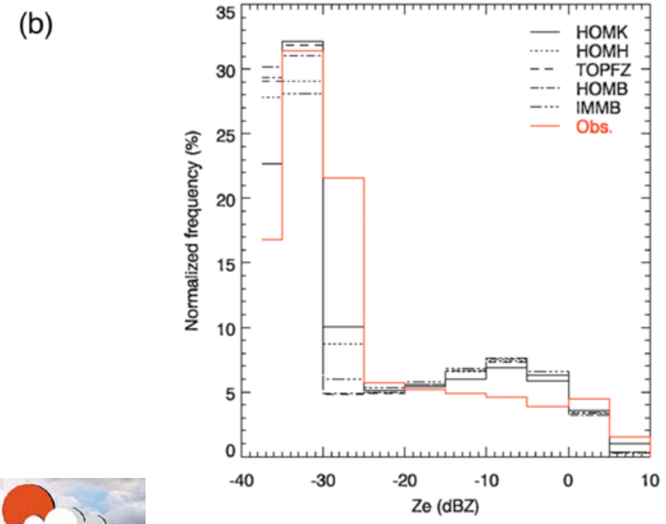
■ Compare with Radar measurements

FEB06



NOV16





- FEB06: agree with observations. The overprediction in the beginning is due to heatt bubble initialization.
  NOV16: underpredicted.
- Different HFPs do not make significantly differences, but KOOP scheme gives the results a little closer to the obs.

FEB06

$^{\$}$**Quantities**	**Obs.**	**HOMK**	**HOMH**	**TOFZ**	**HOMB**	**IMMB**
Q_c (g m^{-3})		3.60E-02	3.88E-02	3.93E-02	3.75E-02	4.27E-02
N_c (cm^{-3})		4.84	5.09	5.22	5.16	6.03
Q_r (g m^{-3})		4.09E-02	4.16E-02	4.25E-02	4.14E-02	4.12E-02
N_r (cm^{-3})		1.03E-03	1.10E-03	1.09E-03	1.01E-03	9.88E-04
Q_i (g m^{-3})		2.17E-02	2.22E-02	2.27E-02	2.19E-02	2.56E-02
N_i (L^{-1})		49.55	49.39	51.44	49.11	56.34
Q_{pi} (g m^{-3})		5.27E-02	4.71E-02	4.93E-02	4.81E-02	5.82E-02
N_{pi} (L^{-1})		1.35	1.27	1.30	**1.24**	**4.08**
Precipitation (mm)	2.57	2.62	2.63	2.63	**2.63**	**2.76**
LWP (g m^{-2})	1000.89	799.67	799.42	798.29	798.343	803.09
IWP (g m^{-2})	900.5	690.13	699.59	695.13	696.818	774.26
*Updraft velocity (m s^{-1})		4.59	4.60	4.59	**4.59**	**4.76**
$^{*}r_{ei}$ (μm)		430.26	420.73	418.14	**415.71**	**348.01**
Imm. freez. rate (m^{-3}s^{-1})		3.19E-03	3.20E-03	3.21E-03	**3.40E-03**	**9.9E-02**
Hom. freez. rate (m^{-3}s^{-1})		0.46	0.57	0.57	**0.64**	**0.85**

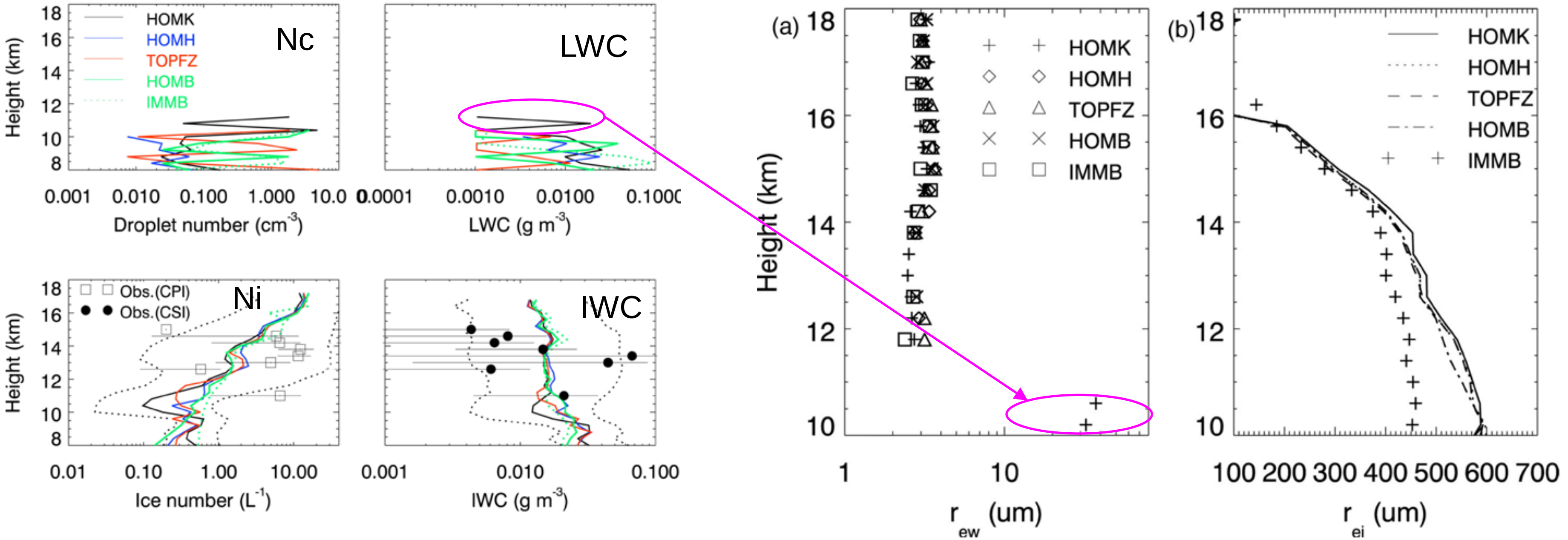
NOV16

$^{\$}$Quantities	**Obs.**	**HOMK**	**HOMH**	**TOFZ**	**HOMB**	**IMMB**
Q_c (g m^{-3})		1.13E-02	1.10E-02	1.09E-02	1.08E-02	1.01E-02
N_c (cm^{-3})		12.76	12.46	12.31	12.11	11.84
Q_r (g m^{-3})		7.71E-03	7.56E-03	7.52E-03	7.41E-03	6.56E-03
N_r (cm^{-3})		7.36E-05	7.21E-05	7.18E-05	7.05E-05	6.02E-05
Q_i (g m^{-3})		3.65E-03	4.05E-03	4.10E-03	4.02E-03	4.95E-03
N_i (L^{-1})		60.28	104.94	114.48	100.43	102.35
Q_{pi} (g m^{-3})		2.10E-03	2.34E-03	2.33E-03	2.32E-03	2.83E-03
N_{pi} (L^{-1})		0.13	0.19	0.20	**0.22**	**0.55**
Precipitation (mm)	0.24	0.26	0.26	0.26	**0.27**	**0.30**
LWP (g m^{-2})	1878	1882.00	1781.00	1805.00	1820.00	1800.40
IWP (g m^{-2})	1929	1843.00	1894.00	1854.00	1914.00	2034.00
*Updraft velocity (m s^{-1})		4.46	4.46	4.47	**4.49**	**4.66**
$^{*}r_{ei}$ (μm)		359.53	338.21	339.71	**281.61**	**265.18**
*Anvil lifetime (min)		170	160	160	**170**	**190**
Imm. freez. rate (m^{-3}s^{-1})		1.36E-03	1.32E-03	1.33E-03	**1.35E-03**	**1.72E-02**
Hom. freez. rate (m^{-3}s^{-1})		3.58	6.02	6.19	**6.1**	**7.81**

Anvil Microphysical Properties

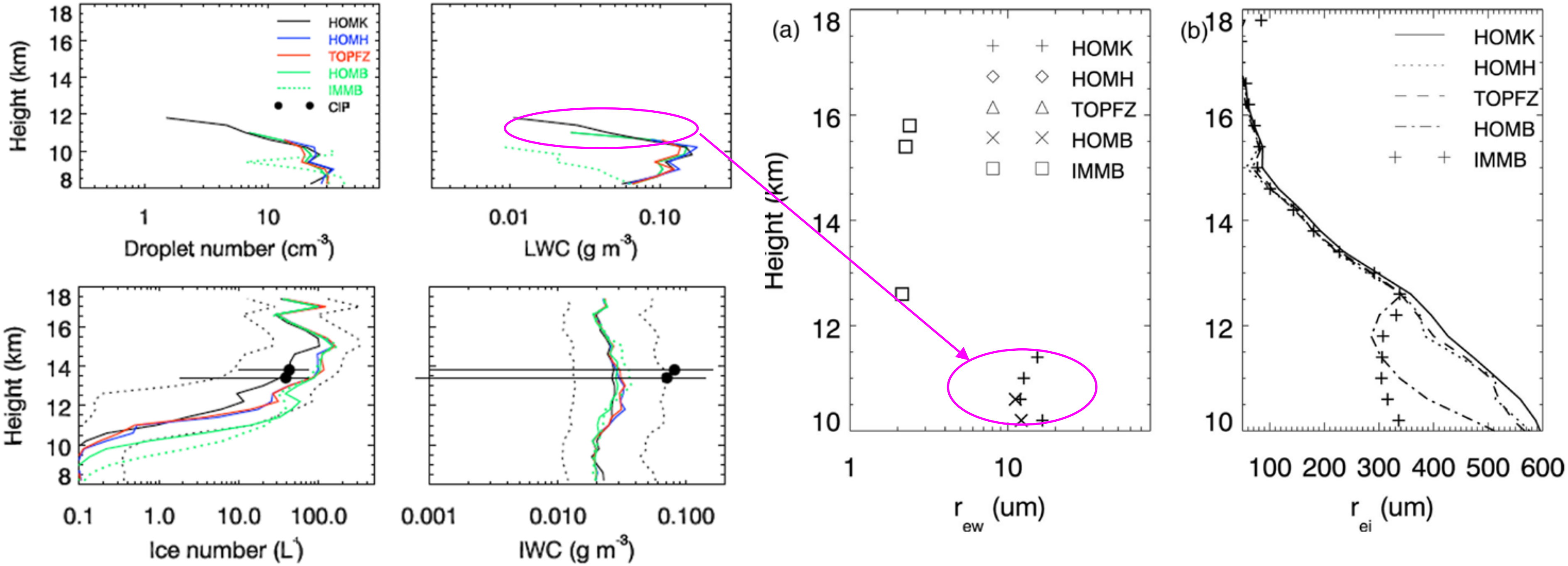
FEB06

Effective radius for droplet and ice



- The observed average ice mass and number fall in the interquatile range of the modeled values.
- KOOP predicts about 2 times lower N_i and Q_i at relatively warmer T (-36 to -40 ^{0}C). BIGG predicts the highest values.
- Cloud liquid exists up to 11 km (~ -39 ^{0}C) with KOOP , while liquid only exists below 10.2 km (~ -33 ^{0}C) with other schemes.
- At low RH, droplets which do not freeze instantly could be transported and grow to form about 30 um droplets.
- Averagely, r_{ei} is about 10 and 25 µm larger with KOOP than those with HEYM and BIGG, respectively. r_{ei} is reduced by up to 150 µm with BIGG IFP.

NOV16

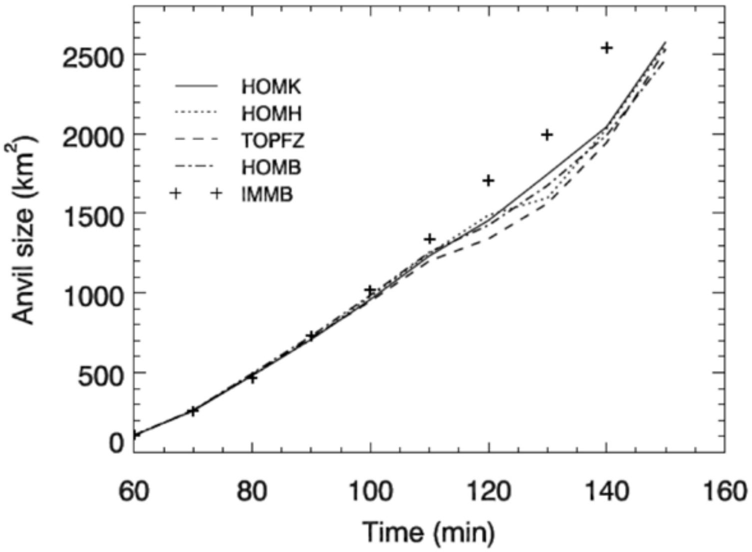


- HEYM and BIGG predict significantly higher N_i than KOOP in the polluted dry case.
- LWC is dramatically lower with BIGG IFP and no liquid above 10 km.
- Cloud liquid exists at higher levels with both KOOP and BIGG, because they have very low nucleation rate for small droplets at T> -45 ^{0}C.

- r_{ei} changes more significantly in this polluted dry case.

■ Anvil size and lifetime

FEB16



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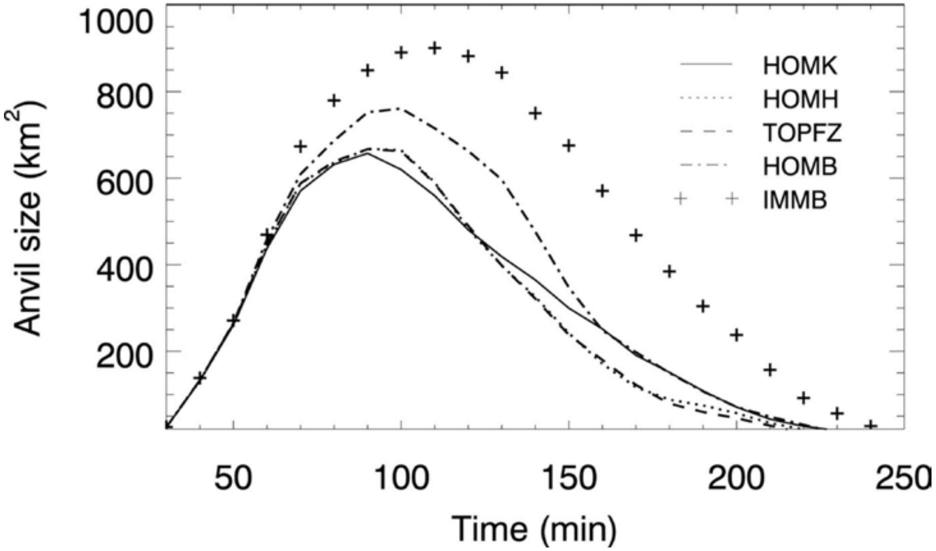
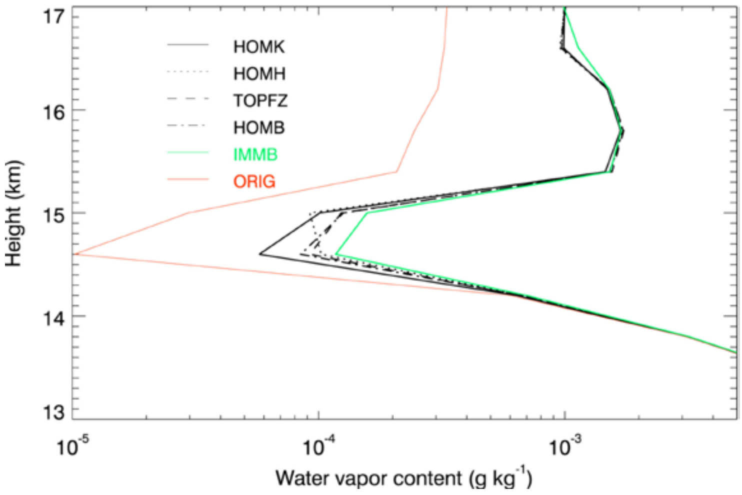
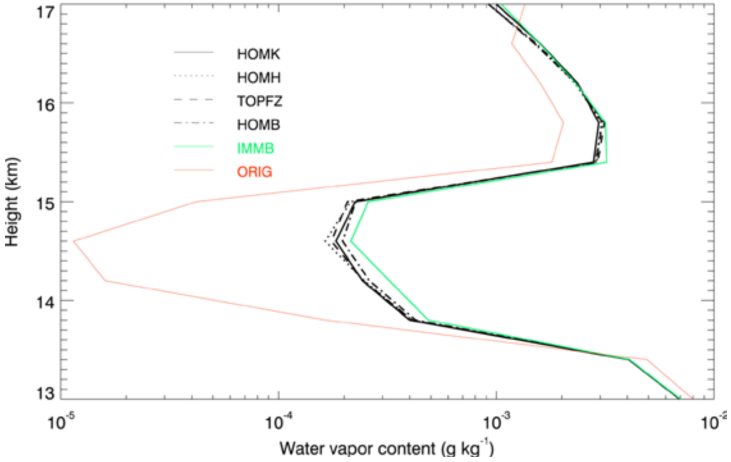


- The changes on anvil size are much more significant in the polluted dry case.
- Anvil evolution is different: smaller ice particles in HOMH, TOPFZ and HOMB result in a faster decrease in the anvil size. The anvil size in HOMK is up to 60% larger after 2-hr later.
- BIGG IFP predicts much larger anvil size and longer lifetime because of much stronger convection due to larger latent heat from droplet freezing.

■ TTL water vapor content (WVC)


FEB16


NOV16

- ✦ The deep convections moisturize the air in the TTL by one order of magnitude at 14-15 km in both cases. However, the moisturizing effect in the polluted dry case is much less than that in the humid case above 15 km.
- ✦ WVC is also more sensitive to HFPS in the humid environment, with 35% lower for KOOP.

CONCLUSIONS

- **Higher immersion-freezing rate results in much stronger convection, much larger anvil size and longer lifetime, and higher WVC in the TTL; homogeneous freezing rates are enhanced by over 20%.**
- **Anvil size and anvil microphysical properties such as ice number concentration and ice particle size are much more sensitive to the homogeneous freezing parameterization (HFP) under the polluted dry condition, while anvil convection and water vapor content of the TTL are more sensitive under the clean humid condition.**
- **Deep convections moisturize the air in the TTL by one order of magnitude at 14-15 km where strongest anvil convections occur in both cases. WVC in the TTL is more sensitive to the HFP in the humid air (about 35% lower for the KOOP scheme).**

Acknowledgements

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