A Model Look at Heterogeneous Ice Nucleation on Mineral Dust

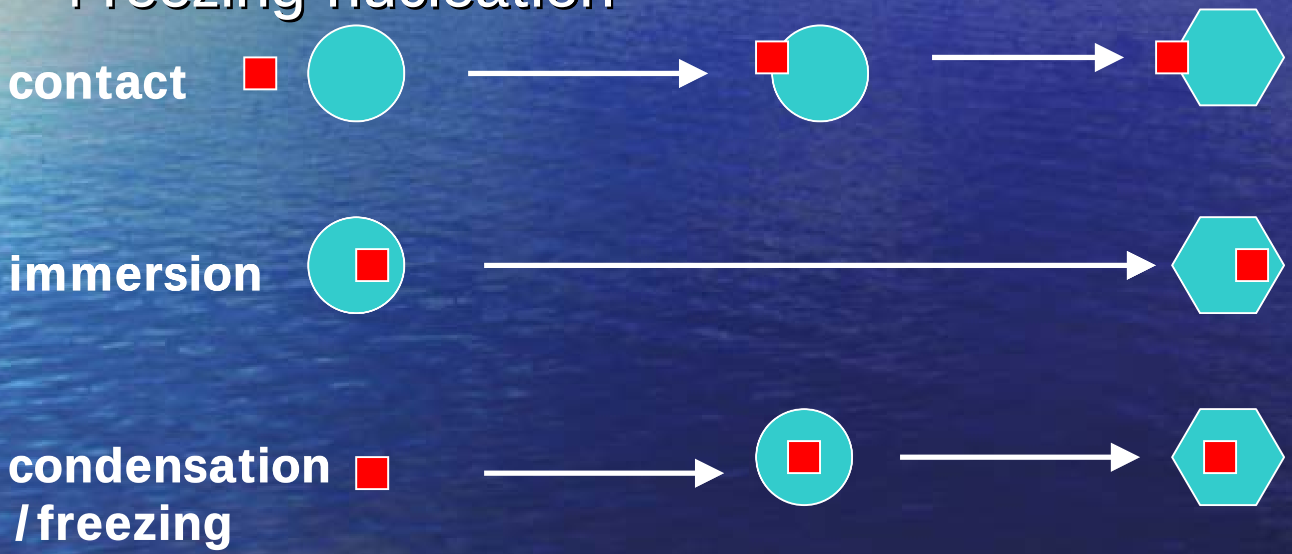
Xiaohong Liu

University of Michigan

Heterogeneous ice nucleation mechanisms

- Deposition nucleation (deposition nuclei)

- Freezing nucleation

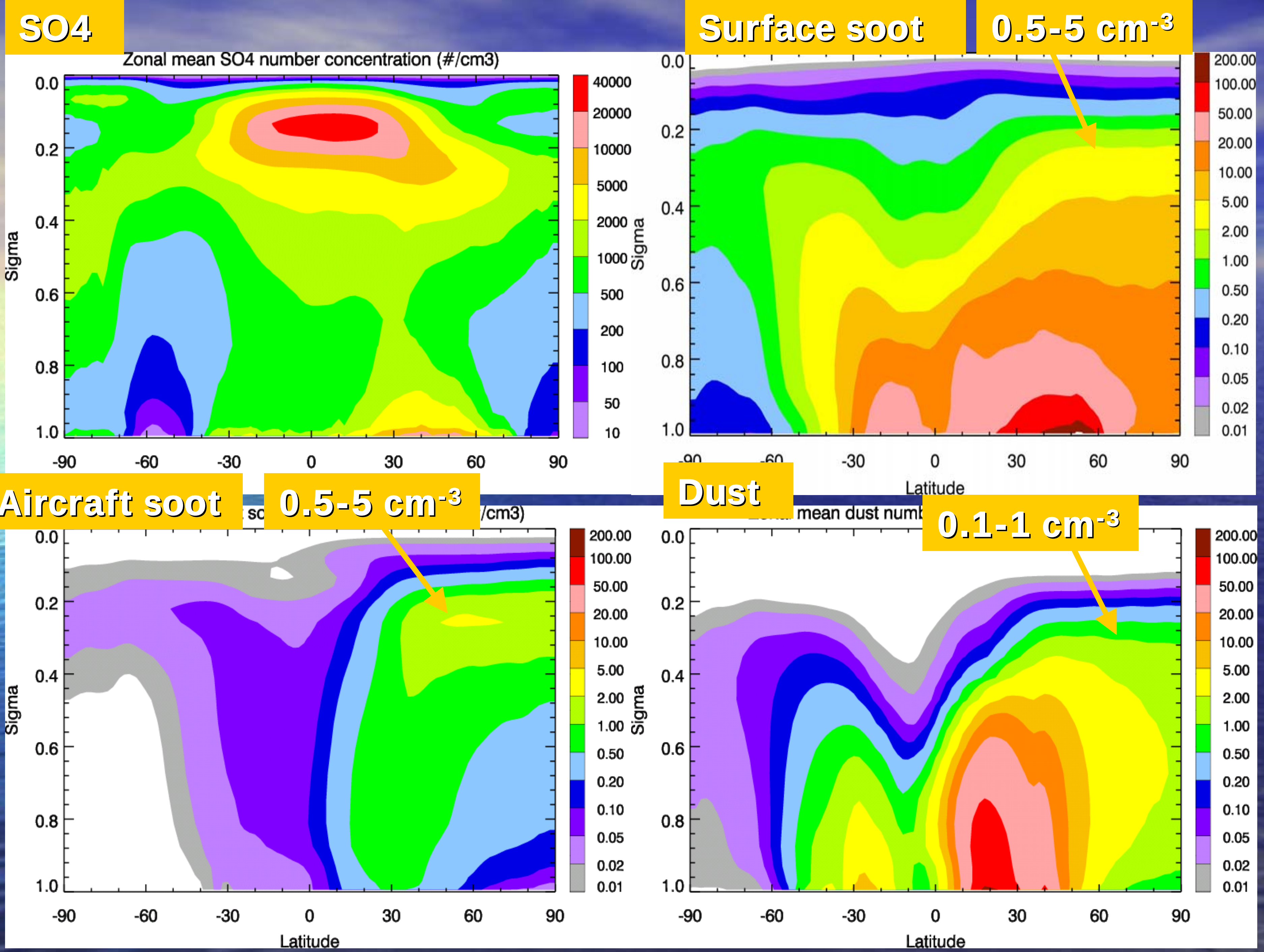


- Two important mechanisms for upper tropospheric cirrus:

  immersion and deposition nucleation
- Potential effective ice nuclei:
  - soot particles

    (DeMott et al., 1999; *Ström and Ohlsson*, 1998; Chen et al., 1998)
  - mineral dust

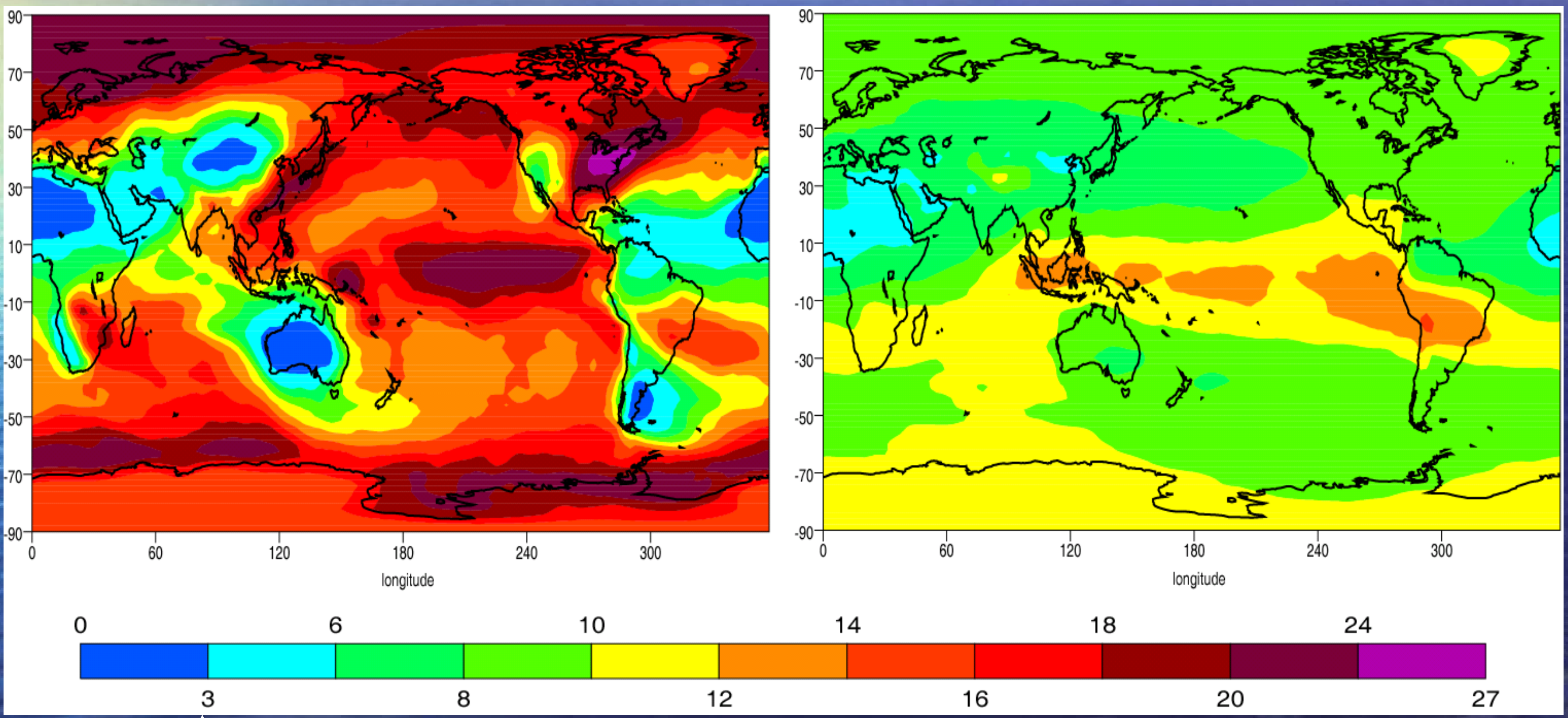
    (Chen et al., 1998; DeMott et al., 2003; Sassen et al., 2003; Zuberi et al., 2002; Hung et al., 2003)



SO4
Zonal mean SO4 number concentration (#/cm3)
Surface soot
0.5-5 cm-3
Aircraft soot
0.5-5 cm-3
/cm3)
Dust
mean dust numb
0.1-1 cm-3
Sigma
Latitude
0.0
0.2
0.4
0.6
0.8
1.0
-90
-60
-30
0
30
60
90
40000
20000
10000
5000
2000
1000
500
200
100
50
10
200.00
100.00
50.00
20.00
10.00
5.00
2.00
1.00
0.50
0.20
0.10
0.05
0.02
0.01

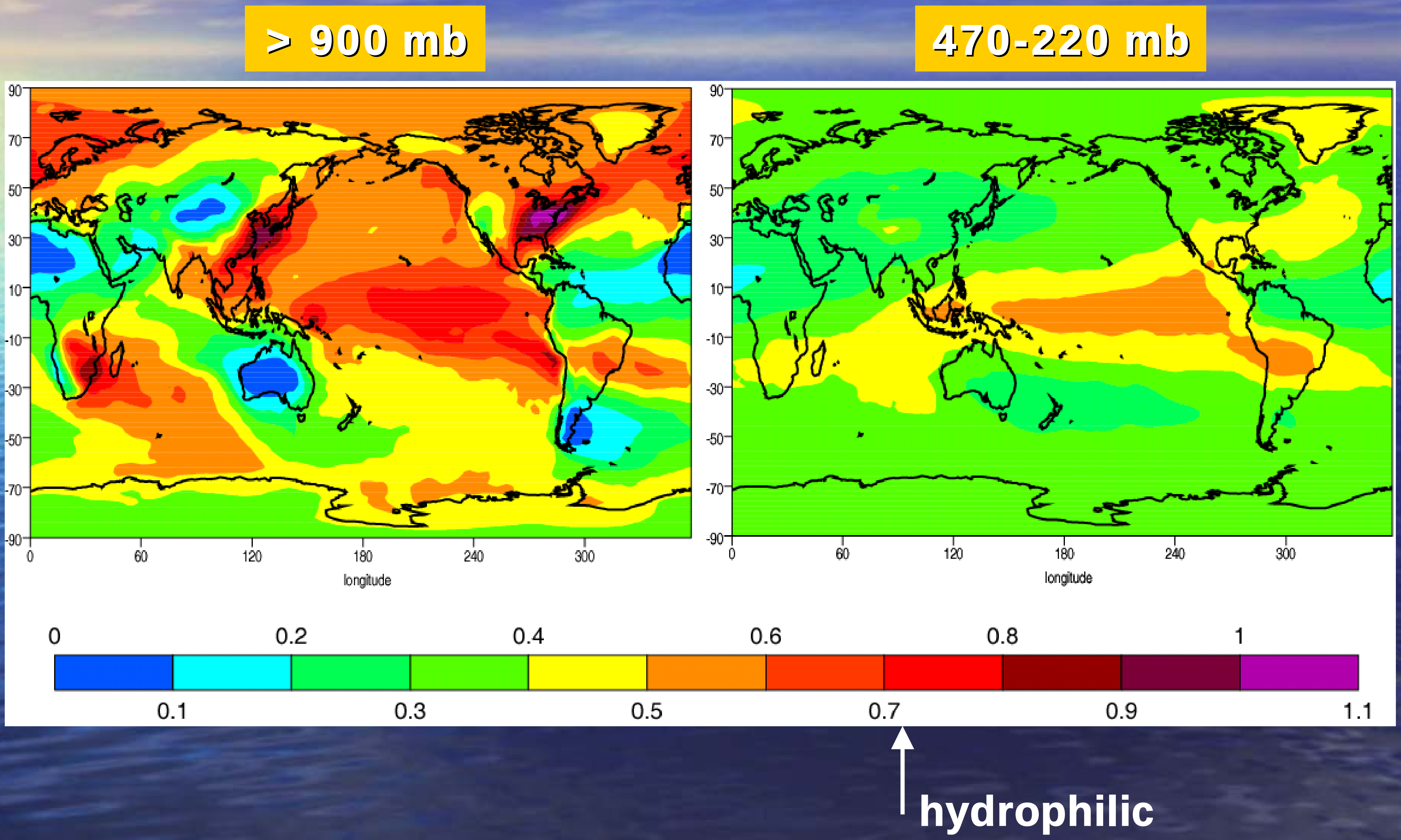
Mass fraction (%) of SO4 on dust bin 1 (0.05-0.6 um radius)

> 900 mb **470-220 mb**



hydrophilic

Mass fraction (%) of SO4 on dust bin 2 (0.6-1.2 um radius)



Adiabatic parcel model to study immersion nucleation on mineral dust

- Include ice nucleation and initial growth of ice crystals in a constant updraft
- Thermodynamics of sulfate aerosol: Kohler equation
- Parcel cooling rate:

$$\frac{dT}{dt} = -\frac{g}{C_p} w + \dot{Q}_{LH},$$

- Deposition growth rate of ice crystal: Pruppacher and Klett (1997)

- Homogeneous freezing of sulfate based on effective freezing temperature (T_{eff}) approach (Sassen and Dodd, 1988)

- Immersion nucleation on mineral dust based on
  - Classical theory (Pruppacher and Klett, 1997). The ice nucleation rate per particle is

$$J'_S = \frac{4\pi r_N^2 kT}{h} c_{1,S} \exp\left[-\frac{\Delta F_{act}}{kT} - \frac{\Delta F_{g,S}}{kT}\right]$$

wettability parameter $m_{i,s}$ (= cos θ) ??

- Zuberi et al. (2002)'s Lab measurements: The difference in heterogeneous and homogeneous freezing temperature for ice in $(NH_4)_2SO_4$-H_2O particles with kaolinite (mineral dust) immersions remains constant at 7 K. The effective freezing temperature is

$$T_{eff} = T + \lambda \Delta T_m - 7.0$$

so that

$$J_{haze} = J_w(T_{eff})$$

$m_{i,s} = -0.2 \sim 0.0$

for immersion nucleation on dust

variable $m_{i,s}$ with temperature??

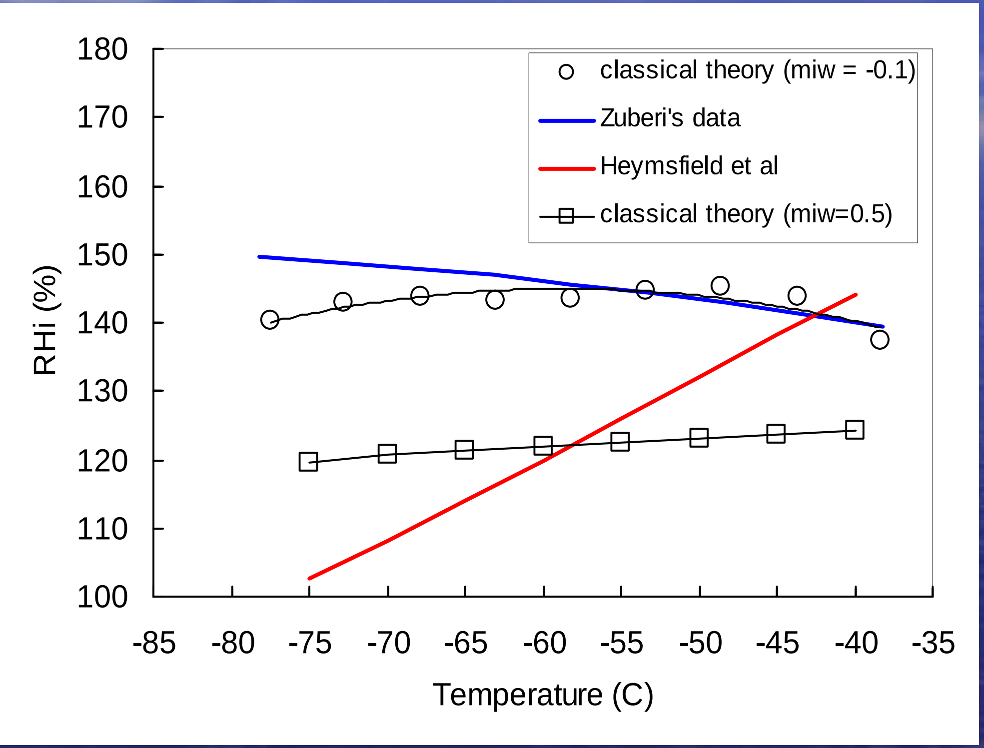
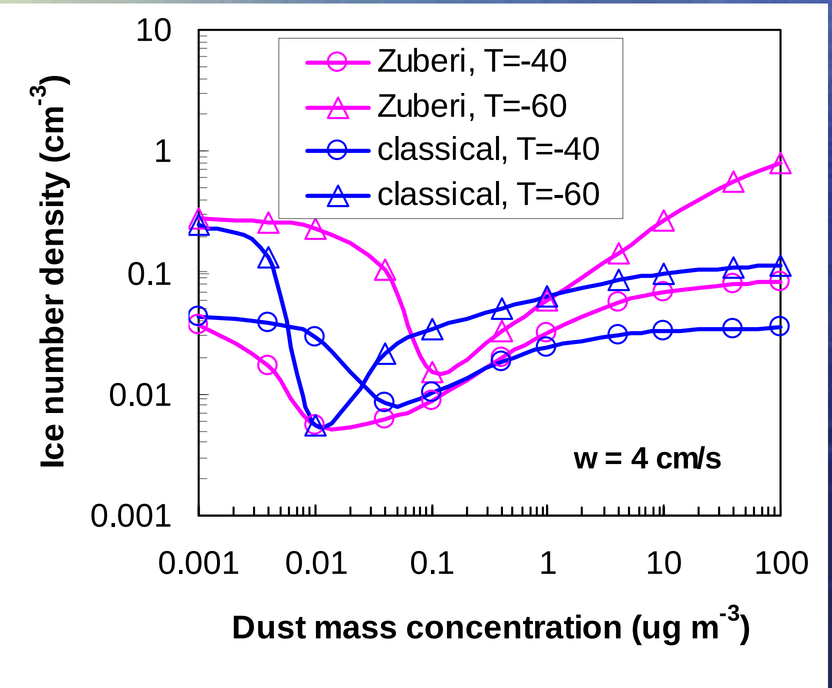
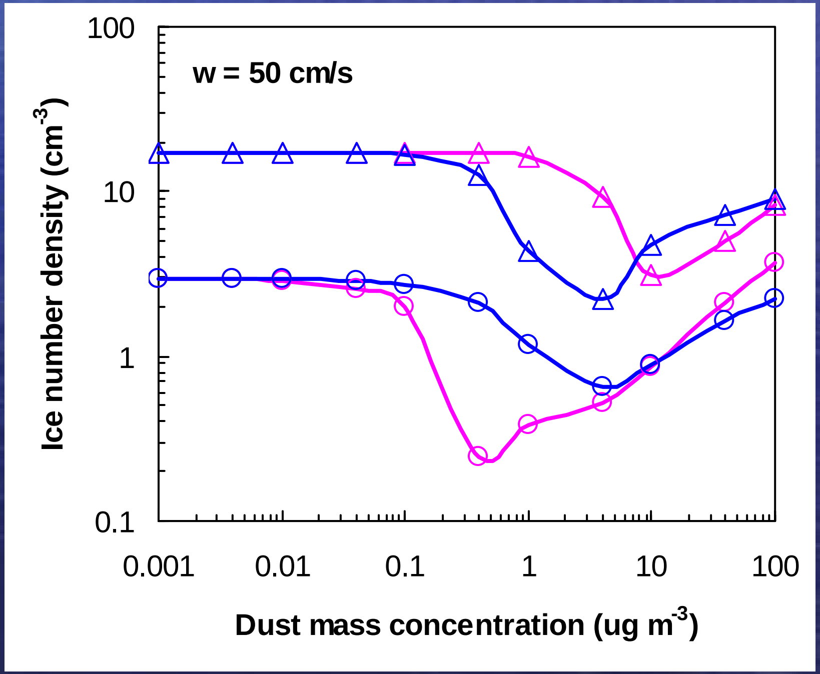


Figure. Critical RHi as a function of temperature

Comparison of model predicted ice number with dust immersion using classical theory (with m_{is}=-0.1) and Zuberi's effective temperature





w = 4 cm/s

w = 50 cm/s

Summary

- Mineral dust number in the UT is probably less than soot number, but still compariable.
- Heterogeneous ice nucleation on mineral dust based on classical theory suggests m_{is}= -0.2~0.0. (similar to Hung et al., 2003)
- Ice number is quite insensitive to dust mass (number) from classical theory with

  m_{is} = -0.1, but becomes more sensitive when using Zuberi's effective temperature.