Can we use ground-based remote sensing to observe the first aerosol indirect effect at JOYCE ?

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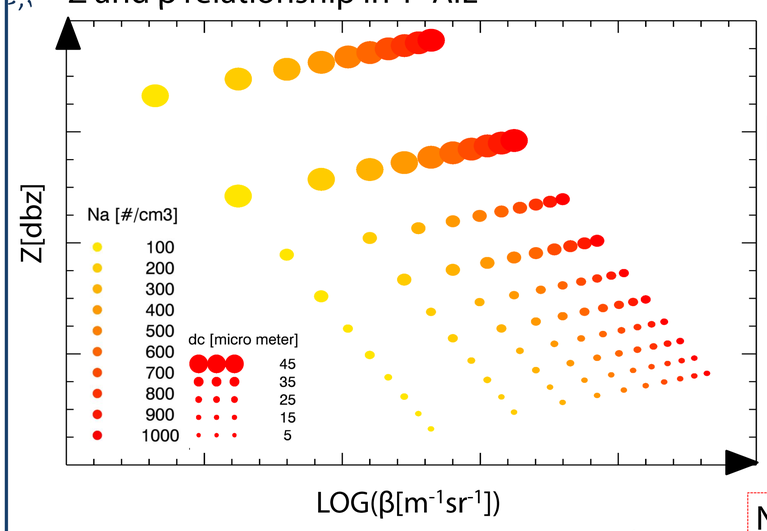
1. Highlights

- **A**erosol **C**loud **I**nteraction (ACI) – 1st Aerosol Indirect Effect (1stAIE) is investigated based on cloud radar reflectivity (Z) and ceilometer back scatter coefficient (β) measurements from **J**uelich **O**bservator**Y** for **C**loud **E**volution (JOYCE), Germany
- Cloud regimes are classified by the ACI identification scheme into 4 categories which might lead to different ACI characterization (regression and correlation of Z and β) :
  - Type 1: Long time single layer clouds (lasting >1 hour)
  - **Type 2**: Single layer clouds developed Atmospheric Boundary Layer (ABL) (lasting 15-20 minutes) ➡ **our study cloud regime**
  - Type 3: Multiple layer clouds (lasting 15-20 minutes)
  - Type 4: Broken clouds (lasting <15 minutes)
- During the ABL development, 1stAIE of the sub-cloud aerosols on ABL developing single layer clouds is typically observed

2. Principles

- Z and β relationship in 1stAIE



$$Z = \int N_c(d_c) \cdot d_c^6 dd_c$$

$$\beta = \int N_a(d_a) \cdot \pi \cdot d_a^2 \cdot Q_{sc} dd_a$$

Variable	Definition
N_c	cloud droplet number concentration (#/cm³)
N_a	aerosol number concentration (#/cm³)
d_c	cloud droplet size (μm)
d_a	aerosol size (μm)
Q_{sc}	scattering efficiency

1stAIE

$N_a \uparrow, d_a \rightarrow N_c \uparrow, d_c \downarrow$

Negative correlation of Z and β

- ACI index definition $ACI = \frac{dln \int_{cb}^{ct} Z\, dh_c}{dln \int_{cb-290m}^{cb-200m} \beta dh_a}\Big|_{LWP}$

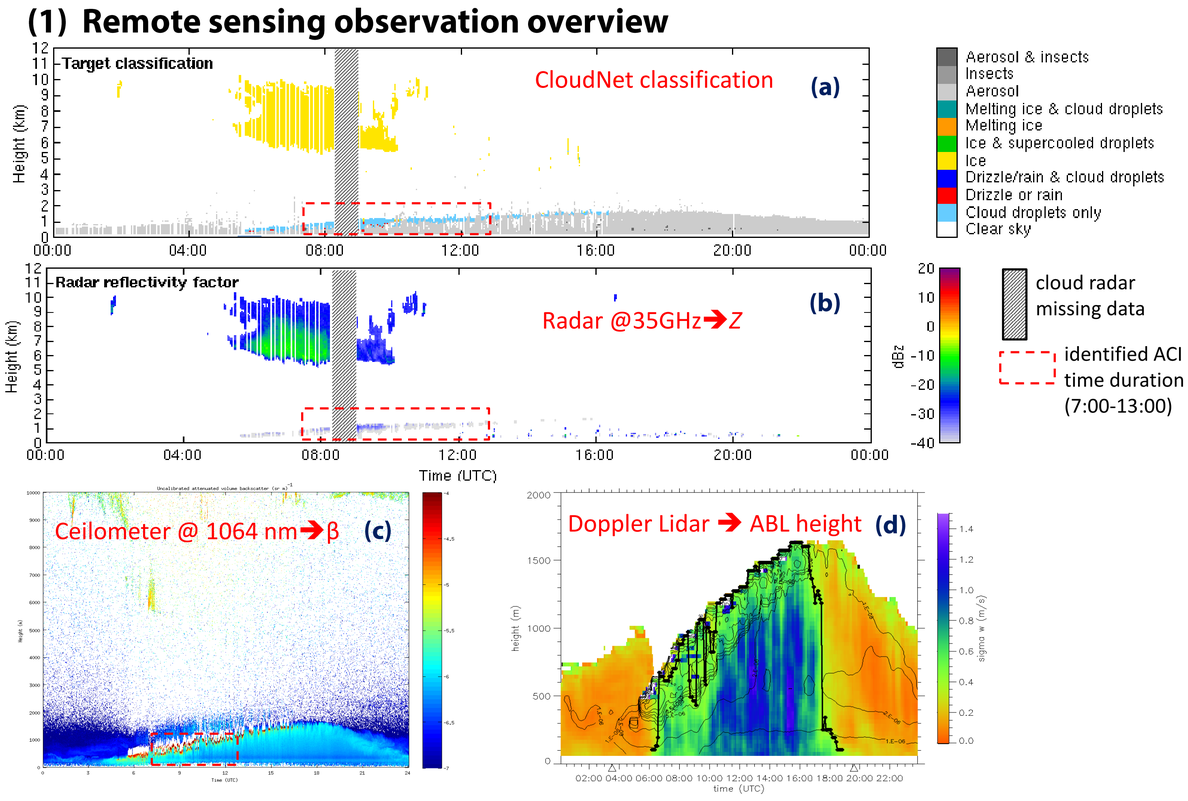
Cloud height (h_c) integrated Z from cloud top (ct) to cloud base (cb), and aerosol height (h_a) integrated β at a certain Liquid water path (LWP) interval (10 g/m²)

3. Results based on JOYCE remote sensing observations

- **Apply automatic ACI case identification scheme**
  - ✓ Only liquid cloud or liquid cloud with ice clouds above, but no precipitation, and no ice clouds attached
  - ✓ Turbulence: ABL mixing height on its lowest 200m below cloud base ➡ **select clouds coupled to sub-cloud aerosols**
  - ✓ Cloud presence time: 15-20 minutes ➡ **ABL developing cloud lasting time**
  - ✓ LWP standard deviation in 30 seconds < 10 gm^{-2}
  - ✓ Temporal resolution = cloud radar temporal resolution (30 seconds)
- **Identify ABL development Type 2 cloud regime: clouds coupled with sub-cloud aerosols**

3.1 A case study on 3rd June 2013

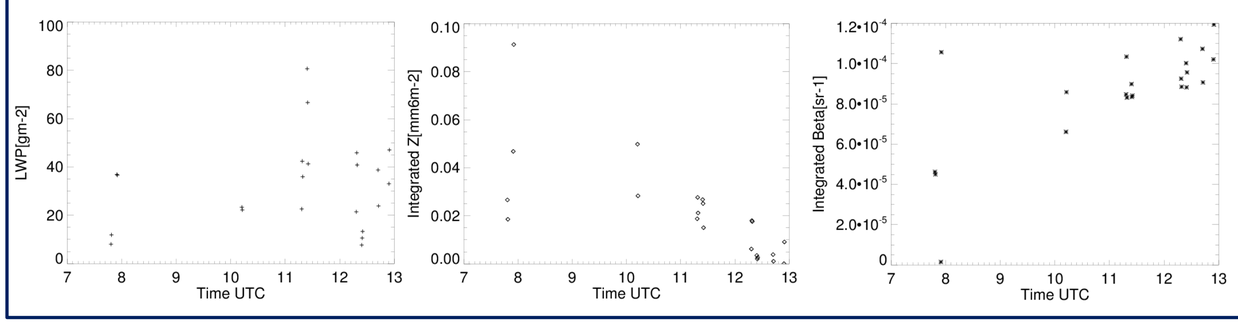
(1) Remote sensing observation overview



(a)CloudNet classification: liquid clouds appear in blue; (b) Cloud Radar at 35 GHz: Z measurements; (c) Ceilometer at 1064 nm: β measurements; (d) Doppler Lidar: standard deviation of wind vertical velocity observations from which derive ABL height

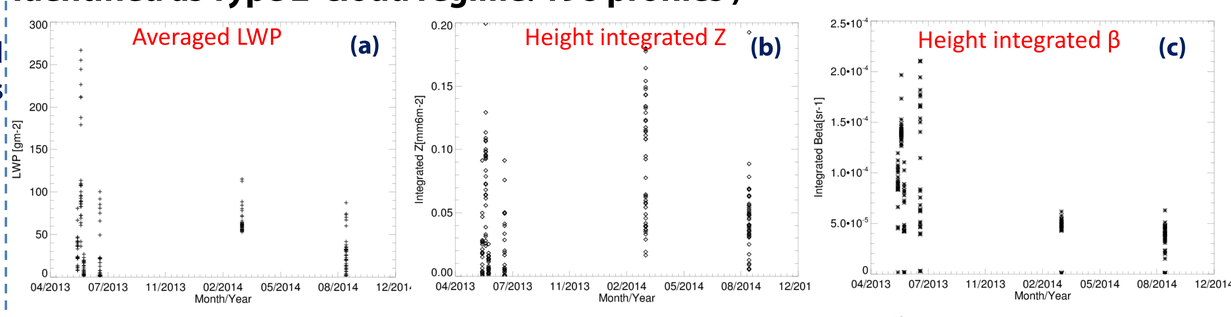
(2) Selection for Type 2: only coupled liquid cloud and sub-cloud aerosol measurements

Selected LWP averaged in 30 seconds | Selected height integrated Z | Selected height integrated β



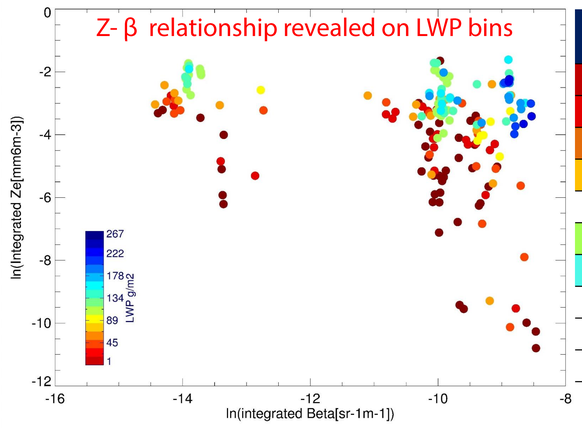
3.2 Long-term observation (from 1st Jan 2013 to 30th Sep 2014)

(1) Identification ABL development over long-term observations (6 days identified as Type 2 cloud regime: 198 profiles)



Time series of the selected column liquid clouds (a) LWP and (b) integrated Z ($ln \int_{cb}^{ct} Z\, dh$) coupled with sub-cloud aerosols (c) integrated β ($ln \int_{cb-290m}^{cb-200m} \beta dh$)

(2) ACI analysis

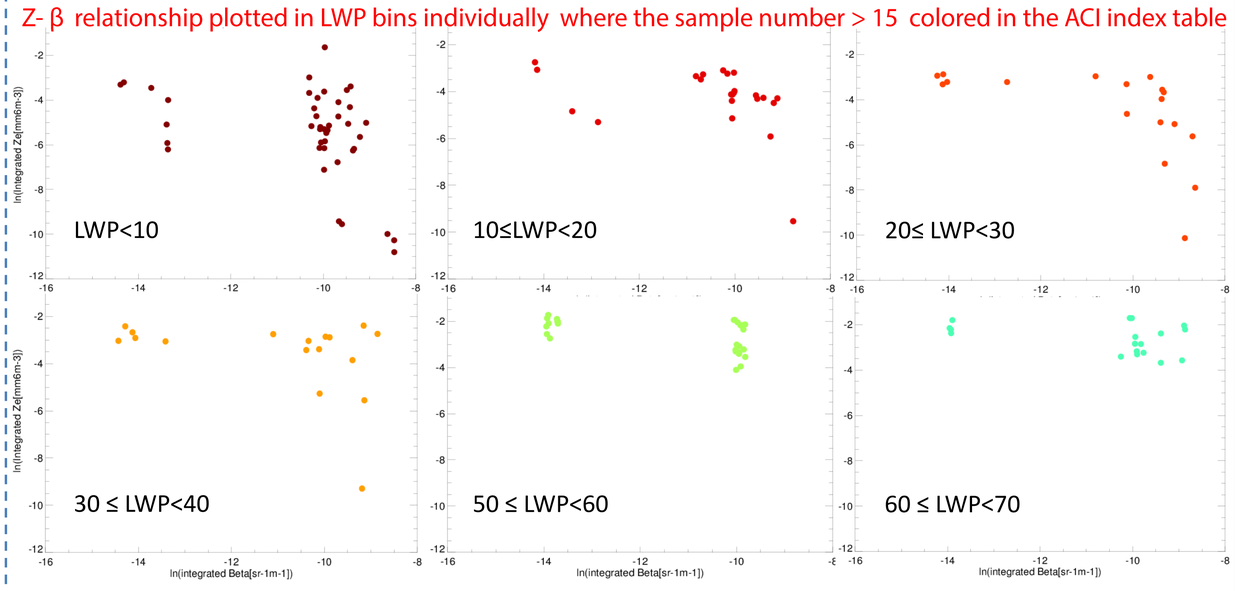


ACI index calculation results

LWP bins (g/m²)	ACI index	Correlation coefficient R(Z,β)	Correlation sample numbers*
<10	-0.51	-0.40	63 (>15)
10-20	-0.31	-0.35	21 (>15)
20-30	-0.54	-0.57	18 (>15)
30-40	-0.31	-0.38	17 (>15)
40-50	-0.38	-0.69	8
50-60	-0.18	-0.50	20 (>15)
60-70	-0.13	-0.35	17 (>15)
70-80	-0.12	-0.36	9
80-90	-0.18	-0.18	12
90-100	-2.25	-0.45	5

*ACI index grouped in LWP bins when sample numbers ≥5

Z- β relationship plotted in LWP bins individually where the sample number > 15 colored in the ACI index table



Summary and Outlook

- ABL developing single layer clouds in our 21-month remote sensing observations showed clear 1stAIE on boundary layer clouds with negative ACI index, but such ABL development cases with coupled liquid clouds and sub-cloud aerosols are not often happened and captured during a year at JOYCE (3 days /year)
- Future work
  - The ACI sensitivity test on LWP bin size and the upper limit of the Z integration
  - The 1stAIE analysis on other cloud regimes, e.g. multiple layer lasting clouds, and long time single layer lasting clouds
  - A Z and β relationship simulation based on aerosol and cloud condensation nuclei in-situ measurements