What controls cloud droplet number concentration of trade wind cumuli?


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Motivation

Quantification of the sensitivity of the droplet number concentration towards changes in the aerosol microphysical properties
Cloud microphysics
- liquid water content (PVM)
- cloud droplet size, velocity and number concentration (PDI)
  • ...

Aerosol microphysics:
- particle number size distribution,
  \( 6 \text{ nm} < D_p < 2.6 \mu\text{m}; \text{SMPS, OPC} \)
- particle number concentration\
  \( D_p > 6 \text{ nm}; \text{CPC, fast CPC} \)
- CCN concentration \( 0.1\% < S < 0.67\%; \text{miniature CCNC, G. Roberts} \)

Meteorology
- 3d wind vector, temperature, humidity, pressure, ..
Two different approaches to quantify the sensitivity of the CDNC towards changes in the aerosol properties:

- Statistical analysis of almost 700 individual clouds during 10 research flights
- Comprehensive sensitivity study using a cloud microphysical parcel model
Measurements at cloud level

clouds measured at 1500 m asl, over ocean
Measurements at cloud level

Clouds measured at 1500 m asl, over ocean

Activated particles
Cloud statistics

Multivariate statistical analysis of 687 individual clouds (10 research flights):

- cloud microphysics
- meteorological parameters
- activated particles inside clouds
- aerosol microphysics below clouds
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measured clouds at different evolution stages (actively growing, decelerated, dissolving)
→ J. Katzwinkel et. al 2014, JAS, in review
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30% most active clouds (defined by LWC and updraft velocity)
What controls CDNC?

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30% most active clouds
What dominates? $w$ or $N$?

30% most active clouds

contours: median number of activated particles

$N \text{ [cm}^{-3}\text{]}$
Aerosol cloud interaction metric

\[ ACI = \frac{d \ln N_{\text{act}}}{d \ln N} \] (Feingold, 2001, JGR):

for different LWC bins

\[ LWC = 0.5 \pm 0.1 \text{ g m}^{-3} \]

\[ LWC = 0.7 \pm 0.1 \text{ g m}^{-3} \]

\[ ACI \approx 0.8 \ldots 1 \]

30% most active clouds
Sensitivity study

Sensitivity study for trade wind conditions:

sensitivity study using cloud parcel model
(Simmel and Wurzler, 2006, Atmos. Res.)

Input: bimodal particle NSD

variable parameters:
• updraft velocity (0.5 ... 5 m/s)
• total particle number concentration
  (100 ... 1000 cm\(^{-3}\))
• ratio between Aitken mode particles and total particle concentration (\(\gamma\))
• hygroscopicity parameter \(\kappa\) (0.1 ... 0.9)

comparable to Reutter et. al, 2009, ACP
Sensitivity study using parcel model:

Sensitivity study

model results

\[ N_{\text{act}}(w,N) \mid \gamma = 0.1 \]

\[ N_{\text{act}}(w,N) \mid \gamma = 0.9 \]

accumulation mode dominated

Aitken mode dominated
Sensitivity study using parcel model:

**aerosol-limited regime**

\[ N_{\text{act}}(w, N) \left| \gamma = 0.1 \right. \]

\[ N_{\text{act}} \text{ [cm}^{-3}\text{]} \]

\[ w \text{ [m s}^{-1}\text{]} \]

\[ N \text{ [cm}^{-3}\text{]} \]

**accumulation mode dominated**

**aerosol and updraft sensitive regime**

\[ N_{\text{act}}(w, N) \left| \gamma = 0.9 \right. \]

\[ N_{\text{act}} \text{ [cm}^{-3}\text{]} \]

\[ w \text{ [m s}^{-1}\text{]} \]

\[ N \text{ [cm}^{-3}\text{]} \]

**Aitken mode dominated**
Influence of particle hygroscopicity ($\kappa$)

Susceptibility of $N_{\text{drops}}$ towards changes in $\kappa$,

$$S(\kappa) = \frac{d \ln N_{\text{drops}}}{d \ln \kappa}$$
Influence of particle hygroscopicity ($\kappa$)

Susceptibility of $N_{\text{drops}}$ towards changes in $\kappa$, $S(\kappa) = \frac{d \ln N_{\text{drops}}}{d \ln \kappa}$

$\kappa$ only weakly affects CDNC

$S(N)$

$S(\kappa)$

model results
Conclusions

in the trade wind regime:

- CCN concentration defines CDNC (aerosol-limited regime)
- ACI metrics close to 1 (physically meaningful maximum)
- cloud base updraft becomes important for
  - large total particle number concentration (e.g., N > 1000 cm\(^{-3}\))
  - Aitken mode dominated particle number size distributions
- \(\kappa\) weakly affects CDNC
Thank you for your attention!