Study of Mechanisms of Aerosol Indirect Effects on Glaciated Clouds

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1. INTRODUCTION

Aerosol-cloud interactions cause the greatest uncertainties in global models' simulation of climate change. Aerosol indirect effects on glaciated clouds are very uncertain. For example, an off-line inter-comparison of various schemes of heterogeneous ice nucleation from the literature revealed 5 orders of magnitude of difference in predicted ice concentrations at -30 degC (Phillips *et al*. 2008).

Insoluble aerosols, by nucleating extra ice heterogeneously, can alter mixed-phase clouds' precipitation production (Phillips *et al*. 2003), lifetime and phase. Conversely, extra soluble aerosols alter the warm rain process in convective clouds, and hence, raindrop-freezing and supercooled cloud-liquid aloft, as well as homogeneous freezing and cirrus properties. This affects the radiation budget.

We have a model with 'double-moment' bulk microphysics, semi-prognostic treatment of multiple aerosol species and representation of all known pathways for ice initiation, namely an 'aerosol-cloud model' (Phillips *et al.* 2009). In this Year 1 of the ASR (ARM) project, the model is being enhanced. In Years 2-3, mechanisms of aerosol indirect effects on glaciated clouds will be studied with it.

2. DESCRIPTION OF AEROSOL-CLOUD MODEL

Overview:

The double-moment bulk microphysics parameterisation (Phillips *et al.* 2007) treats cloud processes with 5 classes of sedimenting hydrometeor (cloud liquid, cloud ice, snow, graupel and rain). The predicted aerosol-sensitive mean size of cloud-particles determines their conversion to precipitation. In-cloud supersaturation and diffusional growth of hydrometeors are predicted explicitly. The known and empirically quantified pathways for initiation of ice and droplets are represented:

(1)Heterogeneous droplet activation at cloud-base and in-cloud, by sulfate, seasalt and soluble organics;

(2)Heterogeneous ice nucleation by dust, soot and insoluble organics, in all modes (deposition, immersion-condensation-freezing, inside-out and outside-in contact-freezing), with the empirical parameterization (EP) by Phillips *et al.* (2008);

(3)Hallett-Mossop (H-M) process of rime-splintering at -3 to -8 degC;

(4)Homogeneous freezing of cloud-liquid with the parametrization by Phillips *et al*. (2007) of the fraction evaporated;

(5)Homogeneous freezing of soluble aerosols (Koop *et al.* 2000).

Aerosol species are predicted in clouds, including interstitial and immersed components of their size distributions. In-cloud nucleation/precipitation scavenging of each is predicted. There is an interactive radiation scheme with dependencies of cloud radiative properties of sizes of ice particles and drops The aerosol-cloud model is described and thoroughly validated by Phillips *et al.* (2009).

Validation and Description of Empirical Parameterization (EP) of Heterogeneous Ice Nucleation:

Compatible categories of identified ice nuclei based on Chen *et al.* (1998) are:- dust/metallic (DM) , black carbon (BC), and insoluble organics (O). Reference values of the total ice nucleus (IN) concentration are from a case of simultaneous CFDC/aerosol observations in Colorado (INSPECT; 'low-dust scenario'). The IN concentration measured in the low-dust scenario is:

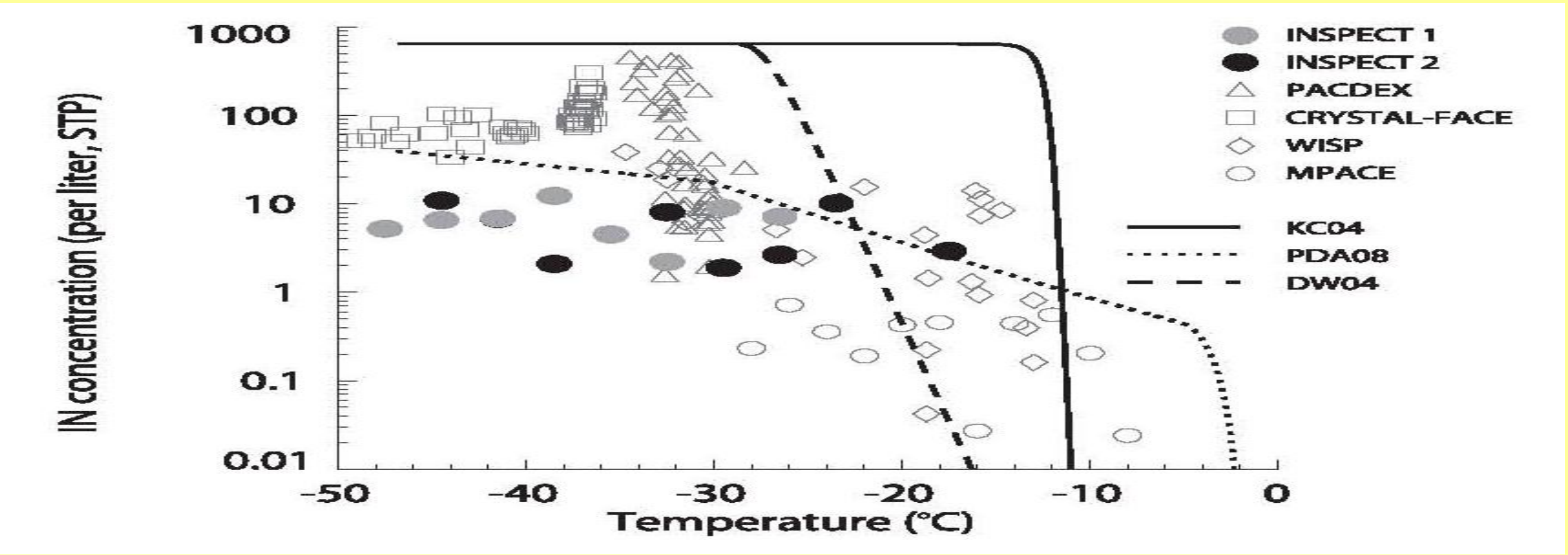
$$N_{IN,*} = N_{DM,*} + N_{BC,*} + N_{O,*}$$

In general, the total concentration of active IN is:

$$N_{IN,} = N_{DM,} + N_{BC,} + N_{O,}$$

For $x = DM, BC$, and O:

$$N_x = \frac{(\alpha_x H_x(S_i,T)\Omega_x)}{\Omega_{x,*}} N_{IN,*}$$



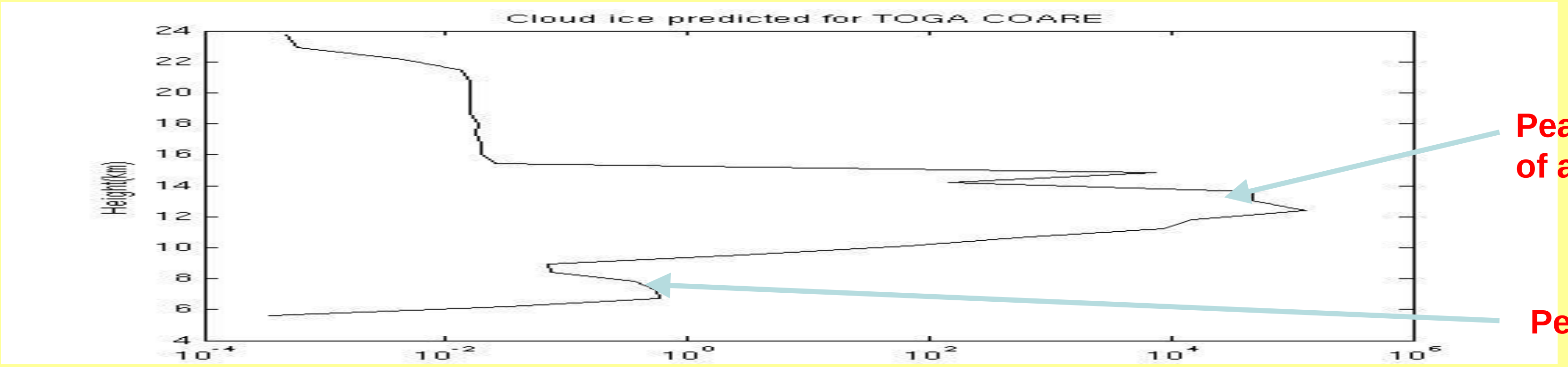
Comparison (above) of EP for background troposphere against aircraft observations from many field campaigns (reproduced from Eidhammer et al. 2009).

Ω_x is the total surface area (per unit mass of air) of the x-th aerosol group. H_x represents suppression of heterogeneous ice nucleation at warmer temperatures and (water) subsaturation. Observations by Chen *et al.* (1998) partially constrain α_x . IMPROVE data from the low-dust scenario (INSPECT) yield $\Omega_{x,*}$.. Contact-freezing nuclei are the same IN with activation shifted to warmer temperatures. Comparison of the EP scheme with laboratory data for artificial aerosol was done by Phillips *et al.* (2008), partly with data for soot from DeMott (1990; 'D90'), DeMott *et al.* (1999; 'D99') and Field *et al*. (2006; 'F06').

3. ENHANCEMENT OF BULK (2-MOMENT) SCHEME OF COLD-CLOUD/AEROSOL INTERACTION

Work Done (Year 1):

The aerosol-cloud model has been coded into the latest version of WRF, with a change of vertical coordinate (from z to σ).



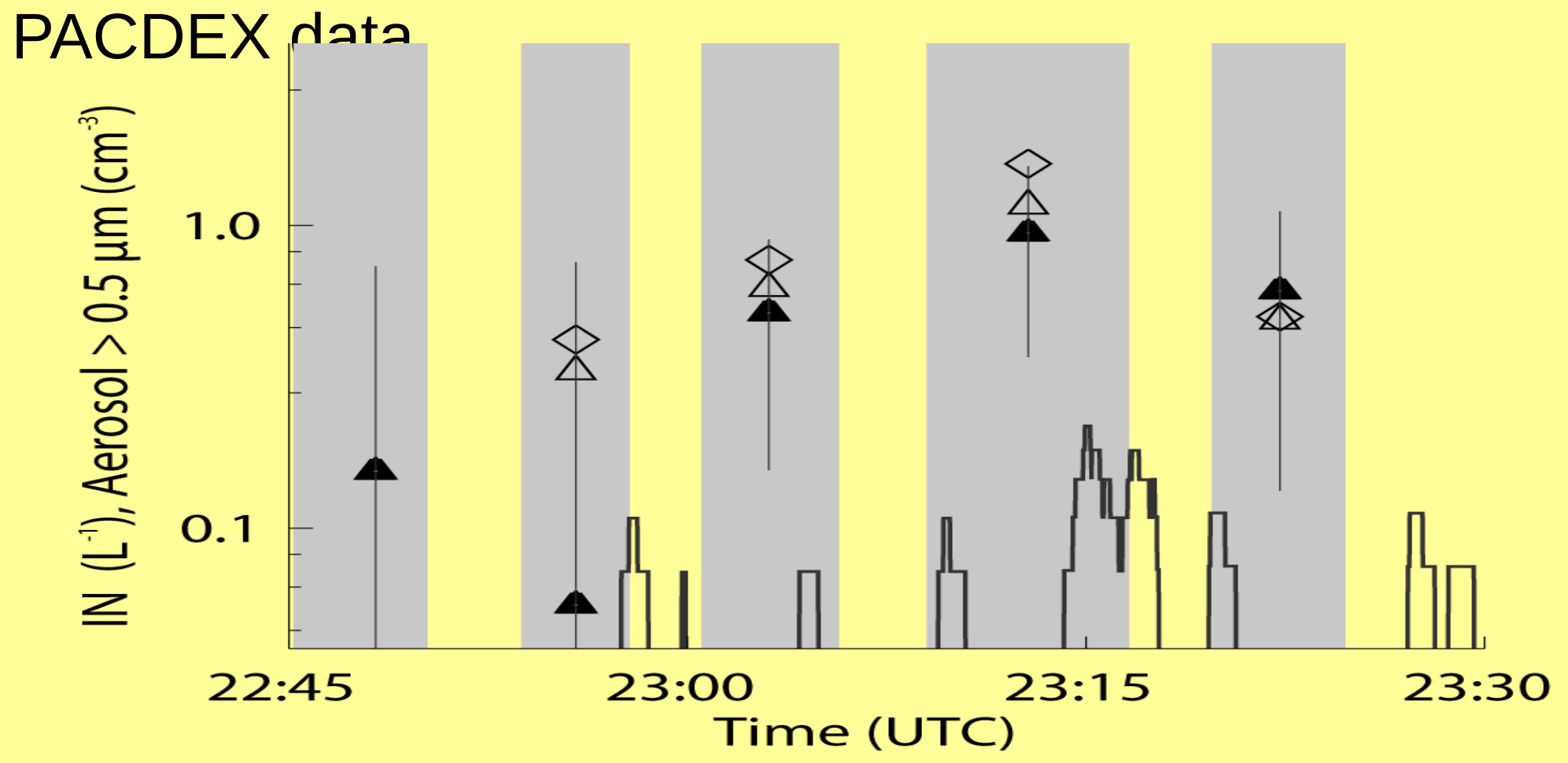
Peak due to homogeneous freezing of aerosols and cloud-droplets

Peak due to H-M process

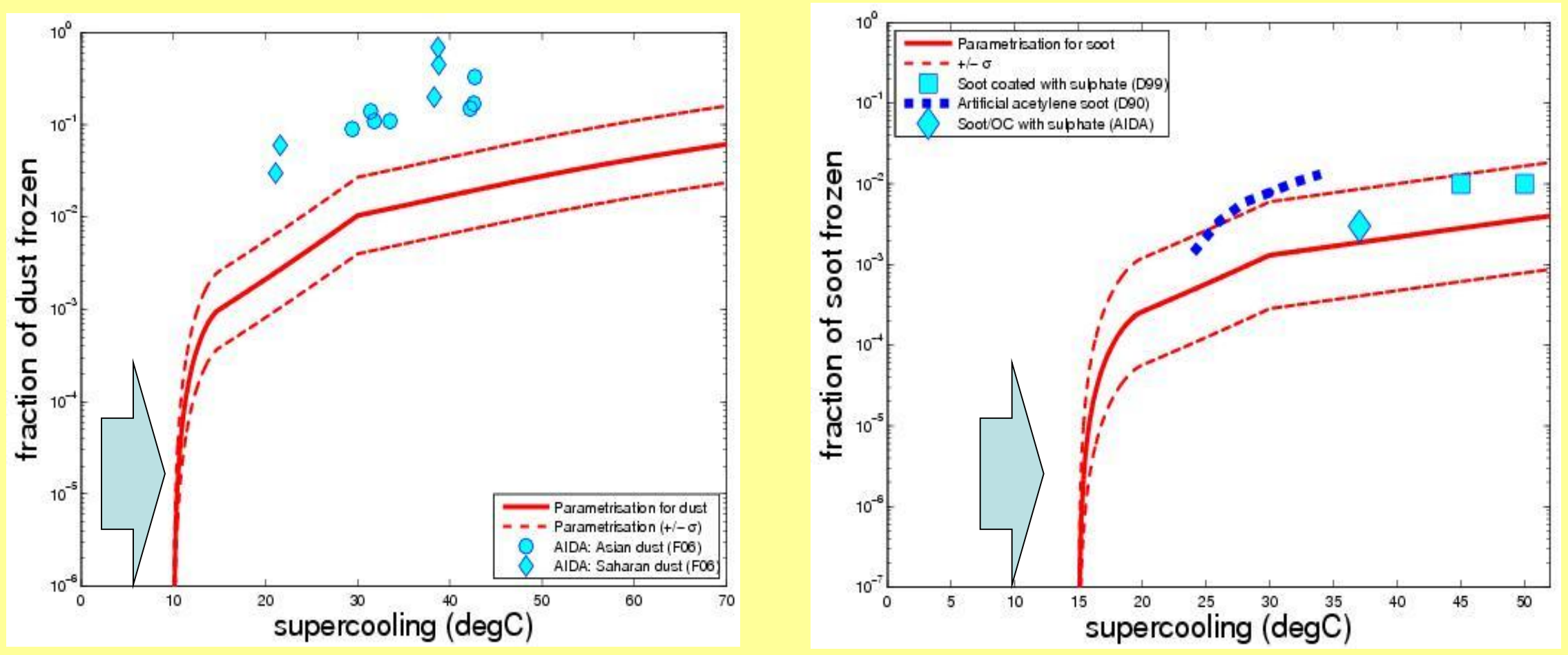
Ice particle concentration (L^{-1})

Tasks Ongoing (Year 1):

1. Validation and refinement of empirical parameterization (EP) of heterogeneous ice nucleation, by comparison with ICE-L and PACDEX data.

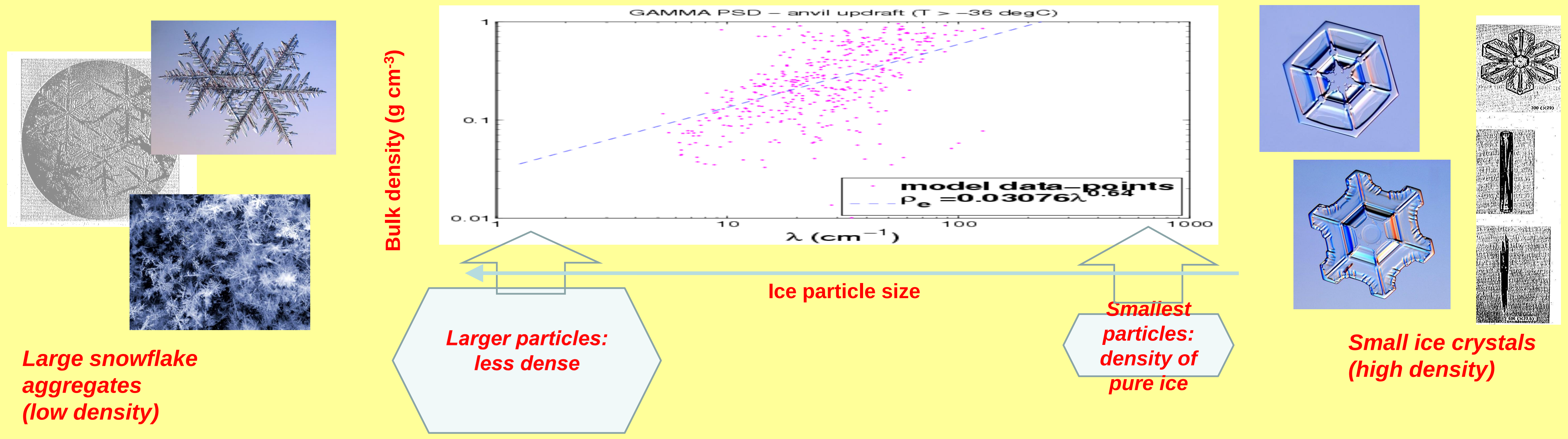


Validation (above) of EP's predicted IN concentration against aircraft data (CFDC) from a wave-cloud observed in ICE-L. Plot reproduced from Eidhammer et al. 2010).



Refinement (blue arrows) of EP's predicted (red line) onset of freezing for dust (left) and soot (right), in view of CFDC data for dust and data for soot from DeMott (1990). Freezing now starts at colder temperatures than previously. Though the artificial dust (blue points, left) has a higher active fraction (AIDA) than predicted, this is expected: Phillips et al. (2008) observed that it has over 1000% more active IN per unit dust surface area than natural atmospheric dust.

2. Accretion of cloud-particles by ice precipitation and their vapor growth will be enhanced in the double-moment scheme by applying relations for size-dependencies of bulk density and shape, for various temperature regimes. Such relations will be derived from ARM aircraft observations following Heymsfield and Iaquinta (2000) and Heymsfield *et al.* (2002, 2004a,b) and from a detailed spectral microphysics model with a crystal-growth component (Phillips *et al.* 2001, 2002, 2003, 2005):



Large snowflake aggregates (low density)

Larger particles: less dense

Ice particle size

Smallest particles: density of pure ice

Small ice crystals (high density)

Predicted ice morphology in the mixed-phase region of a convective cloud, from a detailed spectral-microphysics model** (Phillips et al. 2003, 2005, QJRMS). **This is how morphology will be parameterized in the bulk scheme.

4. SUMMARY AND FUTURE DIRECTIONS

After enhancing the aerosol –cloud model (Year 1), ARM cases from the Cloud and Land Surface Interaction Campaign (CLASIC; Oklahoma, 2007) and Tropical Warm Pool International Cloud Experiment (TWP-ICE; Pacific Ocean, 2006) will be simulated. There will be validation against ARM aircraft, satellite and ground-based observations. Sensitivity studies will elucidate the relative roles of mechanisms for the indirect effect from anthropogenic soluble and insoluble aerosol on glaciated clouds. Such process-level insights are needed to advance their representation in global models.

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