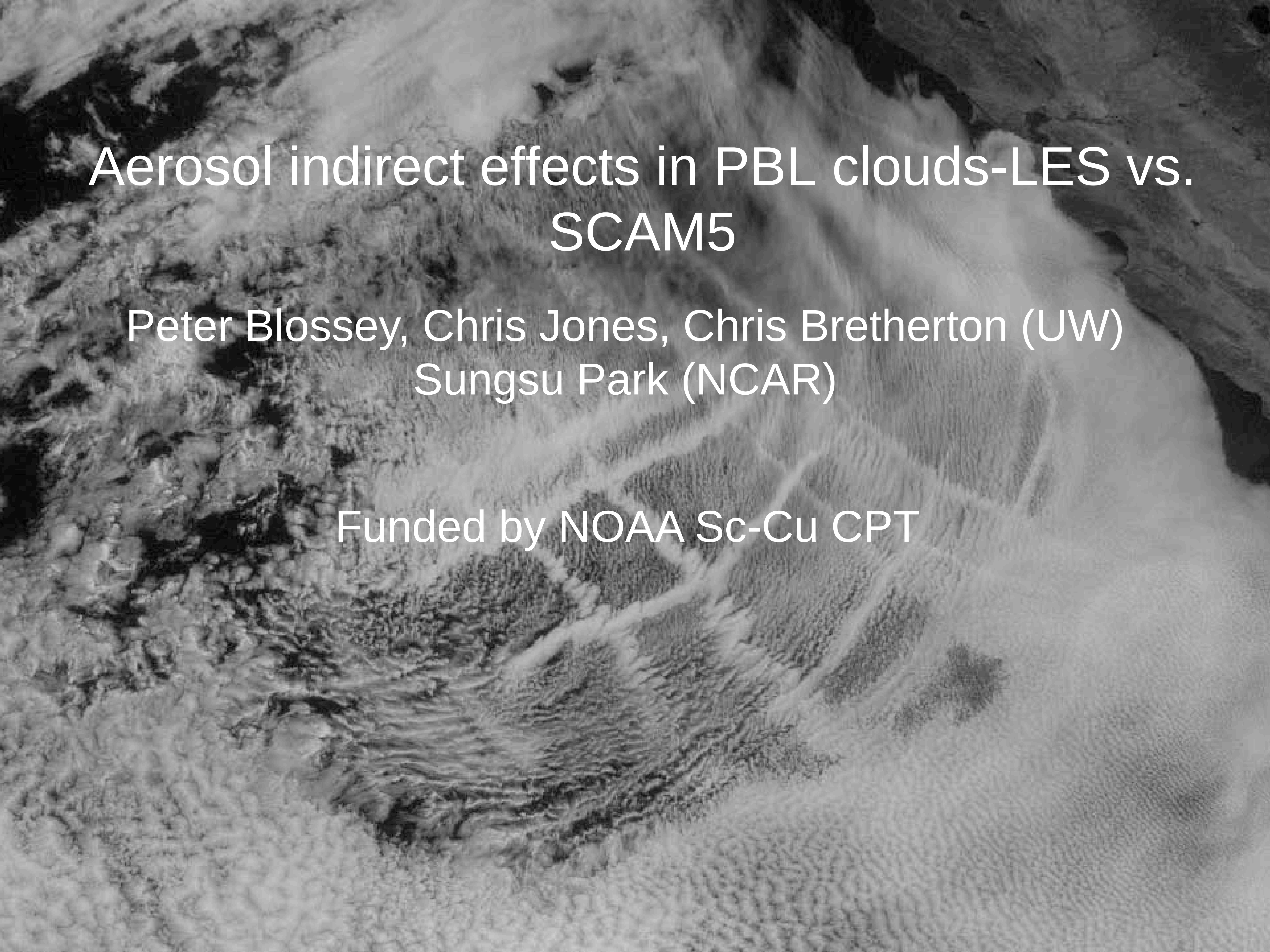

Aerosol indirect effects in PBL clouds-LES vs. SCAM5

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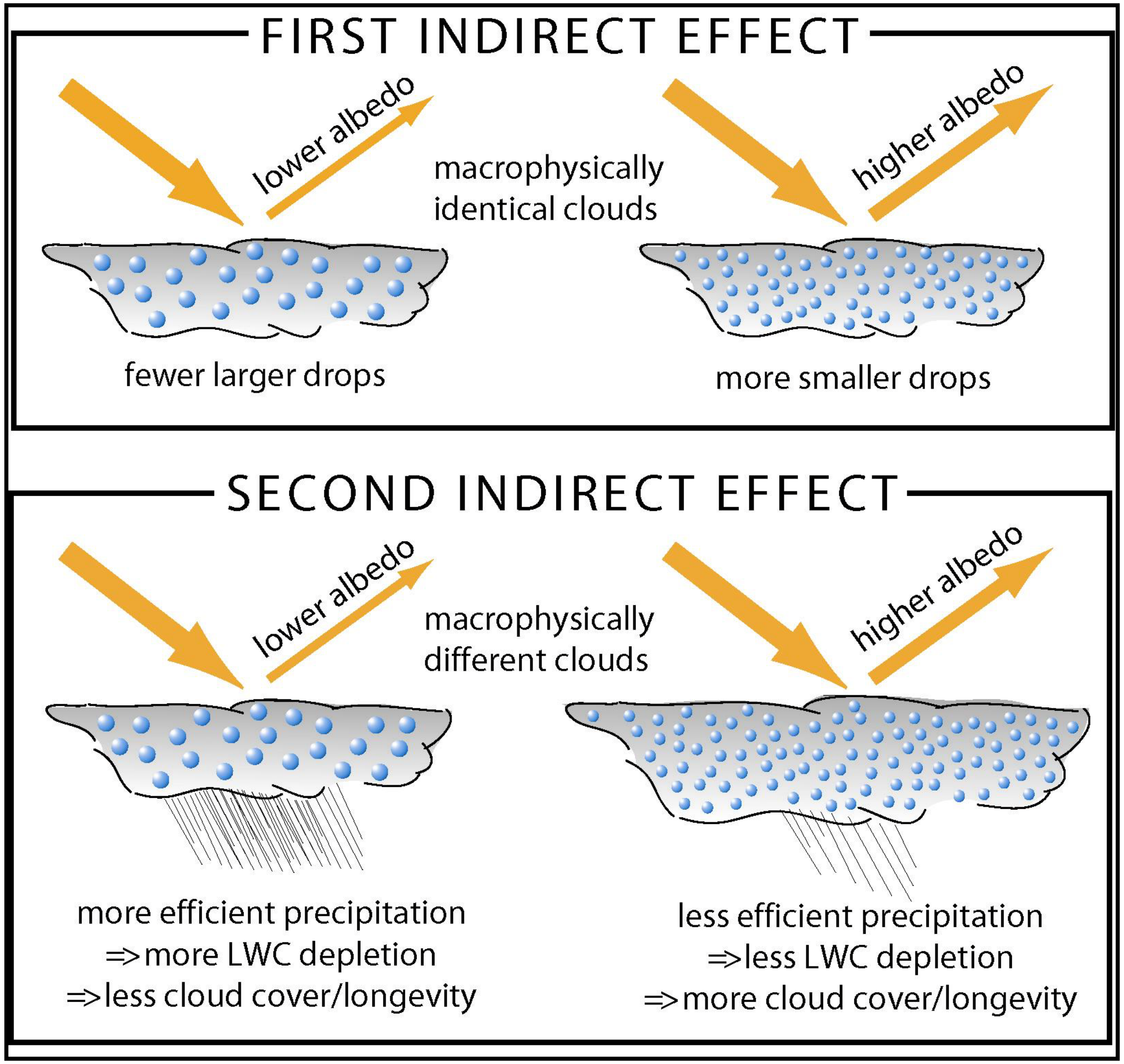
Funded by NOAA Sc-Cu CPT

Aerosol Impacts on Clouds

- Aerosols can impact clouds through
  - cloud brightening (1st indirect effect) or
  - modification of cloud lifetime (2nd indirect effect).

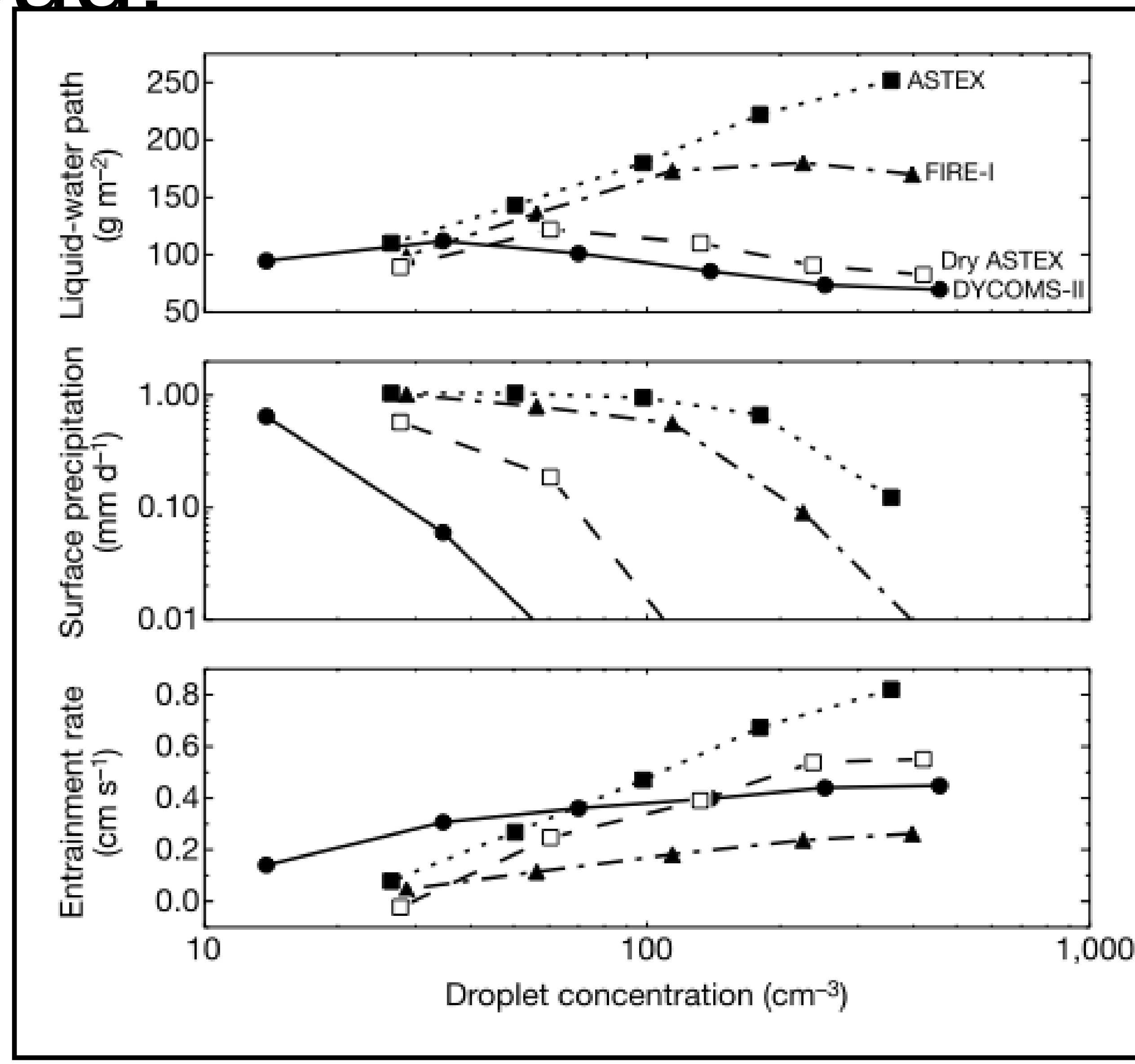


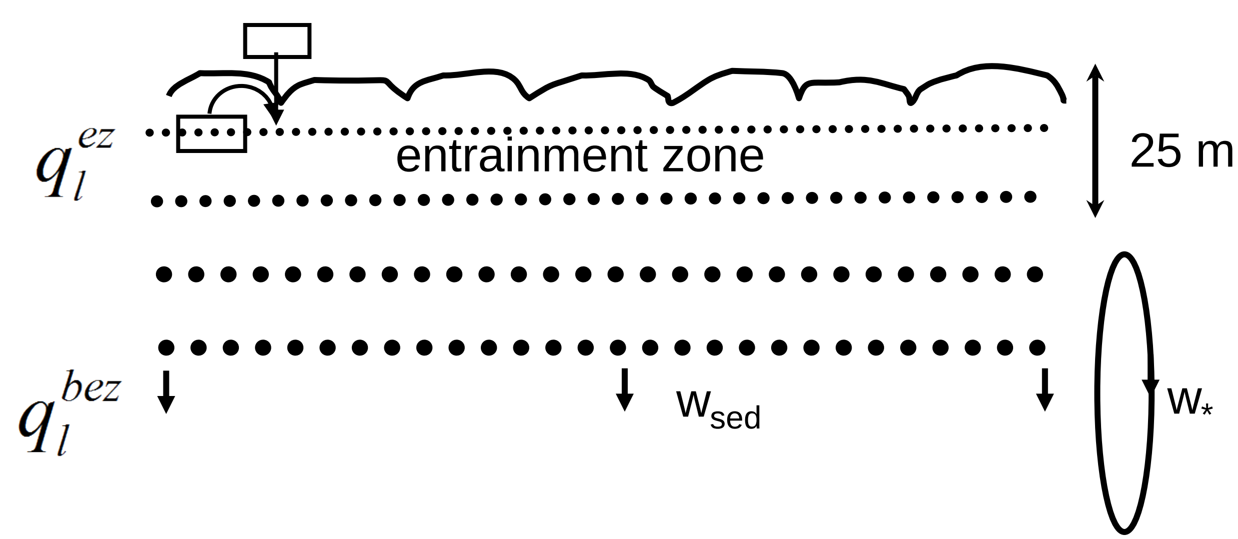
More aerosol thins nearly nonprecipitating Sc cloud.

- Ackerman et al (2004) found that stratocumulus clouds only thicken with increasing cloud droplet concentration N_d until surface precipitation rate becomes small (<0.1 mm d^{-1}).

- Due to enhanced entrainment of dry air with higher N_d.

- Bretherton et al (2007): Higher N_d → Less sedimentation → more efficient entrainment, due to increased evaporation of liquid water in the entrainment zone.





Our Study: Case Setup

- Stratocumulus to trade cumulus transition: a composite case from the Northeast Pacific (Sandu, Stevens & Pincus, 2010; Sandu & Stevens, 2011). Summertime conditions (JJA2006-7).
- Simulation follows composite Lagrangian trajectory over progressively warmer SSTs with fixed subsidence.
- Finish after 3 days before breakup of capping Sc cloud.
- Basis for a GCSS Boundary Layer Cloud WG Intercomparison

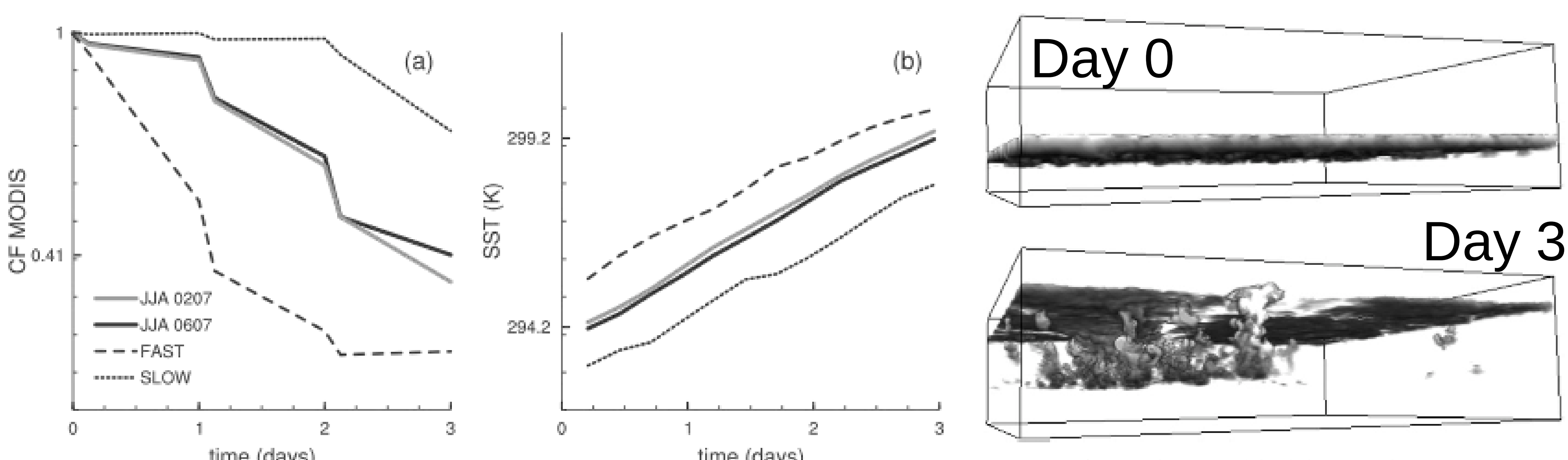
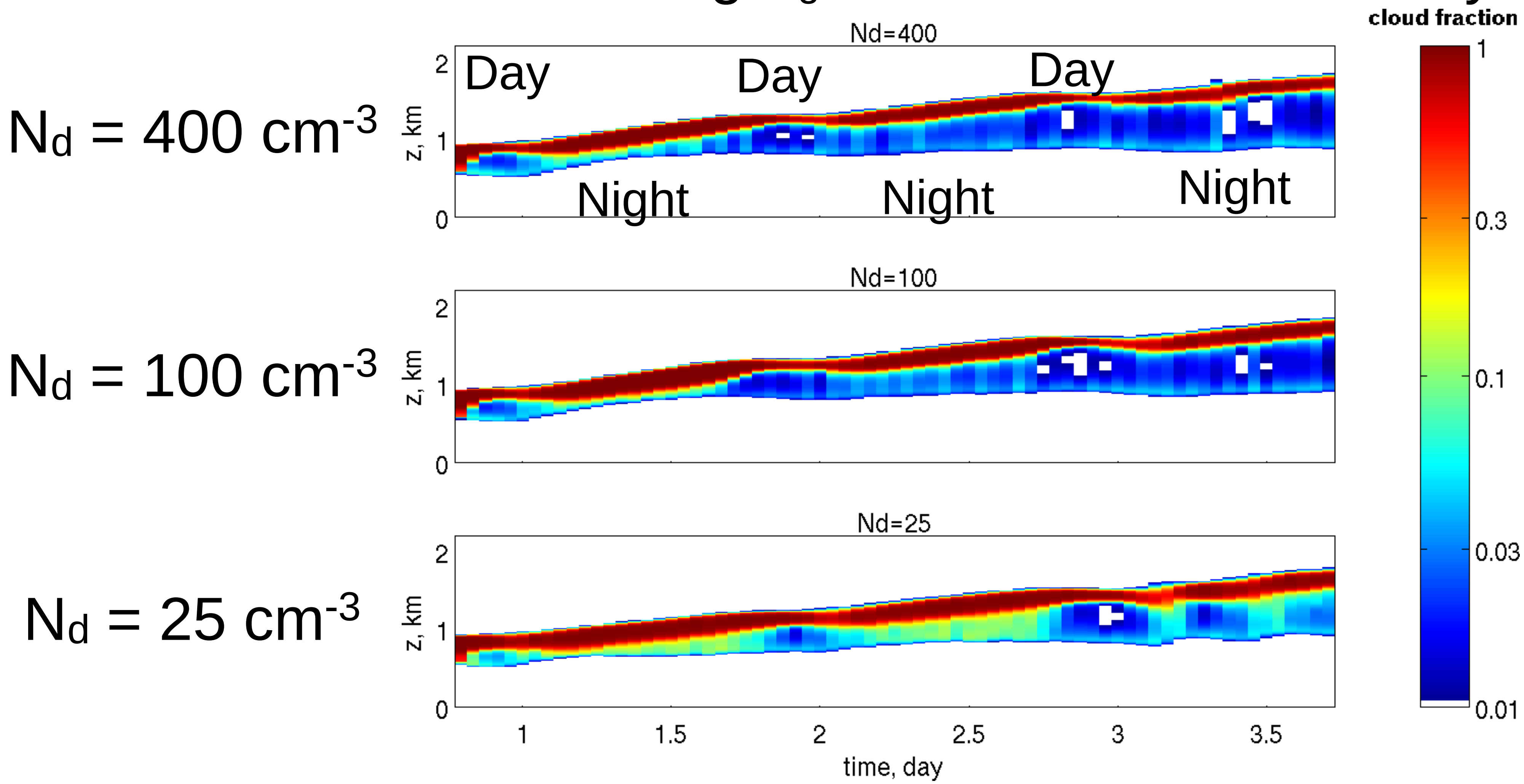


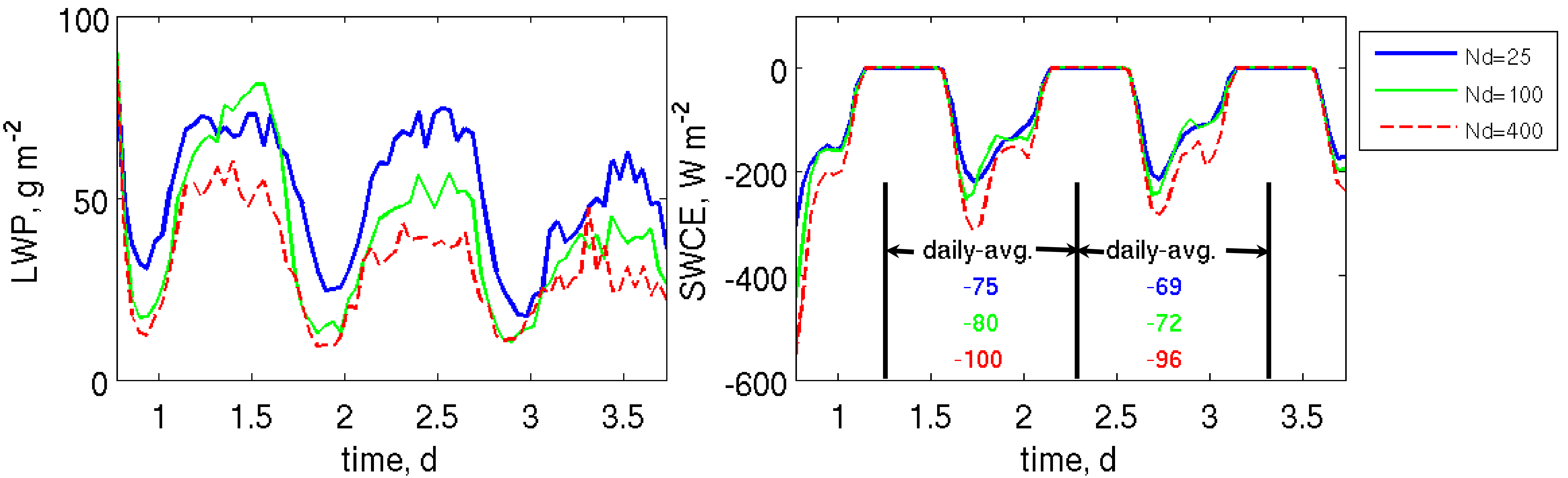
FIG. 3. An image of the cloud field simulated in the REF case, at (top) the beginning and (bottom) the end of the simulation.

LES results

- Large eddy simulation model: System for Atmospheric Modeling, v. 6.8 (SAM, Khairoutdinov & Randall, 2003). Lx=Ly~4.5km. $\Delta x=\Delta y=35$m, $\Delta z=5$m from ~0.5-2.5km.
- Microphysics: Khairoutdinov & Kogan (2000) with fixed $N_d=25$, 100, 400/cm^3.
- Radiation: RRTMG w/cloud droplet effective radius computed from LWC and N_d, assuming $\sigma_g=1.2$. Includes diurnal cycle.



Cloud thickness and albedo response to N_d



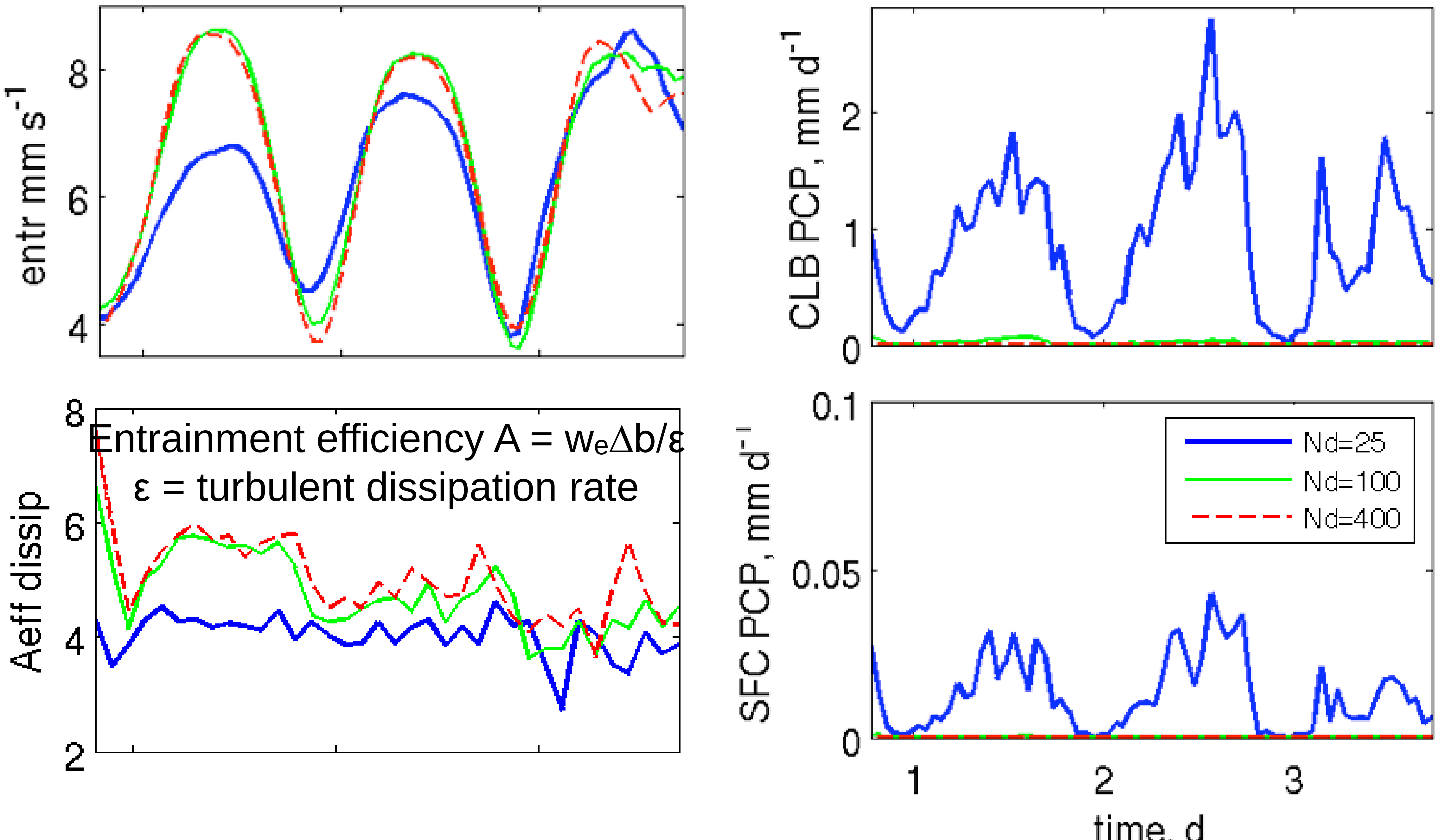
- Optical depth of an Sc layer $\tau \sim LWP^{5/6} N_d^{1/3}$.

  40% decrease in LWP ←→ $4 \times N_d$.

- N_d 25 → 100 cm^{-3}: 35% daytime LWP decrease, little albedo increase.

- N_d 100 → 400 cm^{-3}: little daytime LWP decrease, Twomey effect reigns.

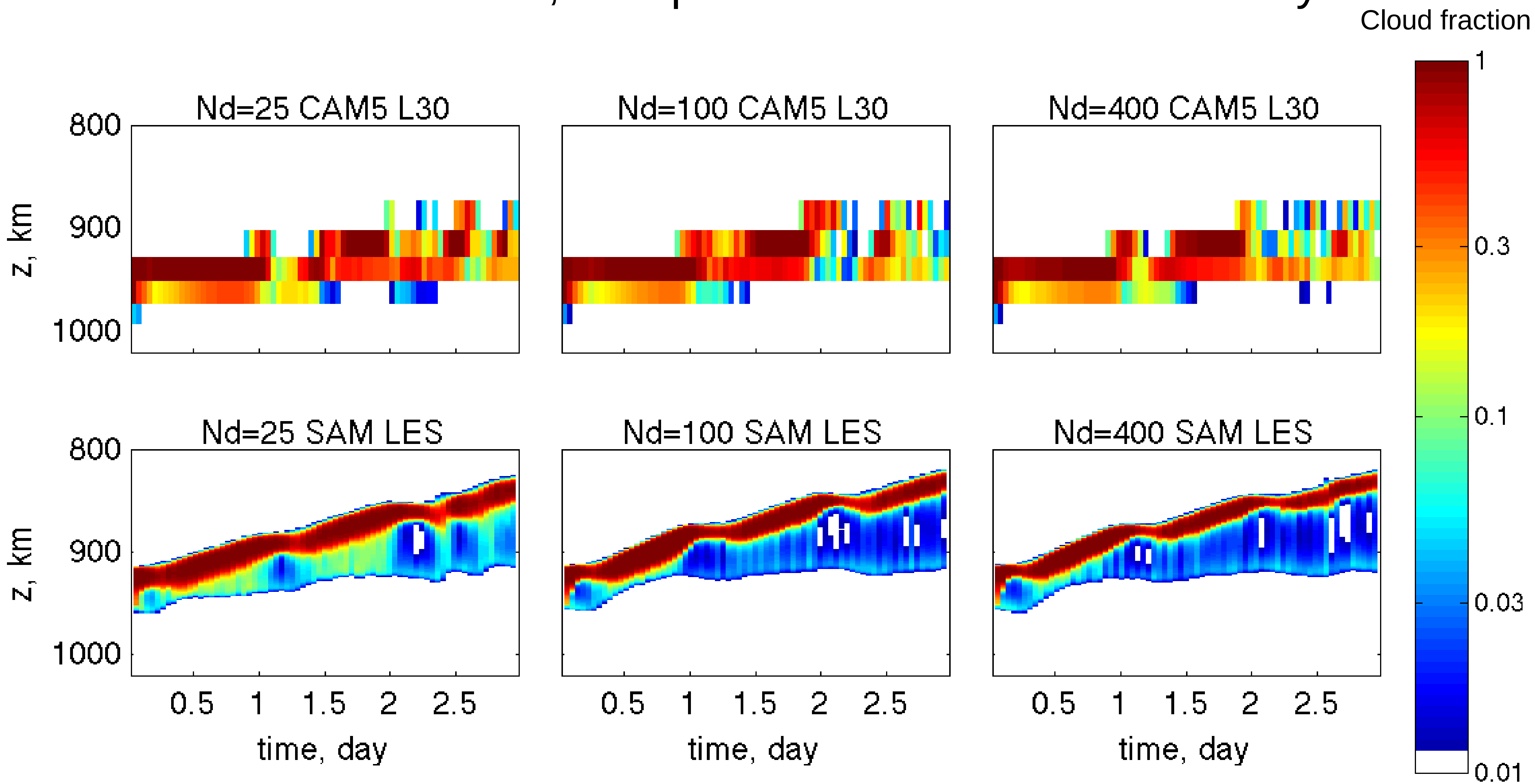
Entrainment and Drizzle



- Entrainment efficiency increases with N_d as expected.
- Drizzle evaporating below cloud base is significant for N_d=25

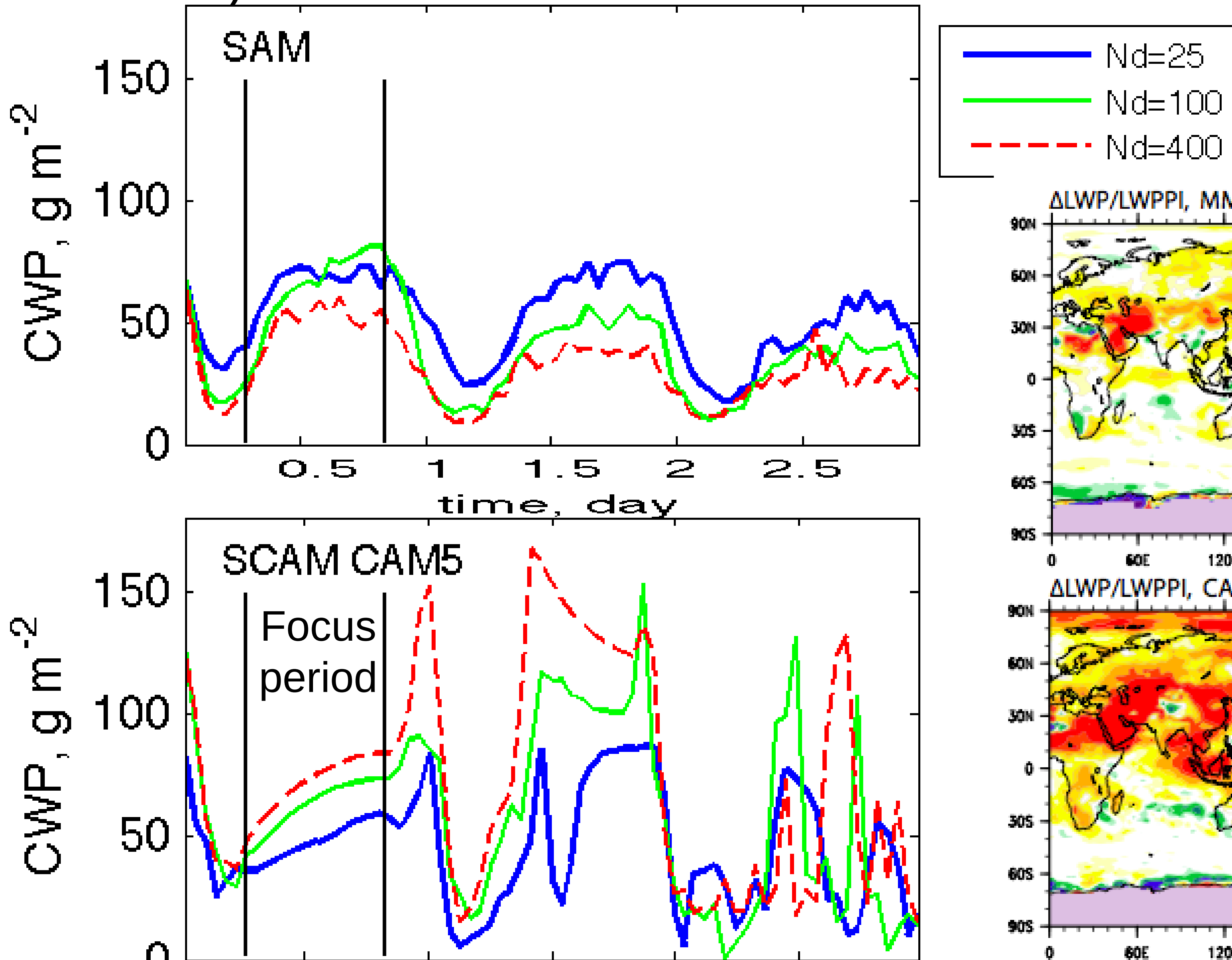
Can SCAM5 reproduce this behavior?

- 30-level SCAM5 not bad, except too little cloud on the last day.

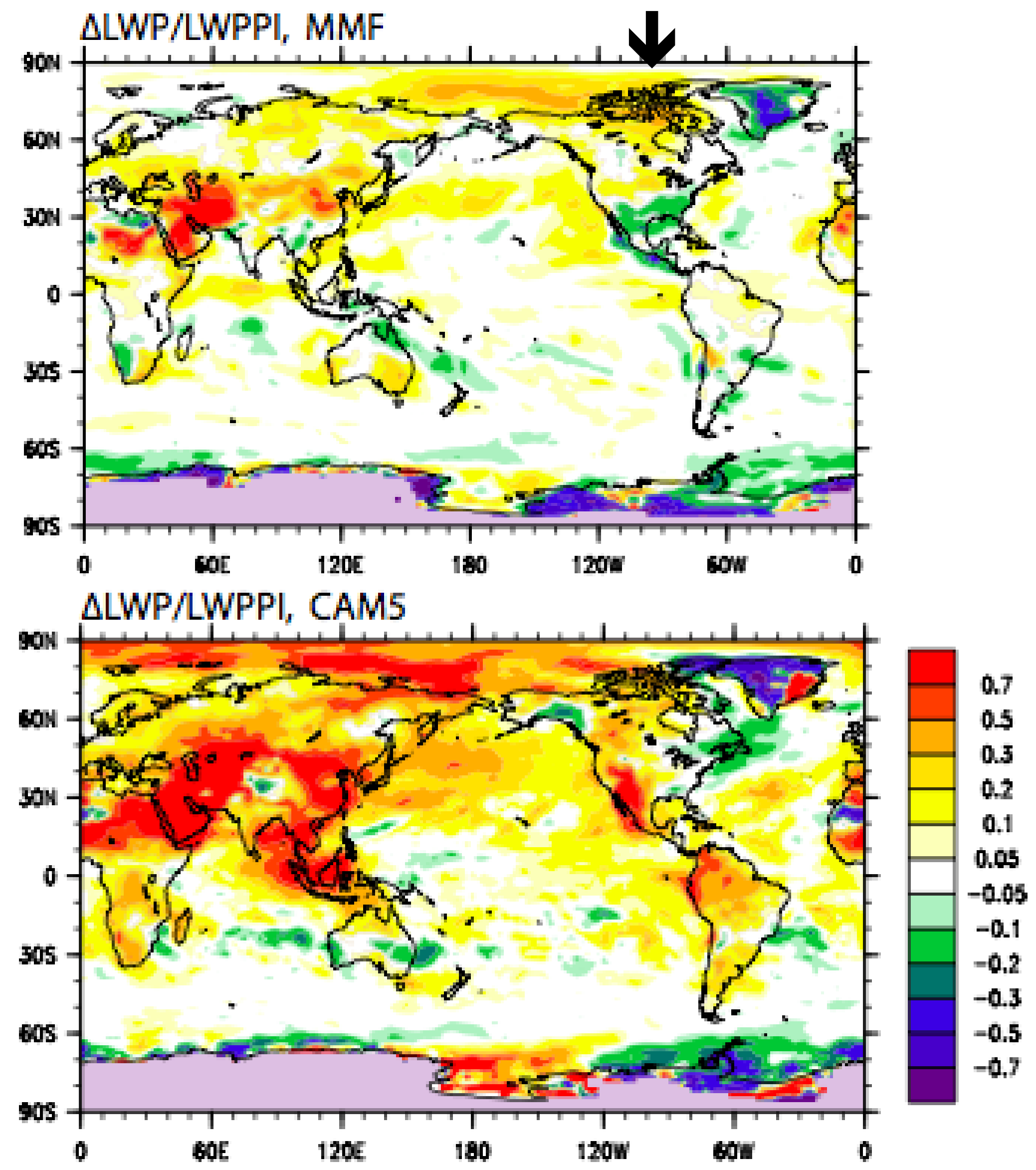


But 2nd indirect effect opposite to LES!

- SCAM5 has thicker cloud with increasing N_d. CAM5 simulations also show more positive $dLWP/dN_d$ than SP-CAM, contributing to their stronger aerosol indirect effect (Wang et al. 2011).



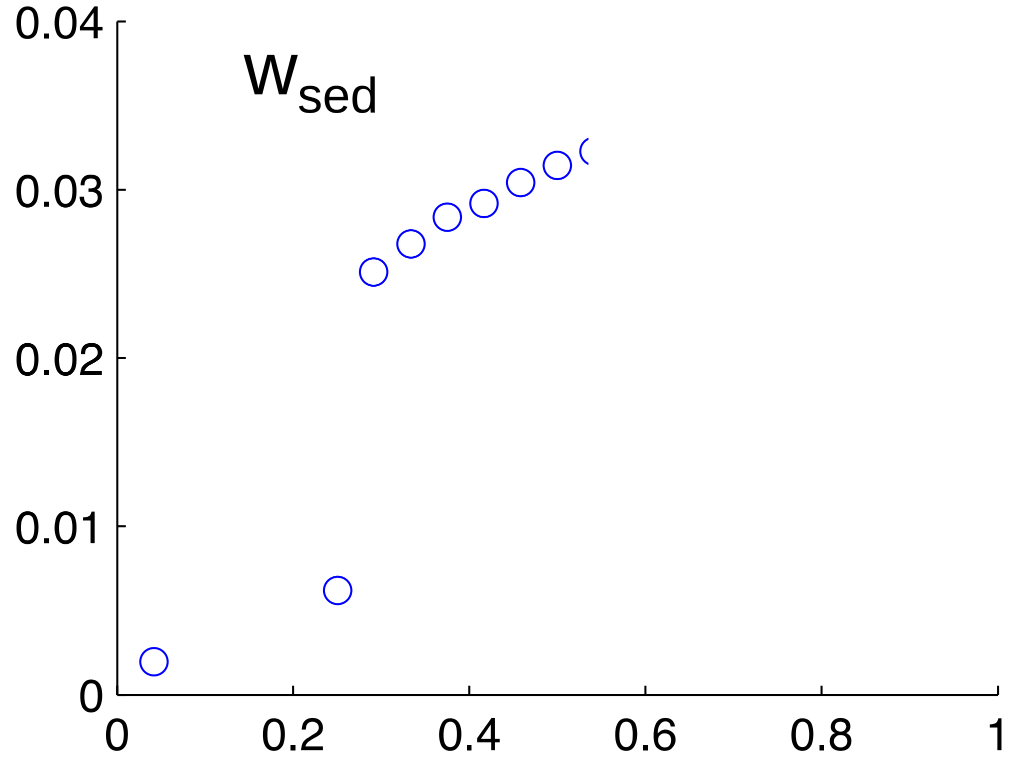
Reminiscent of Wang et al. 2011



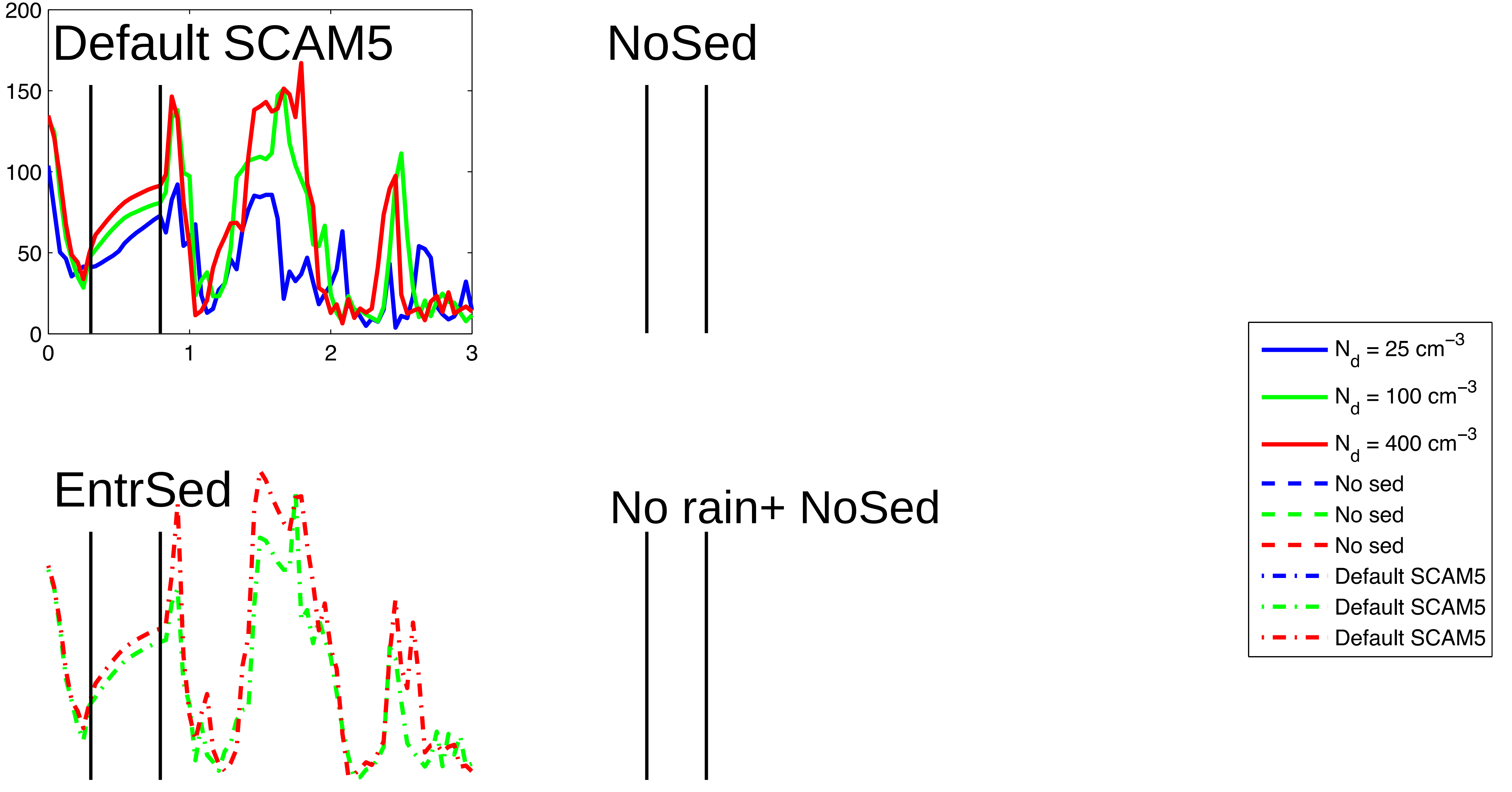
Sensitivity studies

- Default CAM5 has cloud droplet sedimentation at a predicted rate w_{sed} in stratiform microphysics, but no other entrainment-sedimentation feedback
- NoSed: Cloud droplet sedimentation off in stratiform microphysics.
- EntrSed: Add entrainment-sedimentation feedback by multiplying evaporative enhancement factor evhc – 1 in UWMT entrainment rate by (Bretherton et al 2007)

$\exp(-a_{sed}w_{sed}/w_*)$, $a_{sed} = 9$ (LES-tuned), w_* = convective velocity ~ 1 m s^{-1}

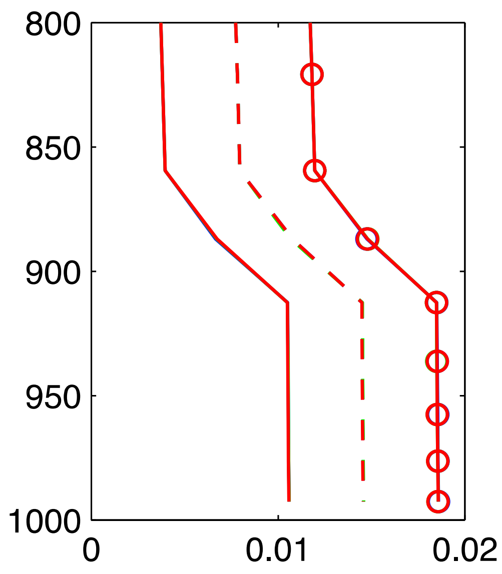


Sedimentation not the issue

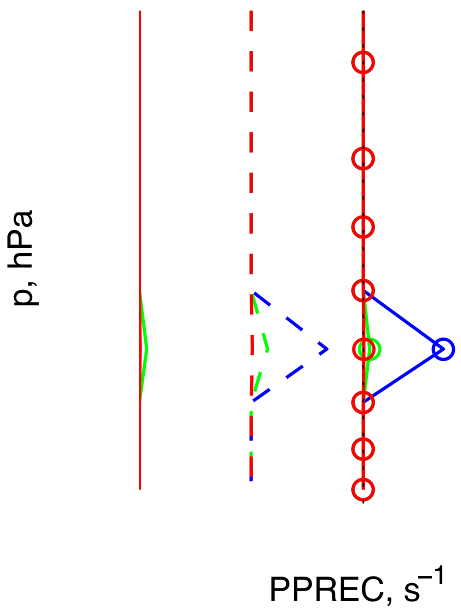


- Differences apparent in first night, when simulated PBL is well-mixed.
- Addition of stratiform sedimentation reduces LWP in all cases
- Addition of entrainment-sedimentation feedback brings some LWP back
- But N_d = 25 vs. 400 LWP difference as large with no sedimentation.

So evaporating drizzle is a likely culprit



EntrSed NoSed Default



- Look at t = 0.5 day (first night). Significant evaporating drizzle for Nd = 25.
- Loss of q_l during each timestep comparable to 400-25 Δq_l

Conclusions

- Large eddy simulations of composite Sc→Cu transition over NE Pacific.

- Aerosol sensitivity studied via prescribed cloud droplet number concentrations N_d = 25, 100, 400 cm^{-3} in Sc→Cu transition case.

- LES simulations show cloud thins as N_d increases, due to drizzle and cloud droplet sedimentation effects on entrainment. Leads to near cancellation of first indirect (Twomey) effect on daytime cloud albedo during first full day of simulation.

- SCAM5 simulations produce reasonable transition simulations have opposite dependence on N_d to LES, even if cloud droplet sedimentation is turned off. We don't know why.

- This case may shed light on $dLWP/dN_d$ and 2nd AIE in global CAM5.