Intercomparison of LES of Arctic mixed-phase clouds: Importance of ice size distribution assumptions

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Background

Previous intercomparisons (Klein et al., 2009 and Morrison et al. 2011**) revealed large variations of liquid & ice water paths** (LWP & IWP) predicted by different models simulating Arctic mixed-phase stratiform clouds (M-PACE, SHEBA).

An uncertainty in ice nucleation rate plays a large role, but **constraining ice number concentration (N_i) does not eliminate the spread in LWP and IWP**, or their sensitivity to N_i.

Science Question: What causes the diverse sensitivities of LWP and IWP to ice particle concentration in mixed-phase clouds simulated by different models ?

Simulation setup

Microphysics: **Constrained N_i within the liquid cloud. Prescribed mass-capacitance and mass-fall speed relationships** to constrain growth rates and sedimentation of ice particles. No collision-coalescence among all hydrometeors.

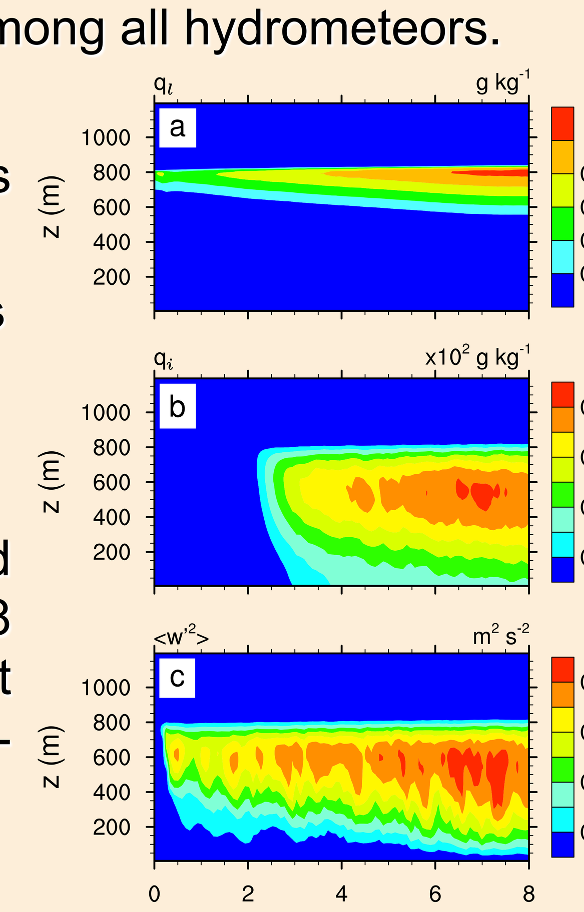
Radiation: **Unified parameterized radiation and heating rates** calculations

Dynamics: **Large-eddy simulations** to resolve essential vertical motions.

3-D domain: 64x64x150 grid points $\Delta x=\Delta y=50$ m, $\Delta z=10$ m.

Initial & boundary conditions based on an idealized ISDAC April 26, 2008 case; No surface sensible & latent heat fluxes; 8-h simulations; 2-h no-ice spin up.

3 model runs: ice0: $N_i = 0.$ L^{-1}
ice1: $N_i = 1$ L^{-1}
ice4: $N_i = 4$ L^{-1}



Time evolution of domain-mean profiles of liquid (top) and ice (middle) mixing ratios and vertical velocity variance (bottom) from SAM-2M ice1 simulation.

11 model configurations

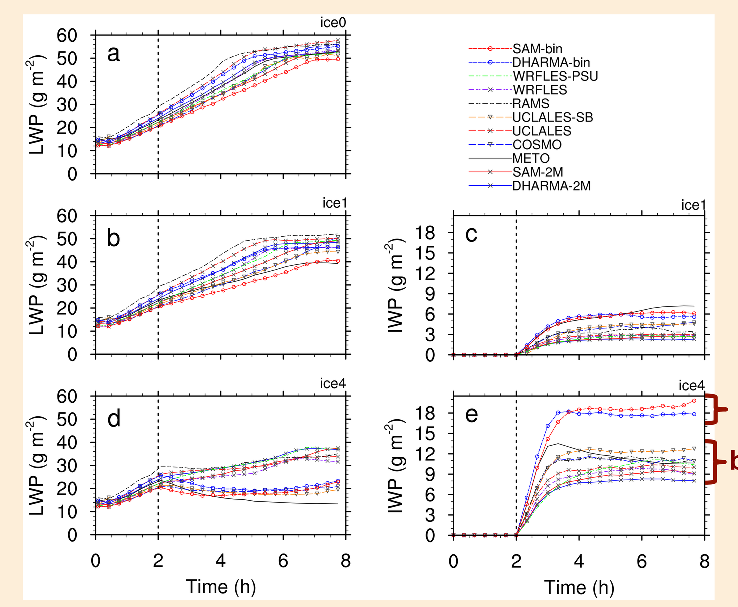
• DHARMA-2M • SAM-2M • WRFLES • UCLALES	Same micro-physics	Bulk 2 moment microphysics
• UCLALES-SB • COSMO	Same micro-physics	
• METO • WRFLES-PSU • RAMS		
• DHARMA-bin • SAM-bin		Bin (size-resolved) microphysics

Models show a range of sensitivities of LWP and IWP to the ice crystal concentration

Quasi-steady state in liquid and ice water paths (LWP and IWP) and precipitation

Differences in LWP due to representation of dynamics and mixing in the models are seen at t=2 h and persist throughout the simulations.

… but these differences are smaller than the differences in LWP responses to the ice effects.



Time evolution of domain-mean liquid (LWP) and ice (IWP) water paths. Dashed lines mark time when ice appears in ice1 and ice4 simulations.

Models with **bin microphysics** predict **higher IWP** than models with bulk schemes

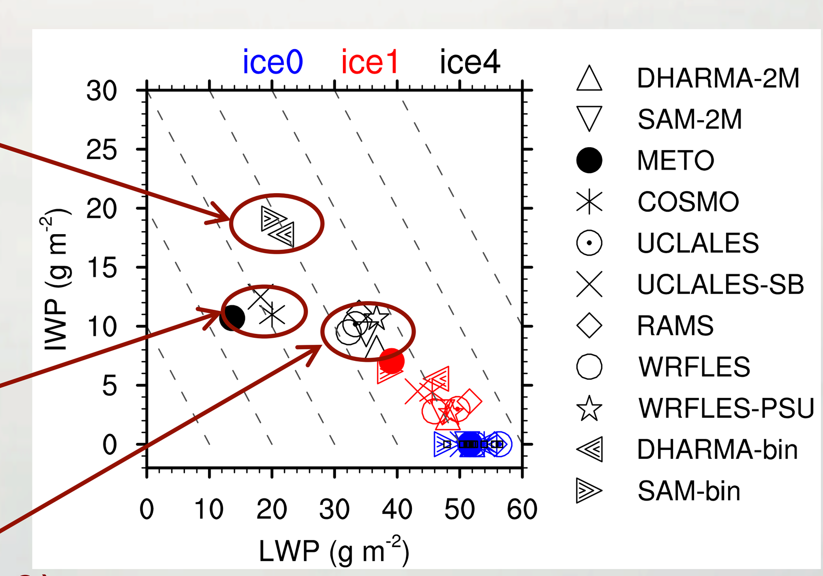
Liquid – ice partitioning and effect of the dynamics and microphysics

Domain mean **LWP and IWP are negatively correlated: Higher ice concentration** leads to **higher IWP and lower LWP**

Bin microphysics (Predicted ice PSD)

Bulk microphysics (Gamma PSD, ν=2)

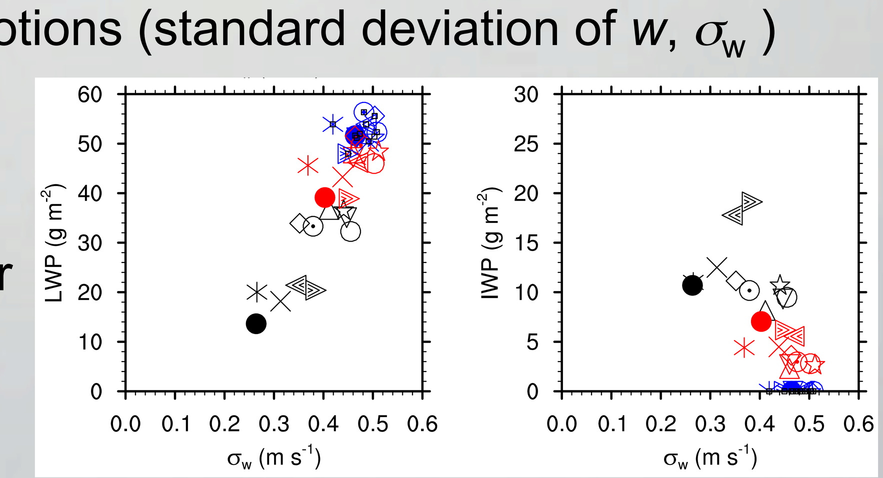
Bulk microphysics (Exponential PSD, ν=0)



Dynamics and microphysics contribute to the spread of the results.

Dynamics dominates LWP differences, as evident from the spread of ice0 simulations and LWP correlation with the intensity of vertical motions (standard deviation of w, σ_w)

Microphysics largely controls IWP response to increasing ice number concentration



Effects of ice particle size distribution (PSD)

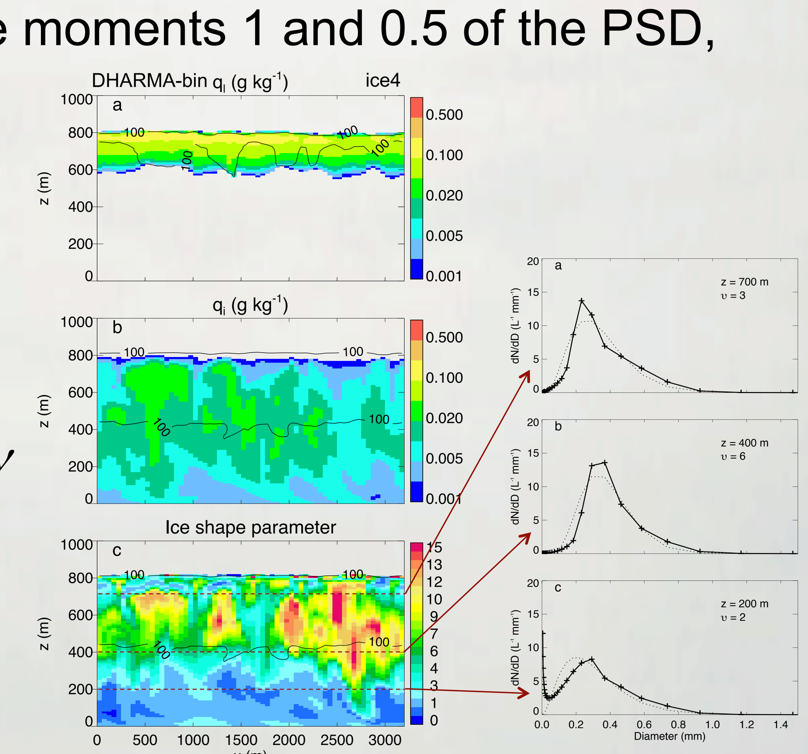
Models with bulk microphysics assume the shape of ice PSD as a Gamma distribution $f(D)$ or an exponential (ν=0).

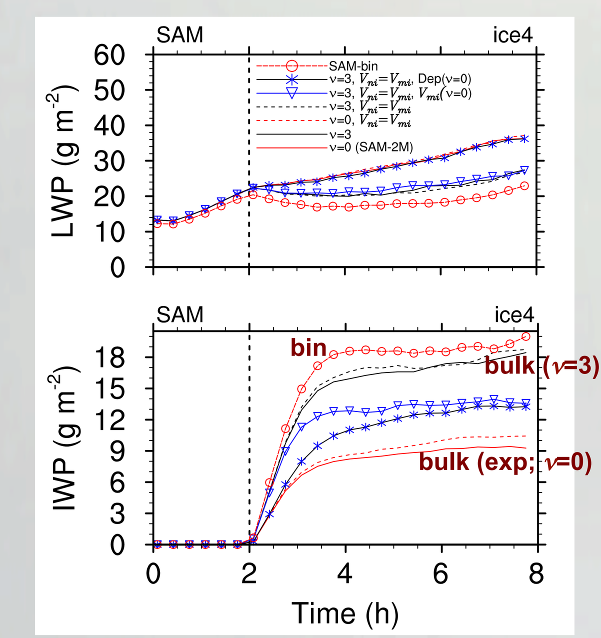
$$f(D) = N_i \frac{\lambda^{\nu+1}}{\Gamma(\nu+1)} D^{\nu} exp(-\lambda D)$$

The PSD affects depositional growth and sedimentation rates that are proportional to the moments 1 and 0.5 of the PSD, respectively.

In reality and in bin models, the shape parameter ν varies in space and time.

Bulk model's LWP & IWP agree with bin simulations when a case-appropriate ν is set, but in general, ν is not known *a priori*.





LWP evolution is controlled primarily through PSD effects on depositional growth rate of ice.

PSD effects on both depositional growth and sedimentation contribute to the increase in IWP.

Summary

Ice particle concentration, and hence ice nucleation, exerts a major control on the structure and evolution of mixed-phase stratiform clouds.

The diverse **simulated sensitivities of LWP and IWP to ice particle concentration** in mixed-phase clouds **are strongly affected by the shape of ice particle size distribution** (predicted or assumed), in addition to single particle properties (relationships among mass, size, capacitances, fall speed, etc.)

References

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