Should autoconversion in marine stratocumulus be parameterized based on sea salt?

Jørgen B. Jensen, NCAR / EOL / RAF

Outline
- Variability of giant sea-salt aerosol size distributions
- Do giant sea-salt aerosol particles get carried up into cloud?
- Common autoconversion formulation (Khairoutdinov and Kogan, 2000)
- Large mean cloud droplet radius (Gerber, 1996; Rosenfeld and Lensky, 1998)
- Implication for condensational growth of drops formed on giant sea salt

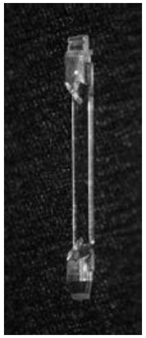
80 VOCALS aircraft soundings

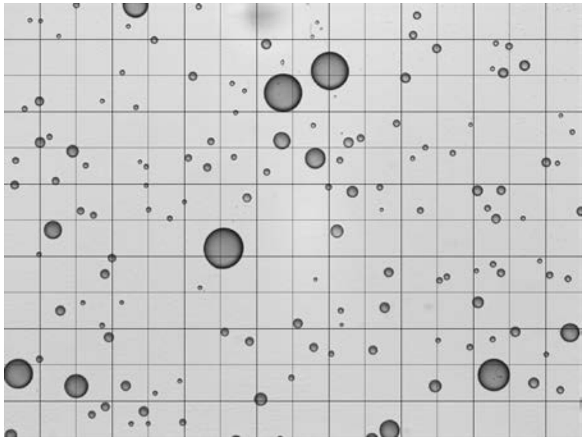
Conclusion

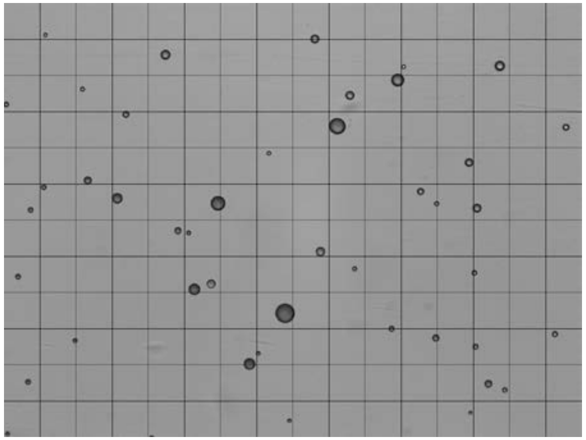
Microscope images of captured giant sea-salt aerosol particles.

VOCALS 2008, z = 200 m.

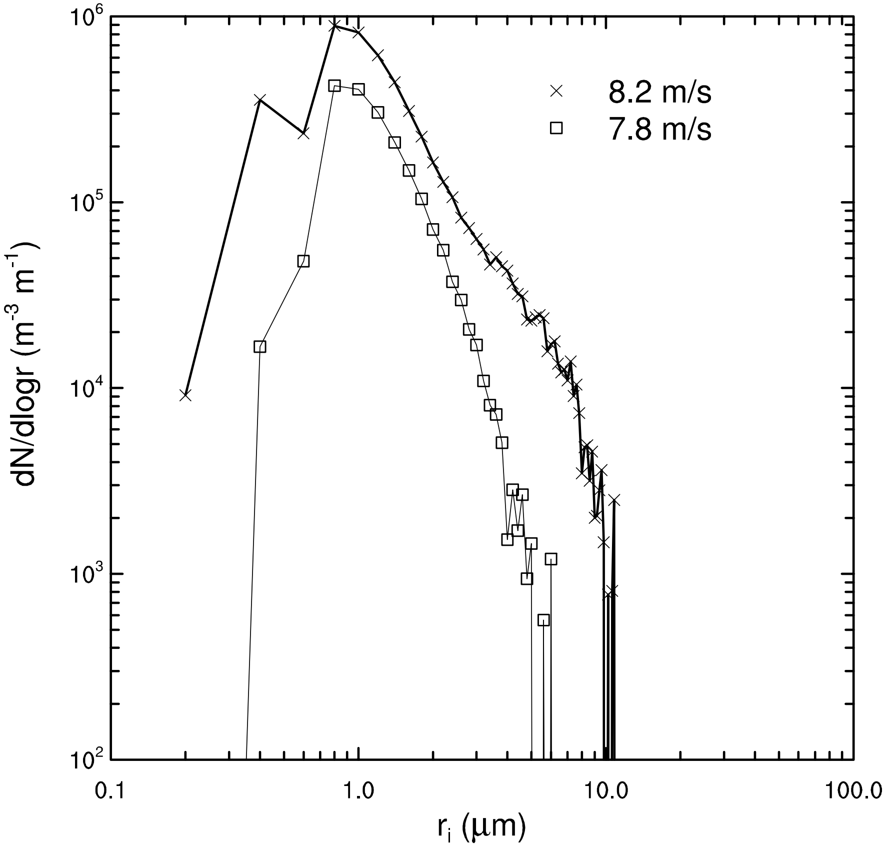
Max. dry radius: 6 and 3 µm.







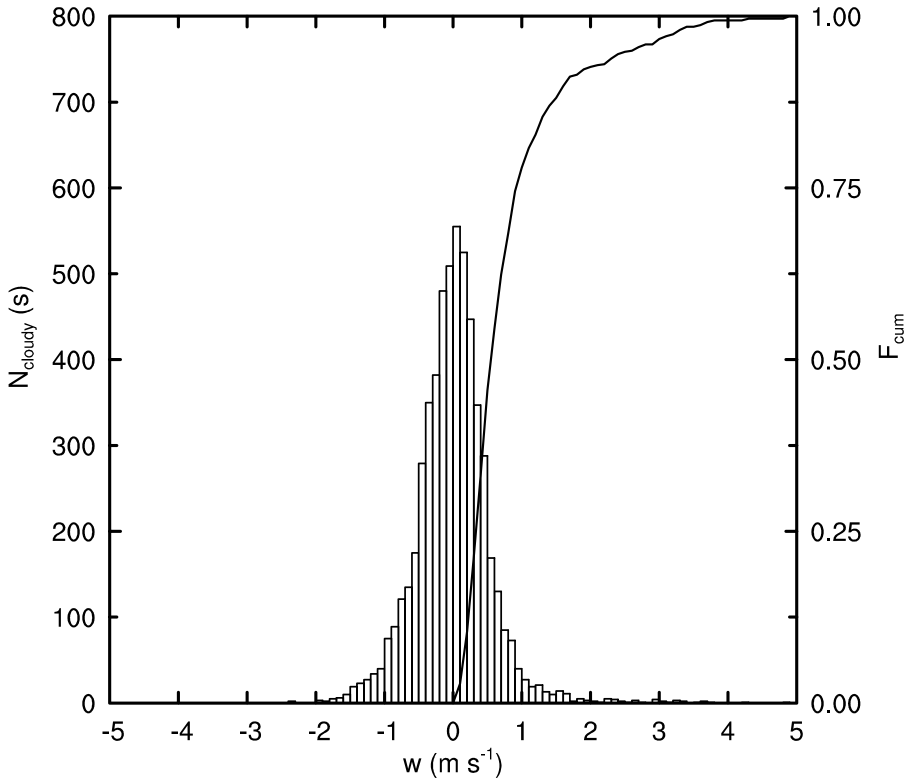
Size distributions, similar wind speeds

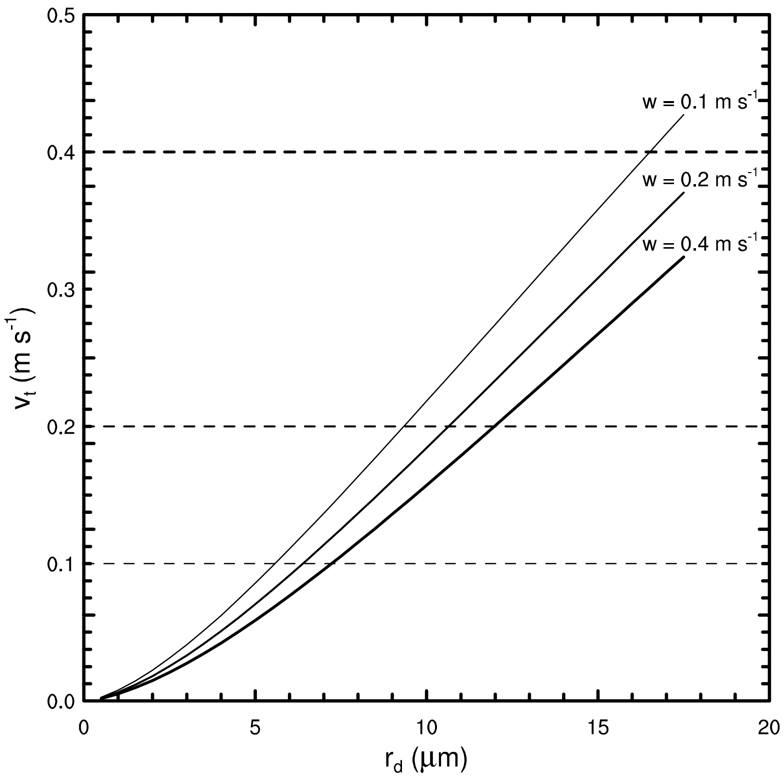


Example of considerable variability:
At r_d = 4 µm, there is a factor 10x difference.

If such giant sea-salt aerosol particles initiate drizzle drops, then we would expect a factor 10x difference in autoconversion rate   (all other equal).

Do giant sea-salt aerosol particles move with air up into clouds? Yes.





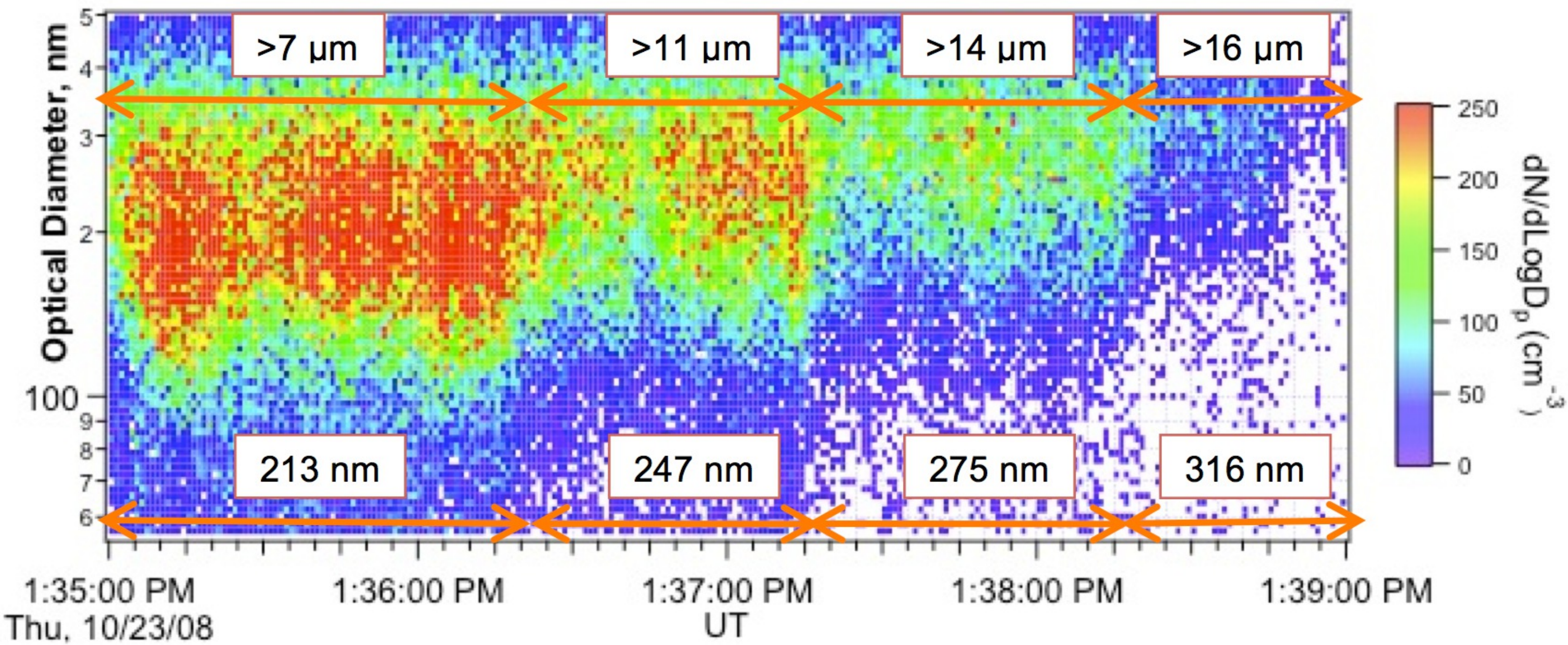
Histogram showing updraft (and downdrafts) from 80 profiles through VOCALS marine stratocumulus.

Average updrafts are 0.37 m/s for VOCALS clouds

Move giant sea-salt with air up towards cloud base. Depending on updraft speed, they will grow at different rates (greater lag from equilibrium size for high updrafts).

For dry radius, r_d = 5 µm, such particles will for almost all updrafts move up into cloud.

Twohy et al (2013), VOCALS: Larger cloud droplets (up to r ≈ 16 μm) are formed on larger CCN (up to ≈ 0.3 μm).



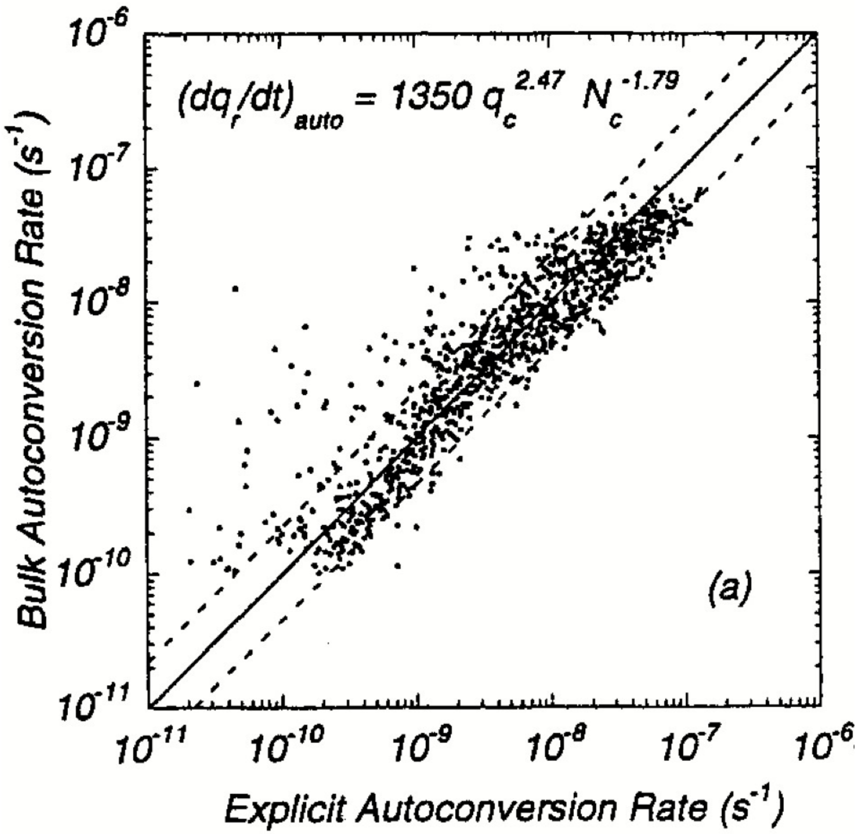
Observations taken with CVI inlet, that can selectively pass all particles above a chosen threshold size.

Conventional formulation of autoconversion:
E.g. Khairoutdinov and Kogan (2000):

$(dq_r/dt)_{auto} = 1350\, q_c^{2.47}\, N_c^{-1.79}$

Developed based on LES model with bin microphysics. Elegant!

Brilliant study, but also reasons to believe that rates may not be quite right.



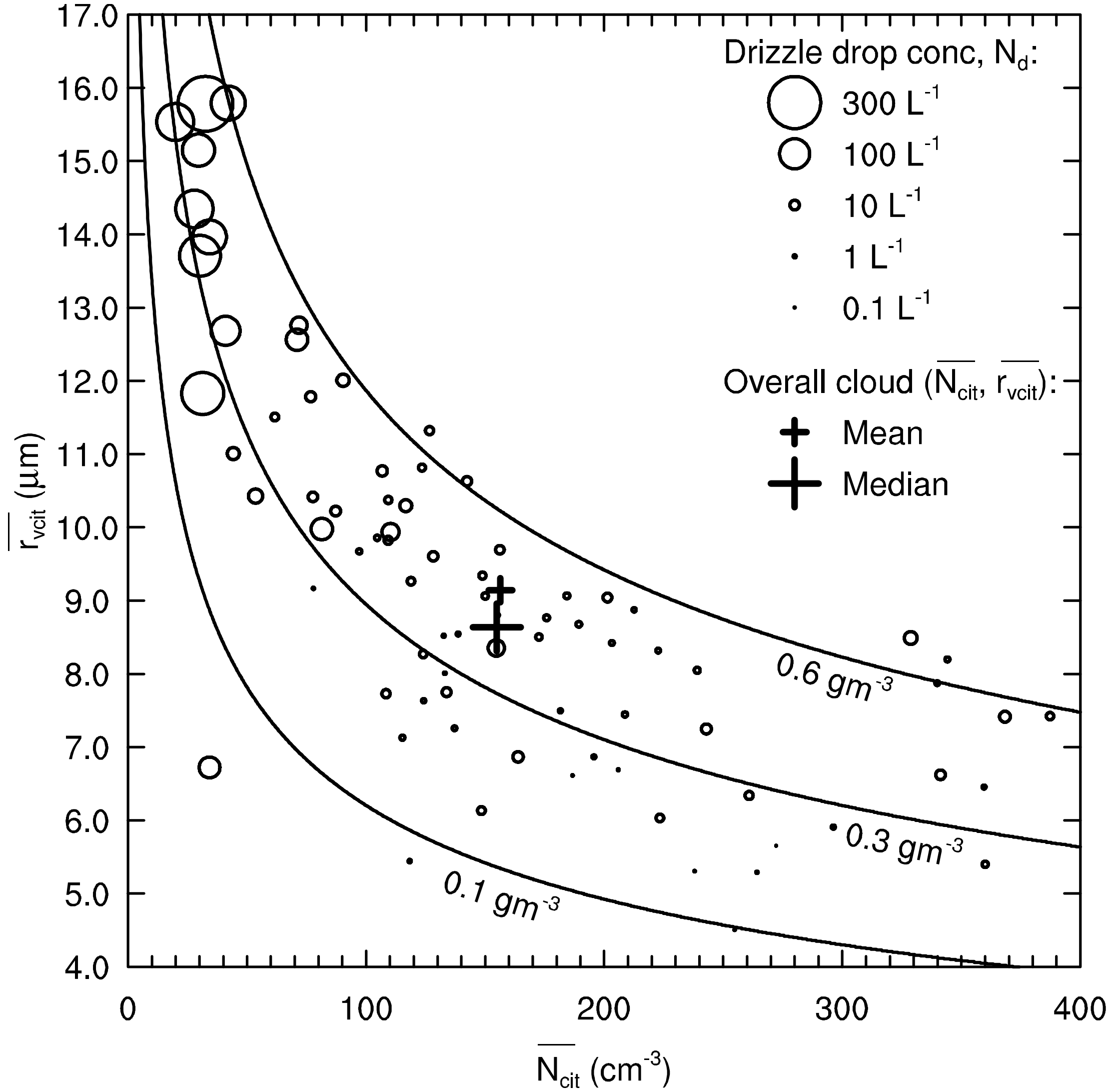
Scheme is only sensitive to properties of the many drops that are formed on small aerosol particles, CCN. (Droplet concentration N_c and size r_c).

Almost insensitive to the few drops formed on giant sea-salt aerosols (minimal contribution to N_c and r_c).

Compared gamma-distribution bulk microphysics model to results from the bin microphysics model.

Scheme has near universal acceptance.

Similar expressions by e.g. Liu and Daum (1964) and others.



Cloud top mean droplet radius.

Cloud top mean cloud droplet concentration.

80 VOCALS aircraft soundings from top to bottom of clouds.

Calculate the average drizzle drop concentration (r > 31 μm) over the entire depth of the cloud. (Observations from fast 2DC probe).

Higher drizzle drop concentrations are associated with larger mean cloud droplet size at cloud top.

But also considerable variation with e.g. LWC.

KK2000 scheme is very sensitive to cloud droplet radius through $q_c^{2.47}$

$(dq_r/dt)_{auto} = 1350\ q_c^{2.47}\ N_c^{-1.79}$

Gerber (1996) showed using aircraft observations that many drizzle drops were observed for cloud droplet effective radius, r_{eff} > 13-14 µm.

Rosenfeld and Lensky (1998) showed from satellite observations that a precipitation threshold exists for r_{eff} > 14 µm.

All qualitatively consistent.

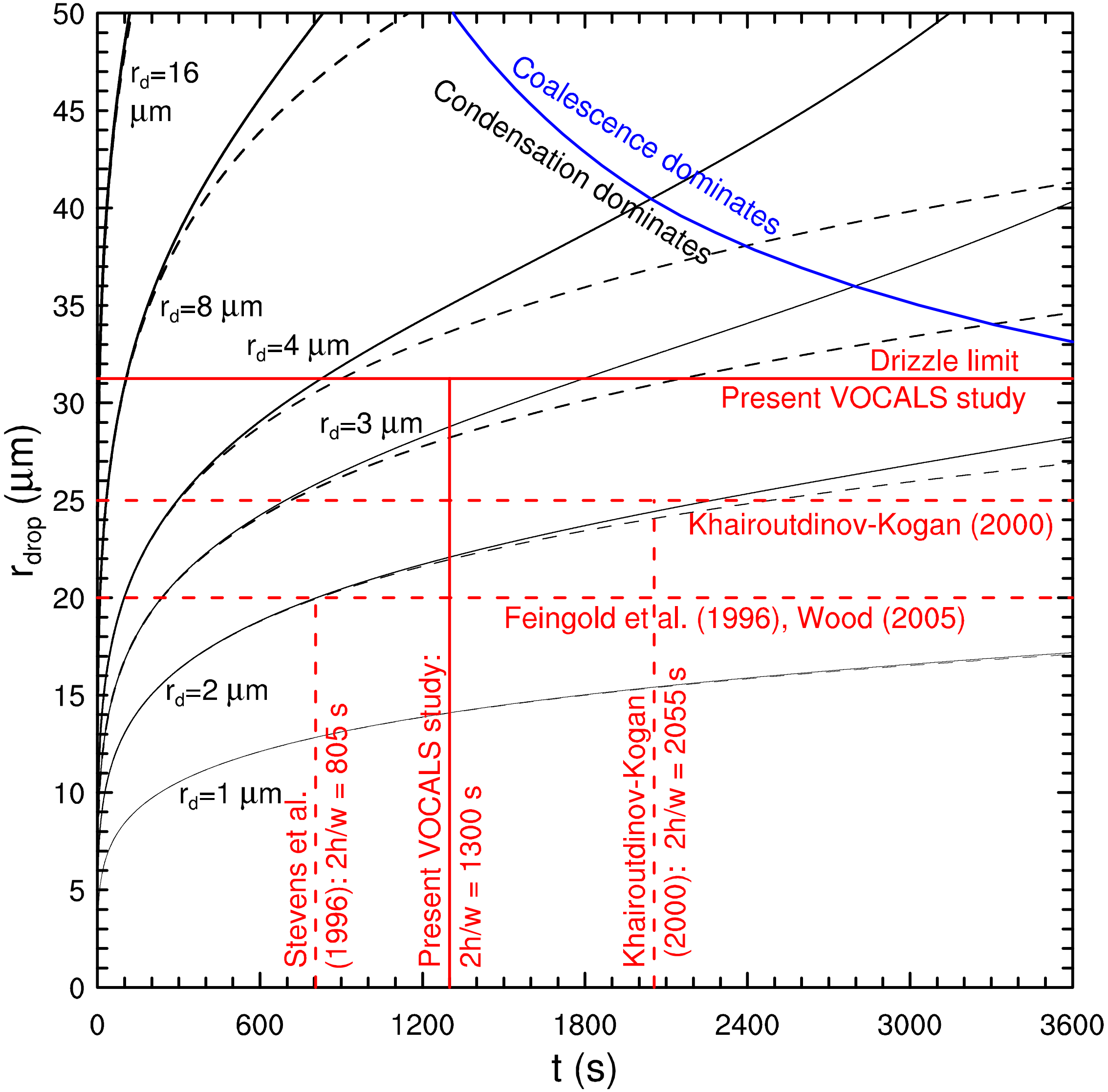
But what does large cloud droplets imply about processes in the clouds?

"Efficient coalescence" !

That is probably the most common answer.

"High supersaturation for a long time" !

Otherwise the majority of cloud droplets, formed on small CCN, cannot grow to large average sizes.



Growth histories of drops formed on giant sea-salt aerosol particles (r_d).

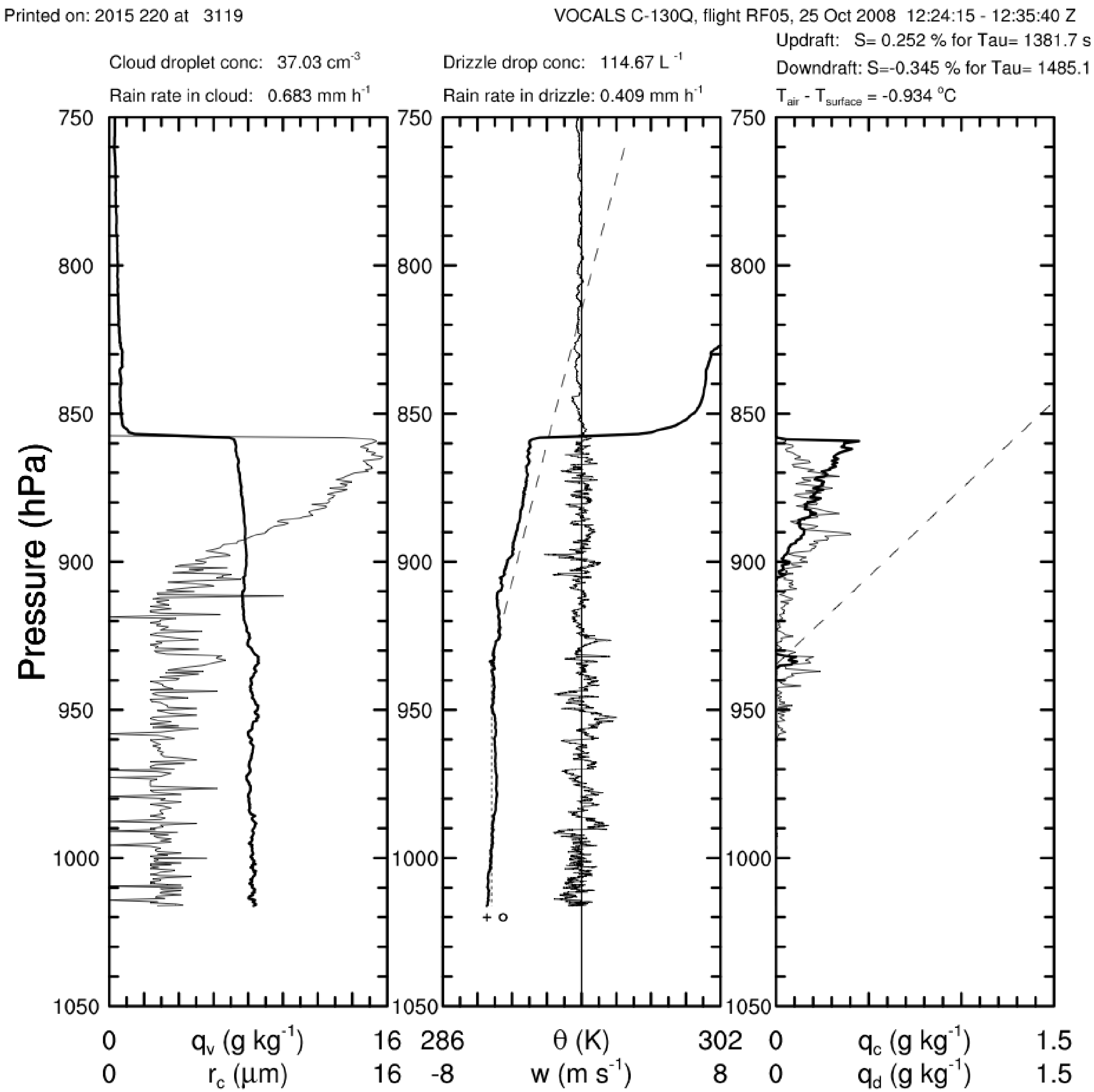
Exactly saturated conditions.

Dashed curves: Only condensation.

Solid curves: Condensation and continuous coalescence.

Not until drops have grown to the upper right domain, does coalescence growth become faster than condensation growth.

Strong acceleration of growth rates for high supersaturation (not shown)



VOCALS vertical profile:

Cloud deck with strong drizzle formation.

Based on Politowich and Cooper (1988), we can infer very strong supersaturations (0.25% over nearly 1400 s average ascent)

Conclusions:

Considerable variability in the concentrations of larger giant sea-salt aerosol particles (e.g. $r_d > 4$ µm). Mainly due to wind speed, but sea-state may also be important.

Almost all giant sea-salt aerosol particles can be carried by common updrafts into cloud.

Among cloud droplets, the larger droplets form on larger aerosols.
Extend to drizzle drops and giant sea-salt aerosol particles?

Condensation on giant-sea-salt is very rapid.

Coaleascence does not become dominant until after air has spend about 20-30 minutes in clouds. Condensation on giant sea-salt aerosol particles dominates the fastest growth rates.