CFMIP/GCSS meeting, Exeter, UK, June 6-10, 2011

The role of dynamics-microphysics-radiation interactions in maintenance of Arctic mixed-phase boundary layer clouds

An assessment using ISDAC-based simulations

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with many thanks to the ISDAC team

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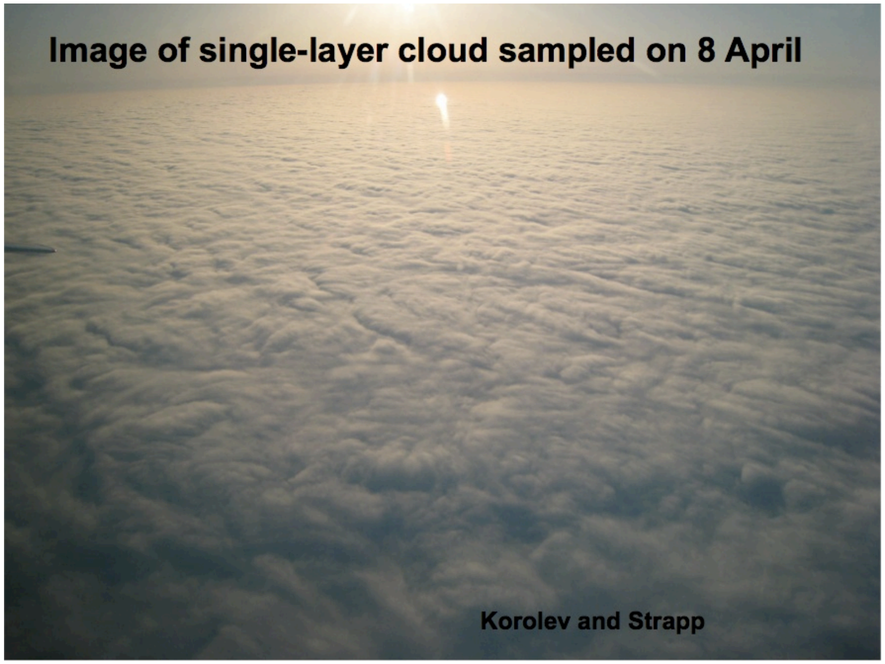
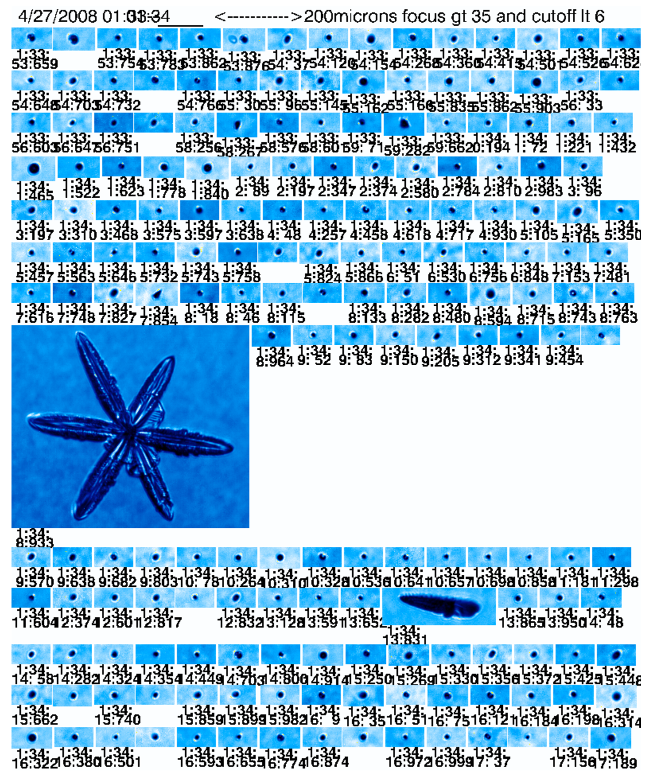
Arctic mixed-phase clouds



- Persistent
- 100’s of kilometers
- hours and days
- Strong radiative impact



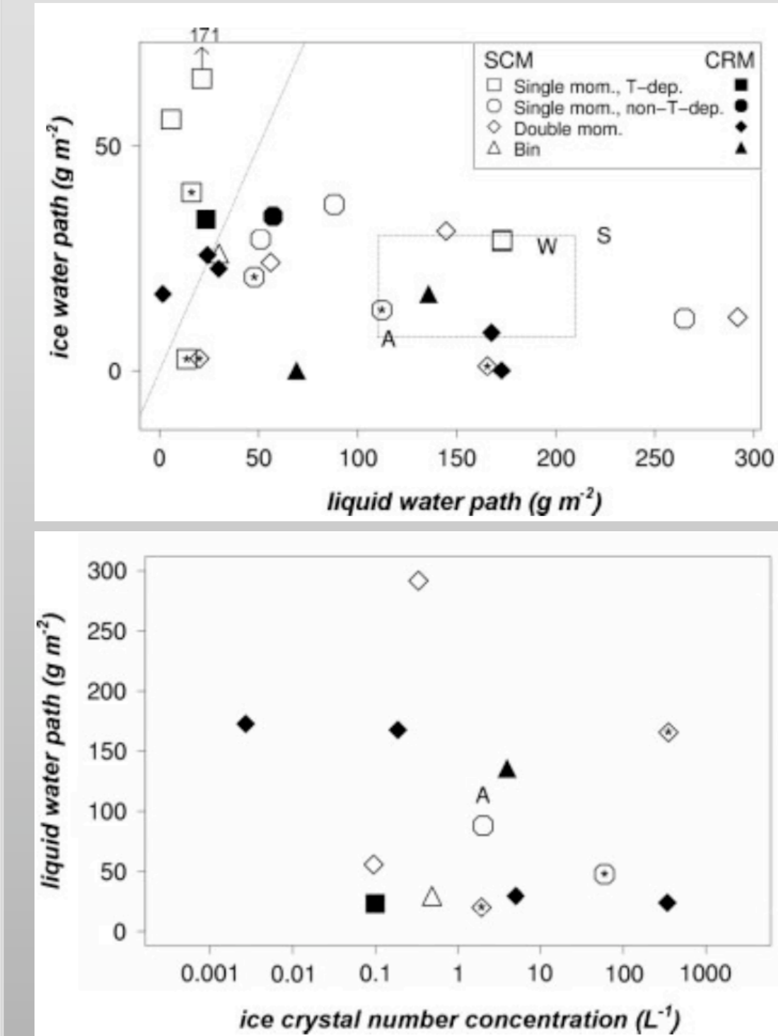
- Both liquid and ice particles are present

Previous assessments of mixed-phase cloud simulations

- Large spread in liquid and ice water paths among models (CRM & SCM) for the same case, initial profiles, large scale forcing, etc. (M-PACE intercomparison)

- Uncertainty in ice nucleation mechanisms plays a big role

M-PACE results (Klein et al. 2009)

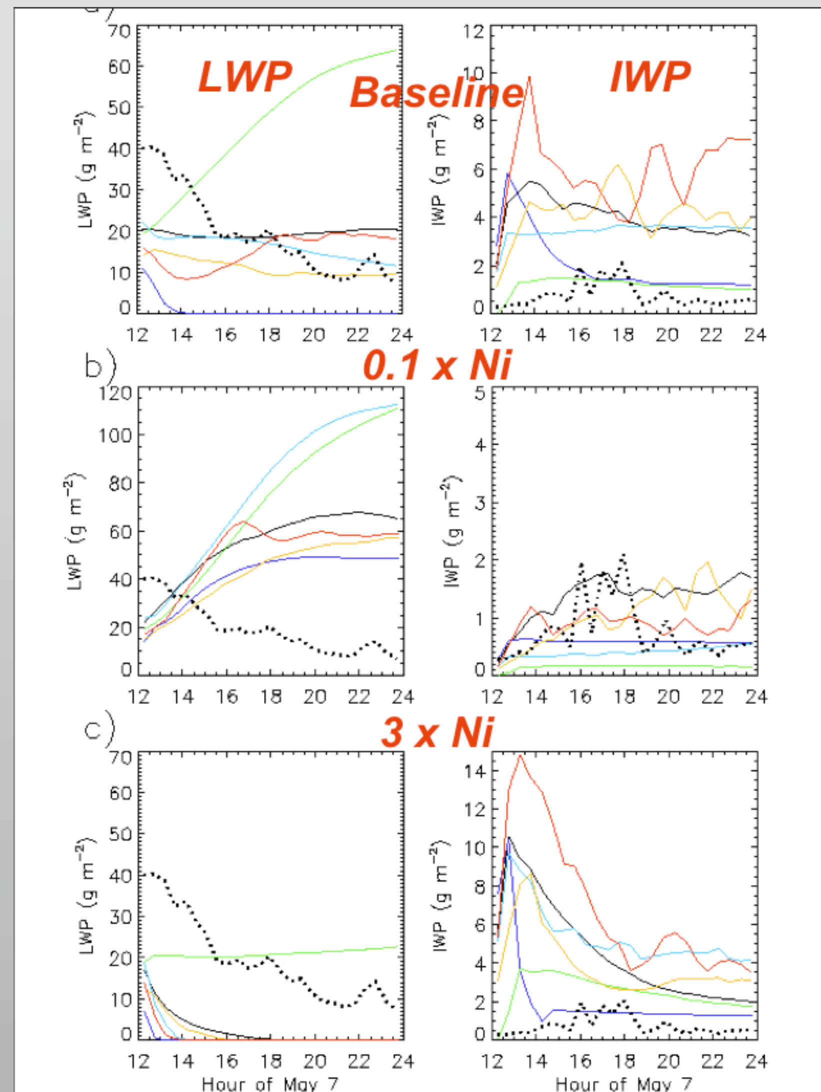


Previous assessments of mixed-phase cloud simulations

- … but constraining ice number does not eliminate LWP spread (SHEBA intercomparison)
- For many models there is a sharp transition from mixed-phased to ice-only clouds when N_i is increased
- What are the causes? Is this sensitivity real? Can it be reproduced in large-scale models?

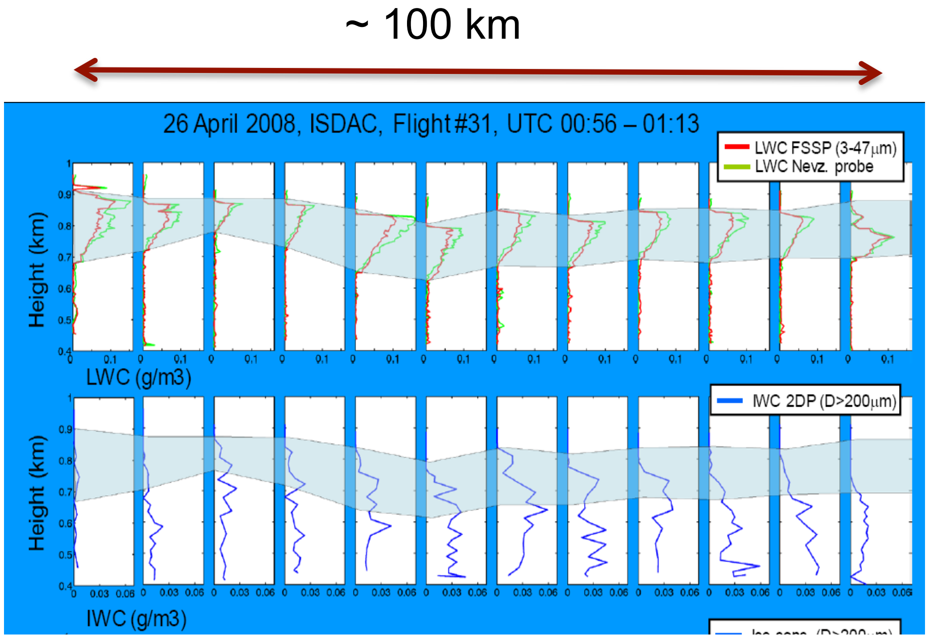
Dynamics-microphysics-radiation interactions are important and need to be understood better?

SHEBA results (Morrison et al. 2011)

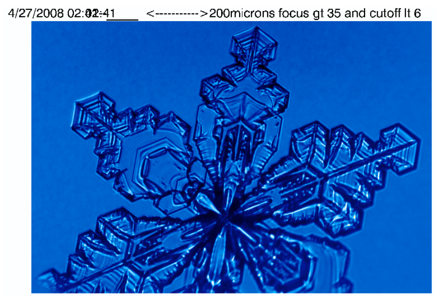


Indirect and Semi-Direct Aerosol Campaign (ISDAC) 26 April 2008, Flight 31

- Quasi-steady state cloud (lasted for many hours)
- Shallow < 300 m (i.e., narrow temperature range)
- Flat top (weak entrainment)



- Dominant diffusional growth, mostly dendrites, little or no collision/coalescence, aggregation, or riming



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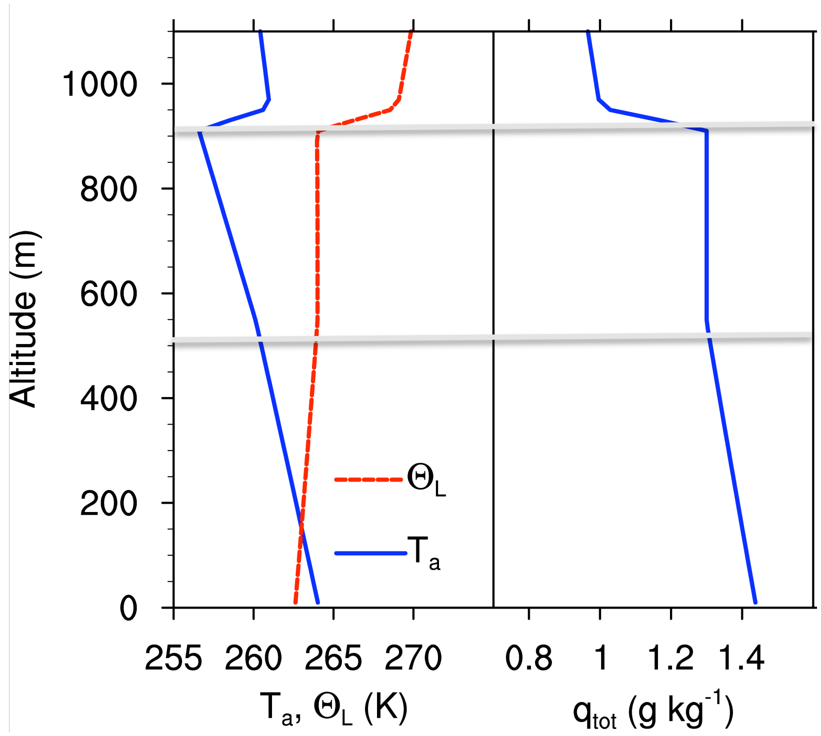
ISDAC FLT31: Initial profiles and model's setup

- Elevated mixed-layer with a temperature inversion at the top and a slightly stable and moister layer below
- Surface heat fluxes = 0, snow/ice covered surface
- SAM v6.7.5
- 50 x 50 x 20 m^3 resolution
- 256 x 128 x 120 domain, Δt=2 s
- Bin (size-resolved) microphysics for liquid and ice
- Liquid-only spin-up for 2 hrs
- Constrained ice number (N_i)

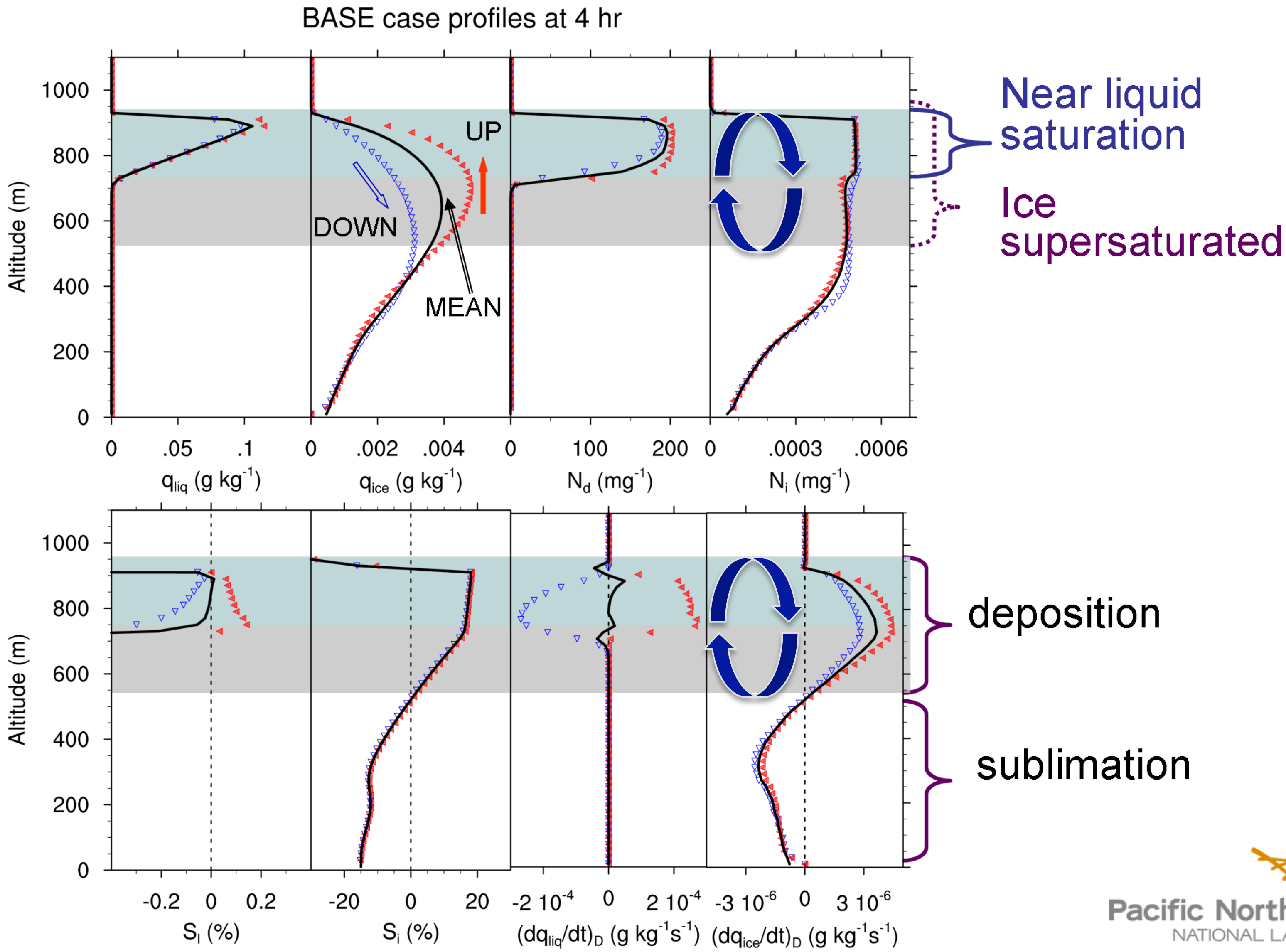


BASE: N_i =0.5 L^{-1}

NO_ICE: N_i =0

HI_ICE: N_i =2 L^{-1}

ISDAC FLT31: Base case cloud properties
(Ni=0.5 L-1)



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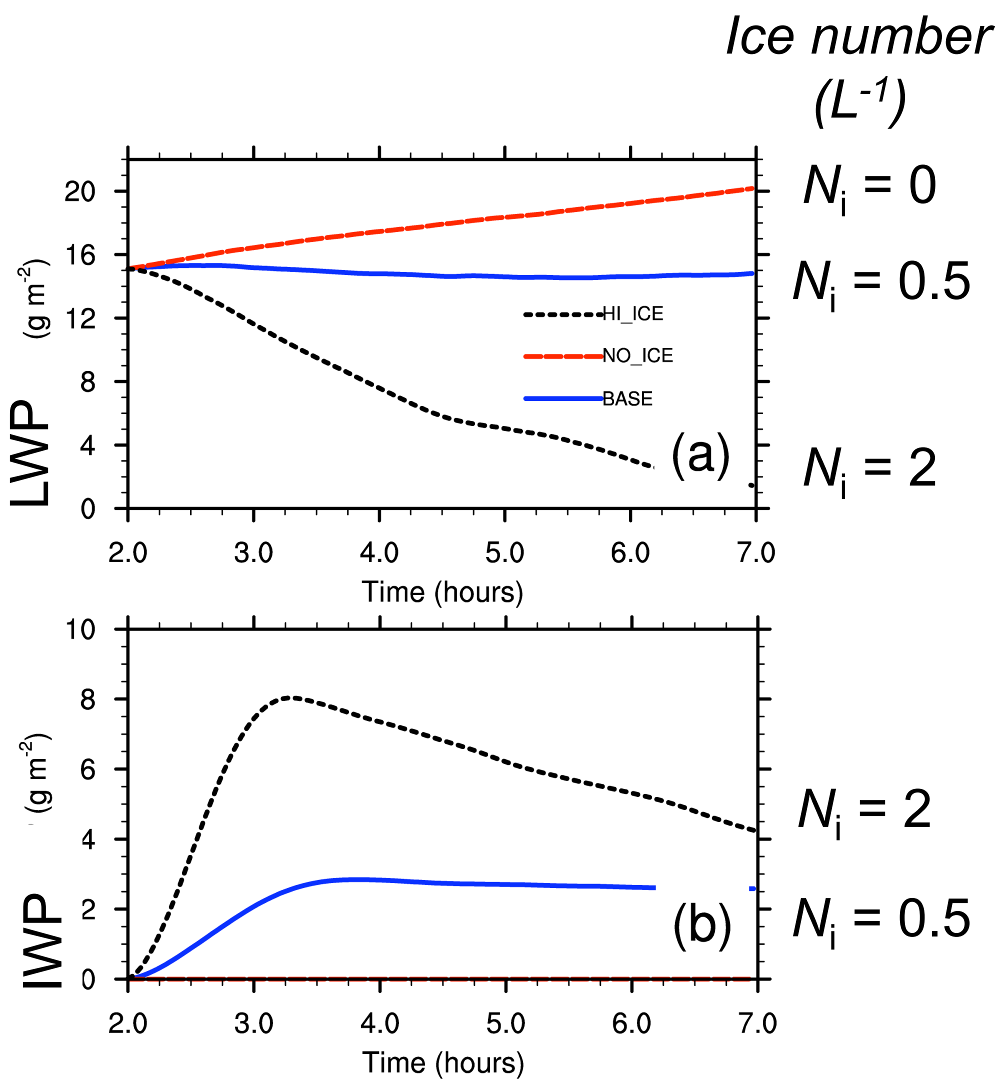
Nonlinear N_i effects or Life and death of a mixed-phase cloud



- Liquid cloud layer is stable with the observed N_i
- Dissipates in ~5 hours with quadrupled N_i
- What processes destroy the liquid ?

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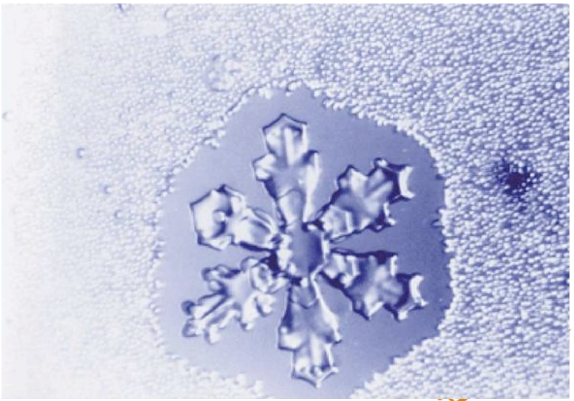
Untangling interactive processes

Ice can affect:

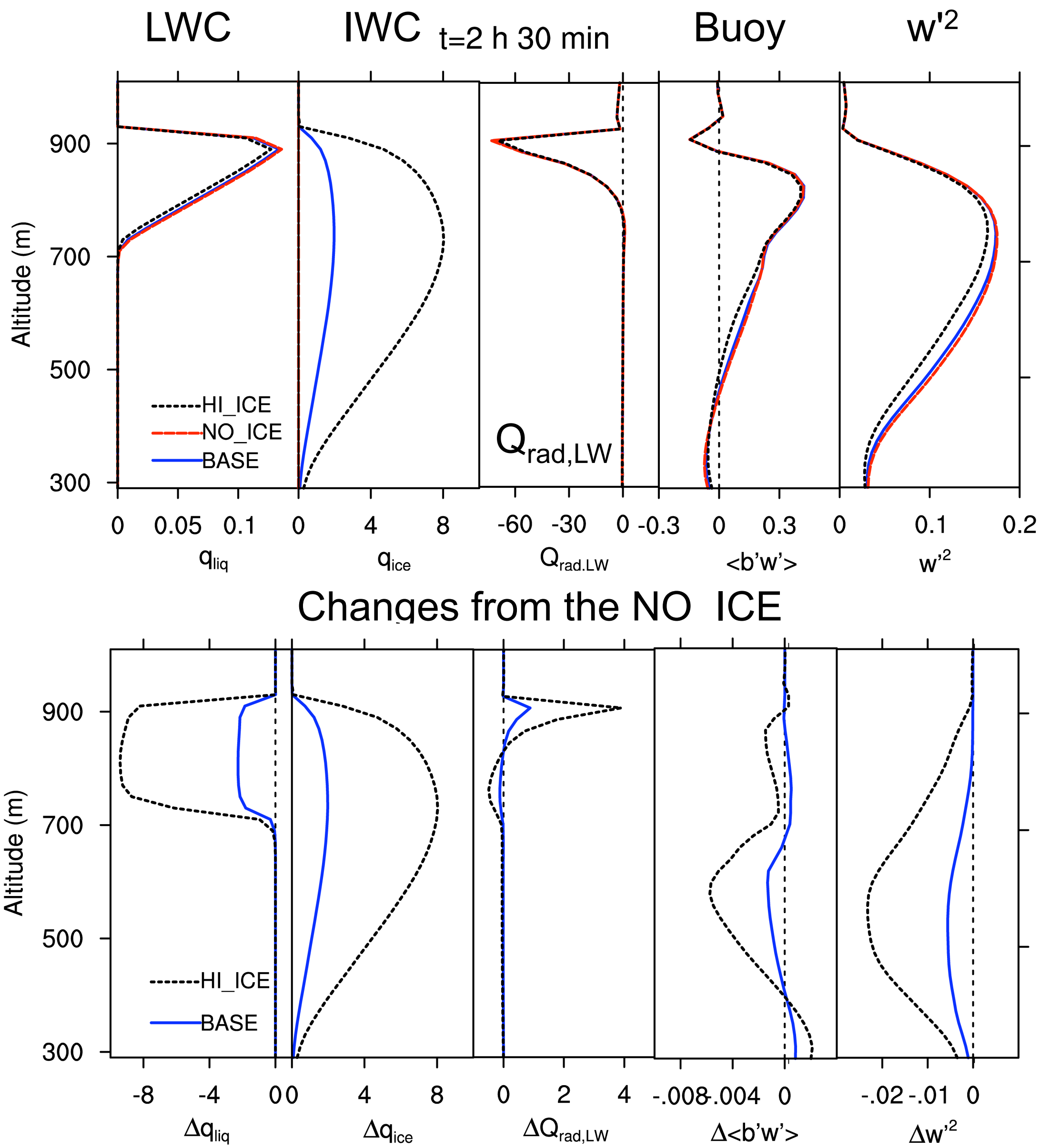
- Moisture content
- Temperature
- Radiative cooling (directly and indirectly through the reduction of the liquid water content)

Feedbacks to dynamics (turbulence or circulation strength, buoyancy flux)

Feedbacks to ice and liquid-to-ice partitioning



Changes in 30 min after the first ice



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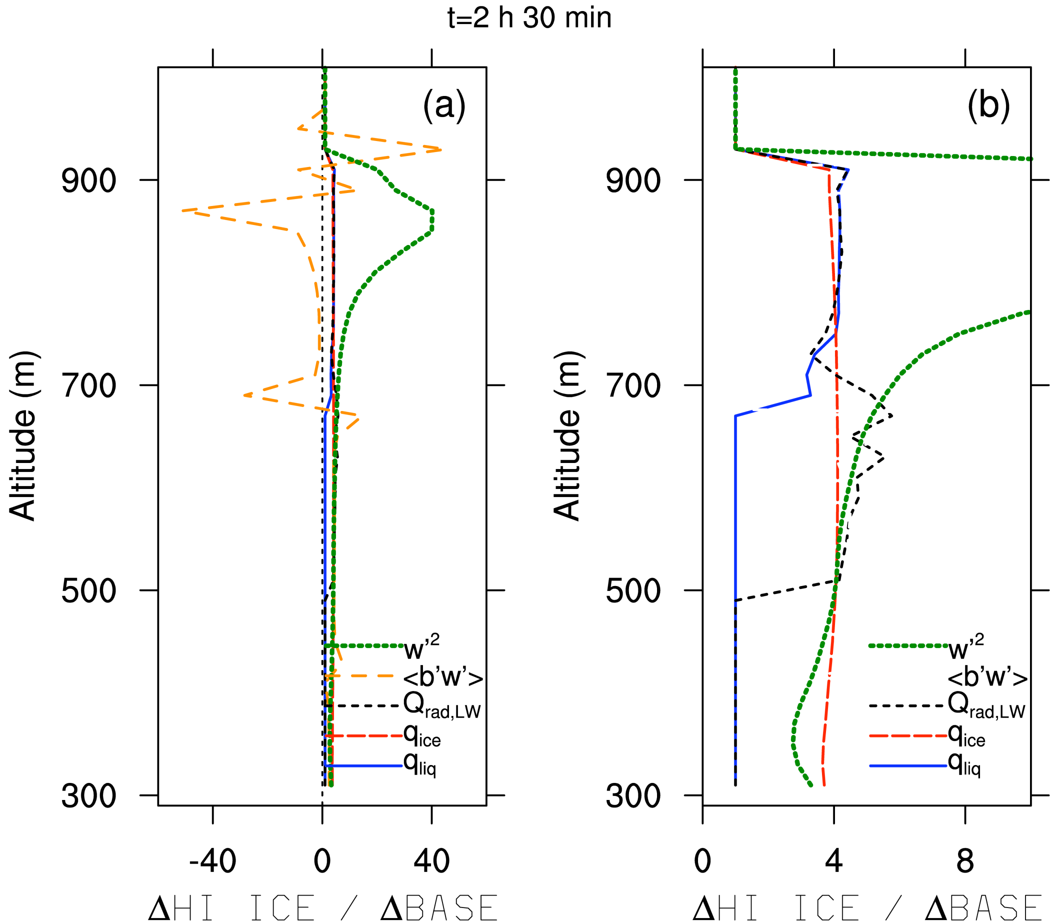
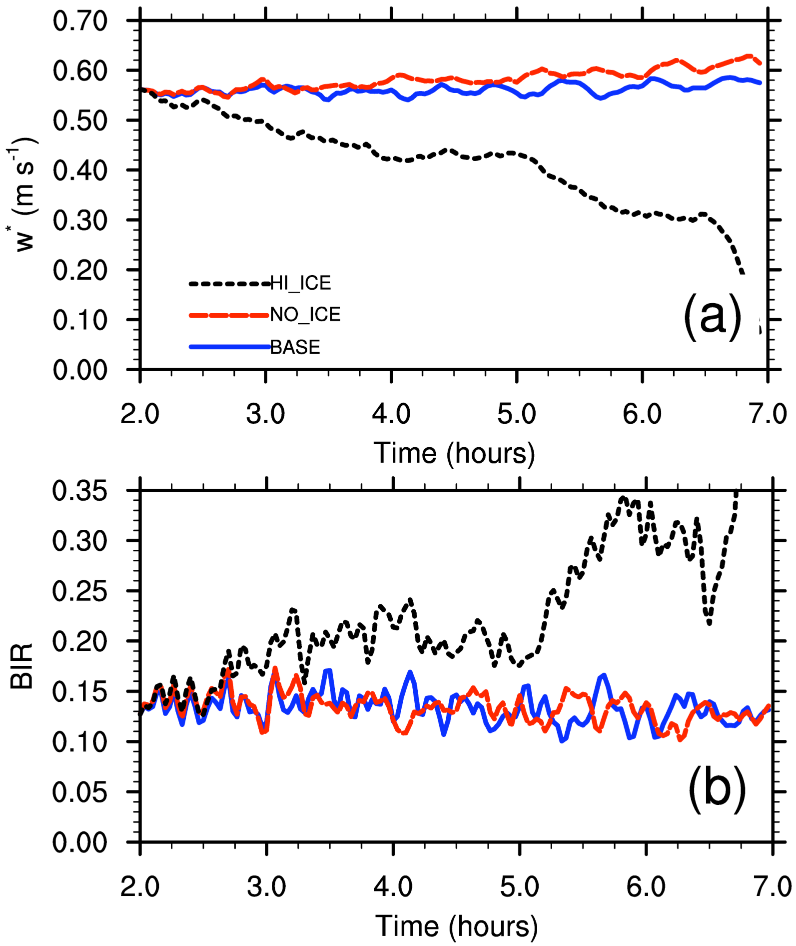
Linear & non-linear responses to changes in N_i



- Initial changes in LWC, IWC and Q_{rad} are proportional to N_i
- Changes in buoyancy flux and vertical velocity variance are non-linear

Quantifying the dynamical effects



Convective velocity scale

$$w^{*3} = 2.5\int_0^{z_i} \langle w'b' \rangle dz$$

Buoyancy integral ratio (BIR)

$$BIR = -\int_{\substack{z<z_b \text{ where} \\ \langle w'b' \rangle < 0}} \langle w'b' \rangle dz \Big/ \int_{\text{all other } z} \langle w'b' \rangle dz$$

For warm stratocumulus
BIR > 0.15 for decoupling

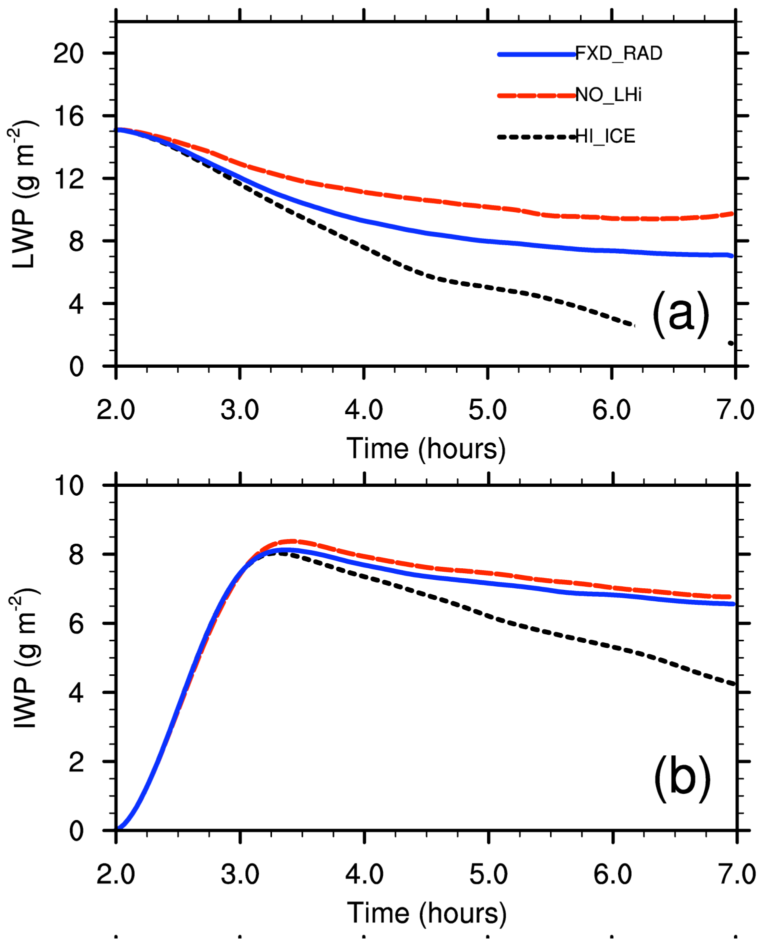
Bretherton and Wyant [1997]

Feedbacks to dynamics (turbulence or circulation strength)

Ice can affect vertical buoyancy flux by

- changing LW radiative cooling
- releasing latent heat during depositional growth

Sensitivity to radiation and latent heat



HI_ICE: N_i =2 L^{-1}

FXD_RAD: Fixed radiation

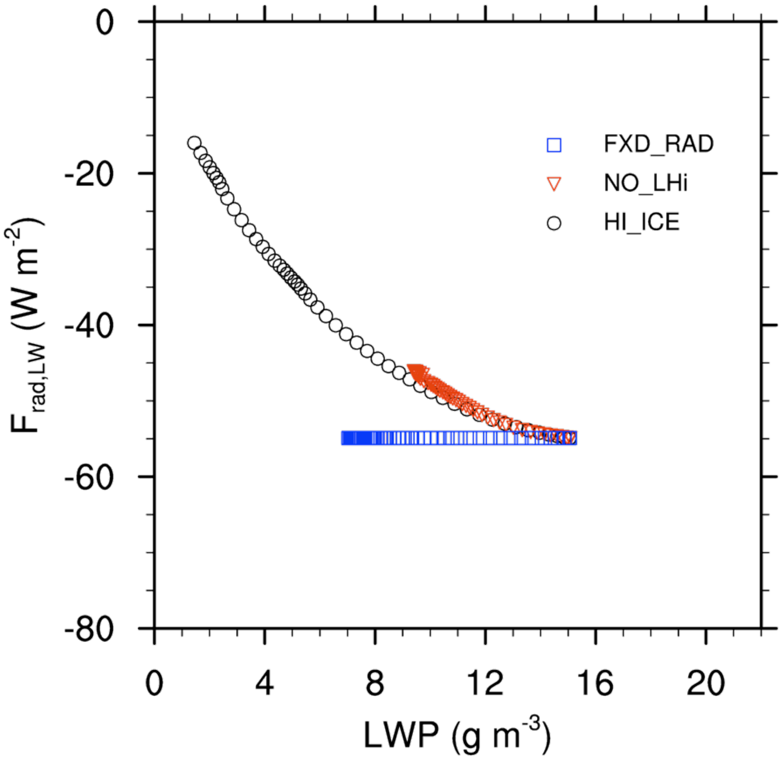
NO_LHi: Ignore latent heat of vapor deposition on ice

LWP is larger in NO_LHi

but

Radiative cooling is stronger in FXD_RAD

Radiation and latent heat effects



Expectedly

• Longwave cooling – LWP feedback is important

Surprisingly

• Changes in buoyancy flux profile due to latent heat of deposition may be equally important

Ovchinnikov et al., 2011, JGR, (submitted)

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ISDAC – based model intercomparison

Plans, logistics, etc

Atmospheric System Research (ASR/ARM) & GCSS

ASR: Data for initialization, forcing and evaluating the simulations

GCSS / GASS: Broader participation, vast model assessment and boundary/mixed layer modeling expertise

Target models: LES/CRM (SCM, Regional to follow?)

Setup details under development:

- Initial profiles, large-scale subsidence, spatial resolution, data format
- Timeline:
  - Case description (Summer 2011)
  - First model results (Fall 2011)
  - Final results & workshop (Summer 2012)

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