Characterization of residuals from ice particles and droplets sampled in tropical deep convective cloud systems during ACRIDICON-CHUVA

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Leibniz Institute for Tropospheric Research

Agenda

- Motivation
- Data overview
  - Comparison HALO-CVI residual particle and cloud particle concentration
    - to derive sampling characteristics of the system “HALO + CVI”
  - Residual particle size distribution
  - Residual particle black carbon content
  - Further residual particle chemical composition
  - Drop charges
- Summary and outlook

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Motivation

- HALO-CVI:
  - Inlet system to sample cloud particles (drops, ice particles)
  - Evaporation of the water or ice phase, releasing residual particles

- Which particles form drops at cloud base ?
- Which of these particles reach the anvil ?
- “inflow – outflow” “cloud processing”

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Measurements behind the CVI inlet

Instrument	Parameter	Partner	This presentation
CPC	number concentration	TROPOS	yes
PSAP	absorption coefficient, BC	TROPOS	yes
Electrometer	drop charges	TROPOS	yes
UHSAS	size distribution	TROPOS	yes
C-ToF AMS	chemical composition	MPI-C	yes
SP-2	BC number concentration	MPI-C	yes
CCNC	CCN concentration	MPI-C	no
Impactor	chemical composition	MPI-C	no
SNOOPY	BC number concentration	DLR-IPA	no
FINCH	INP concentration	Uni Frankfurt	no

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HALO-CVI sampling issues

- Sampling location at the upper fuselage
  - not optimal for cloud particle sampling but no alternatives possible
  - inlet design can only be optimized for a certain flight condition
    - particle trajectory calculations available from Katrin Witte (TN-2008-003-A)
    - 40000 ft, TAS = 209 m/s, T = 226.6 K, p = 187.5 mbar, pitch angle = 3.7°)
  - sampling as close as possible to the front of HALO
  - Intake height was chosen to sample only slightly size dependent
  - Sampling Efficiency: ≈ 100 % (5 < D < 50 µm)

    (but slight oversampling ≈ 120 % for 10 and 30 µm)

    ≈ 0 % (D > 50 µm)

    for the given flight condition

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HALO-CVI sampling issues

- No significant shattering effects at the CVI shroud and inlet

But:

- Unknown but possible shattering of ice particles at the front of HALO (cockpit) that could produce artefact sampling
- TN-2008-003-A (Katrin Witte):
  - 2% of 10 µm and 4 % of 30 µm ice particles have contact with the fuselage
  - percentage of larger particles?
  - trajectory of fragments?

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HALO-CVI sampling issues

- CVI lower cut-off diameter (minimum 5 µm) depends on:
  - CVI counterflow (weak dependence)
  - True Air Speed (strong dependence)
  - Angle of attack (weak dependence for horizontal flights)

➢ CVI undersampling at lower level in dependence of cloud particle size distribution

- FZJ found strong enrichment (factor 10 to 100 in terms of IWC) of small ice particles (< 60 µm) during ML-CIRRUS at the upper fuselage inlet positions (which is much larger as expected from the Technical Note) by TGI measurements.
  (no shattering effect, since this won't change IWC)

➢ CVI oversampling at all levels in dependence of cloud particle size distribution.

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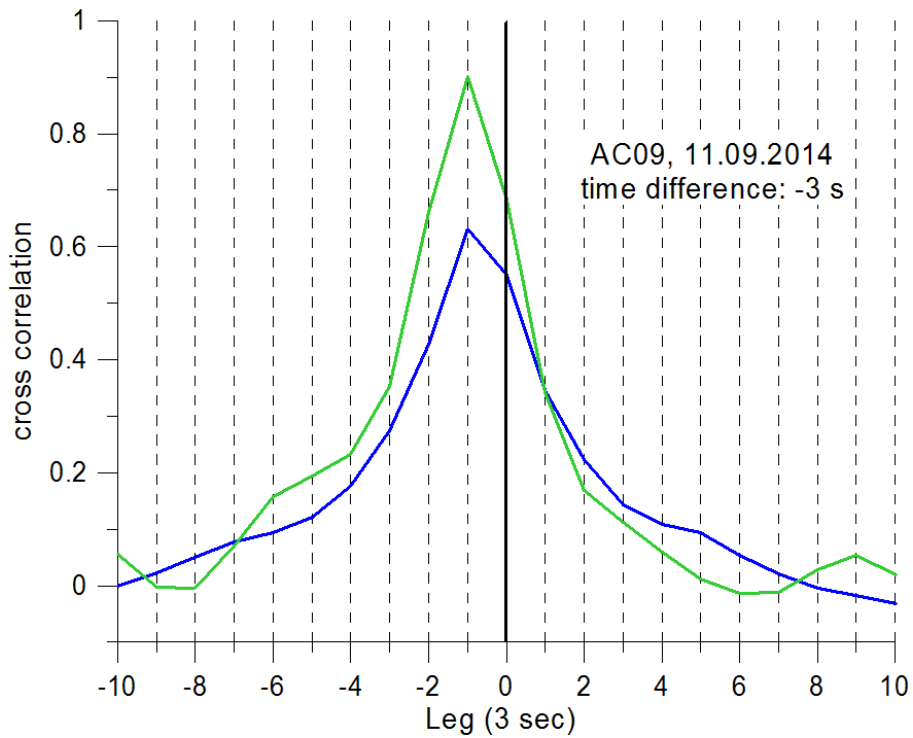
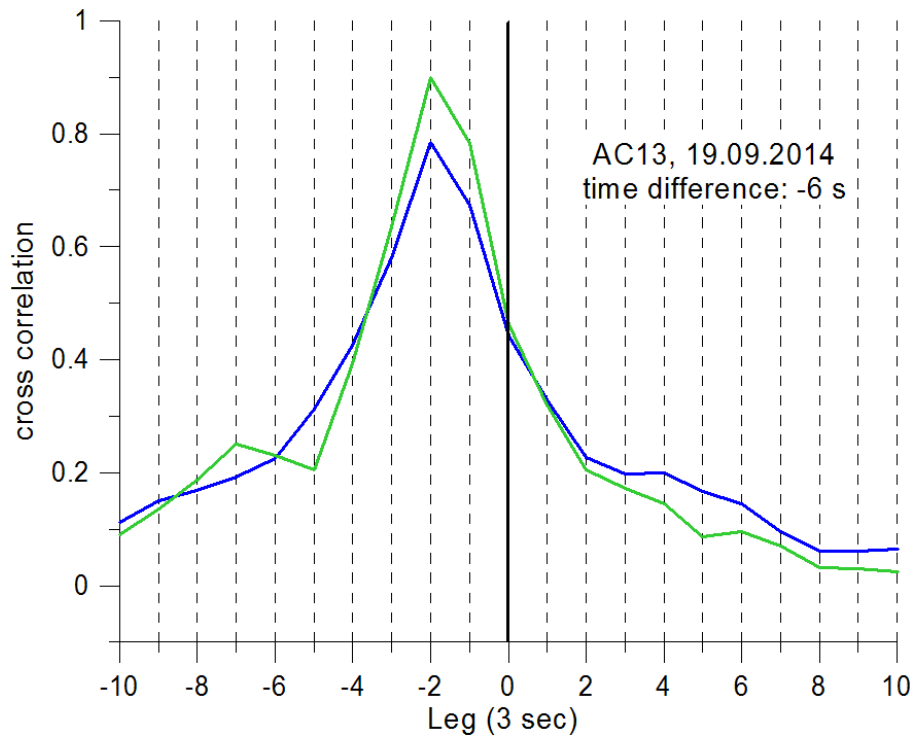
HALO-CVI measurements: number concentration

- Comparison of CVI residual particle and NIXE cloud particle number concentrations:
  - CVI time resolution is 3 sec; averaging NIXE data to 3 sec
  - Cross correlation calculations to determine time shift between CVI and NIXE





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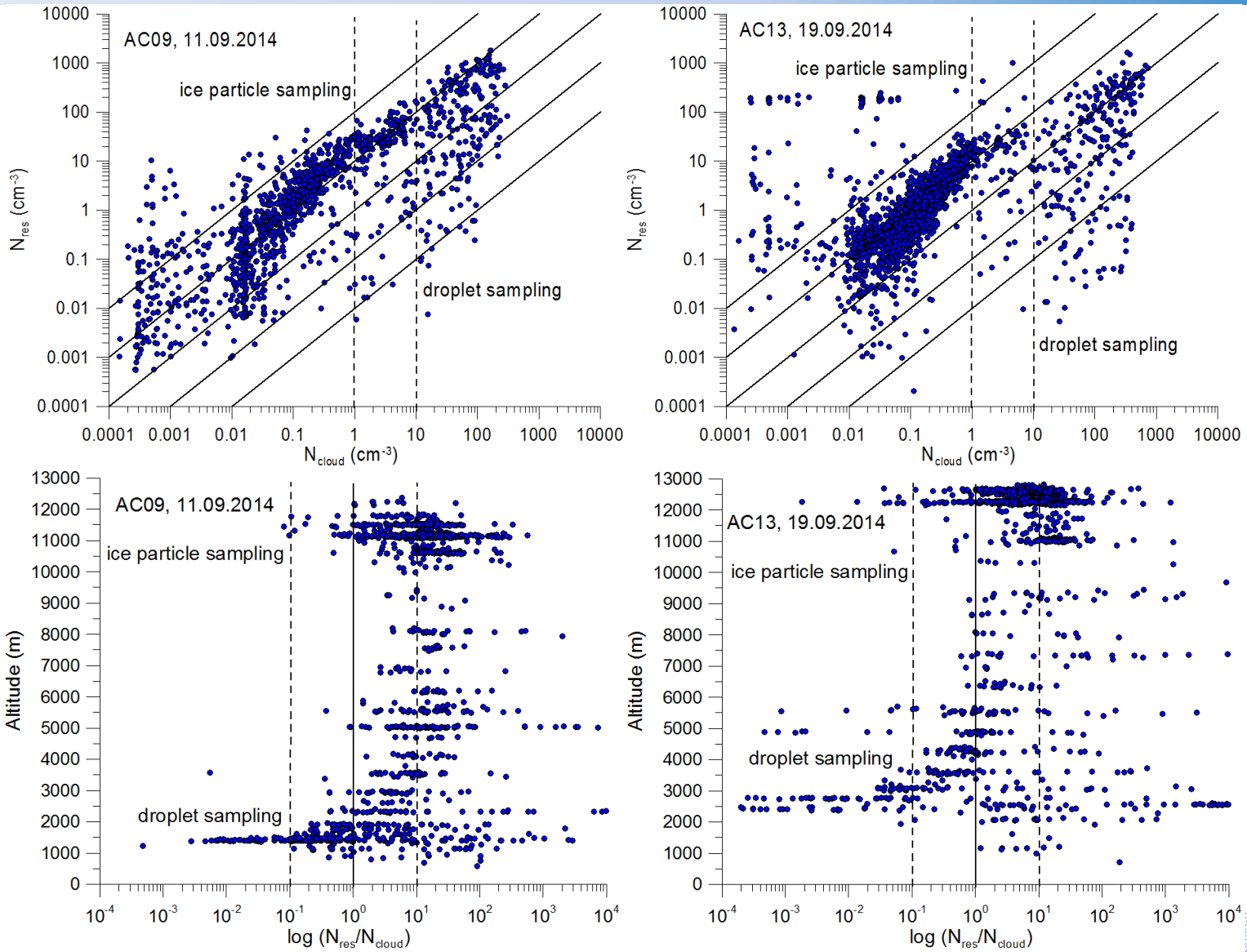
HALO-CVI measurements: number concentration



Lower levels: over- and under-sampling cancels out

Higher levels: over-sampling by a factor of 10, but reduced for highest levels

larger time averaging is needed

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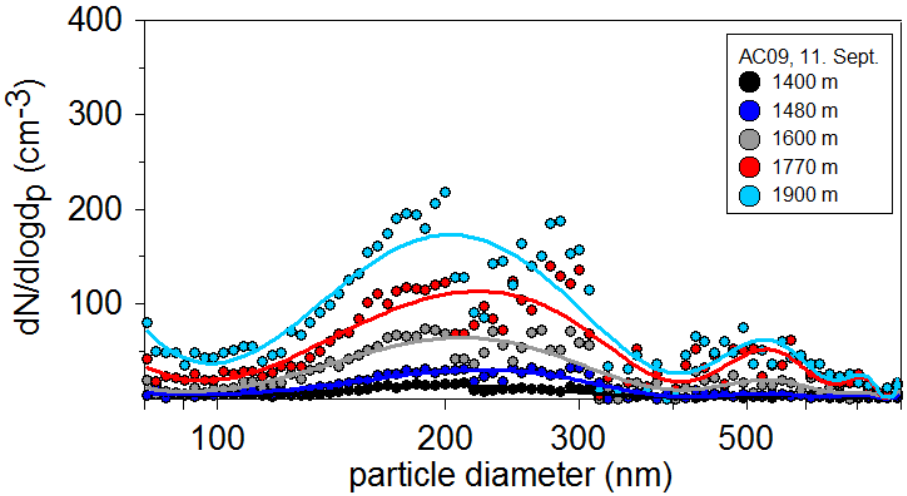
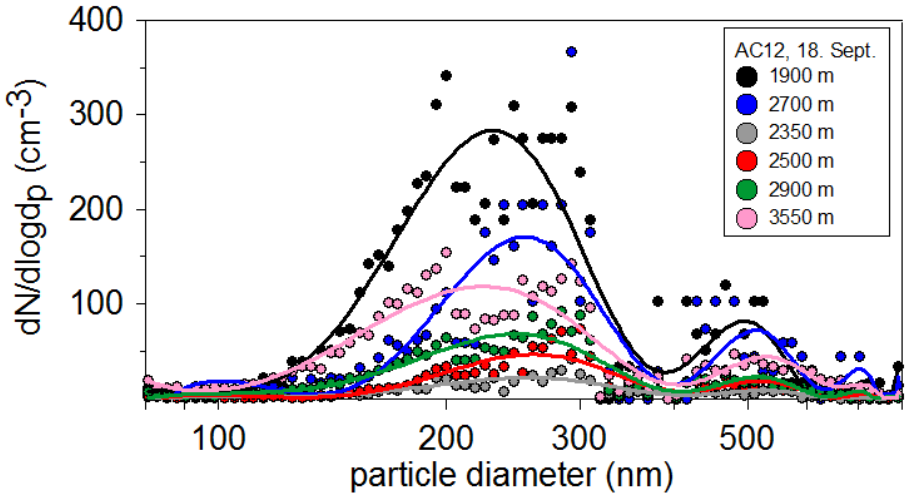
HALO-CVI measurements: size distribution

UHSAS: 80 – 1000 nm





- Preliminary, maybe problems with one amplifier stage
- Lower levels: typical CCN distributions
- Increase of $dN/dlogd_p$ with height most likely due to a reducing CVI cut-off diameter
- Mode diameter between 200nm and 300 nm and slightly smaller for clean conditions
- Second mode at 500 nm ?
- No determination of $D_{50\%}$ activation diameter possible.

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HALO-CVI measurements: black carbon

PSAP: absorption coefficient (m^{-1}), correction from Bond et al. (1999)

MAC = 10 m^2 g^{-1}, BC mass concentration (µg m^{-3})

$$BC_{mass} = \frac{\sigma_a}{MAC}$$

SP-2: BC mass concentration (µg m^{-3}); 60 – 600 nm

BC number concentration (cm^{-3}); 60 – 600 nm

SC number concentration (cm^{-3}); 180 – 600 nm (non-absorbing particles)

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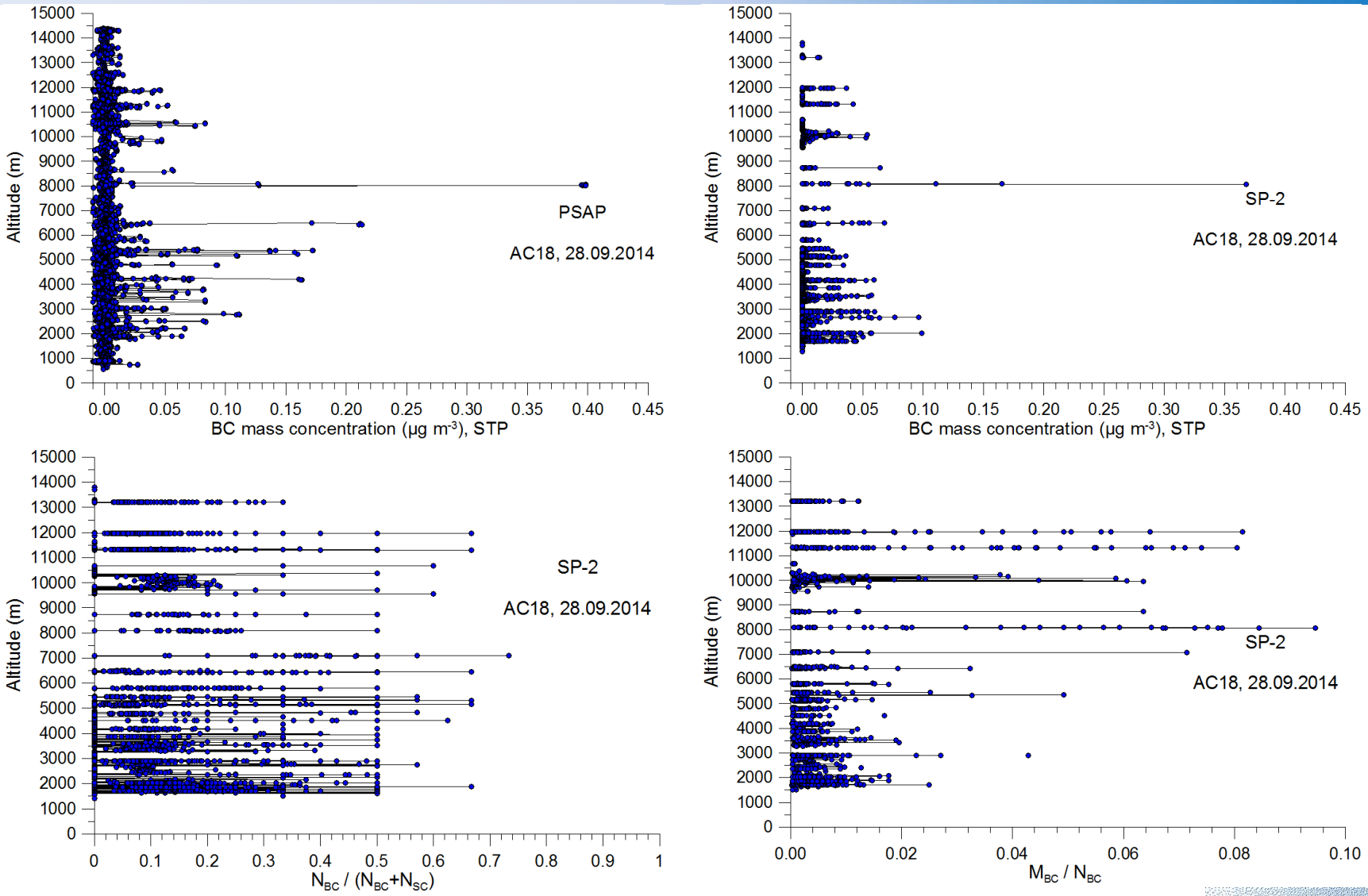
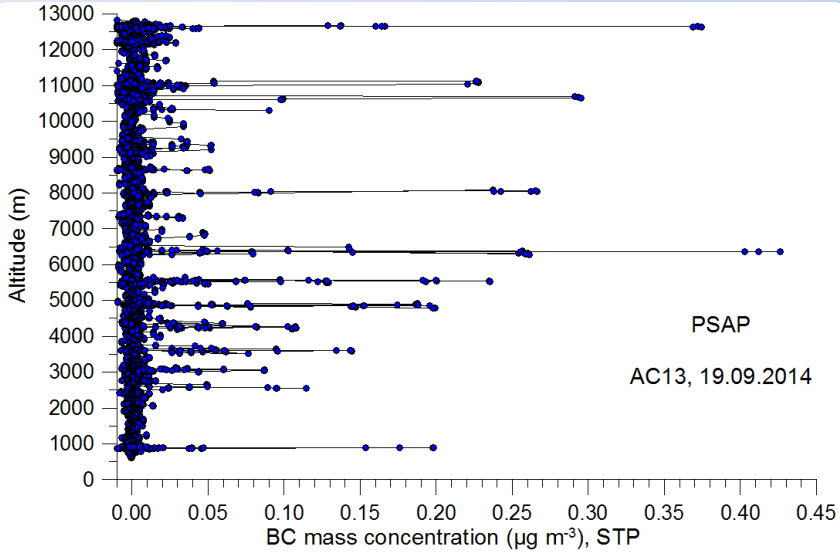
HALO-CVI measurements: black carbon

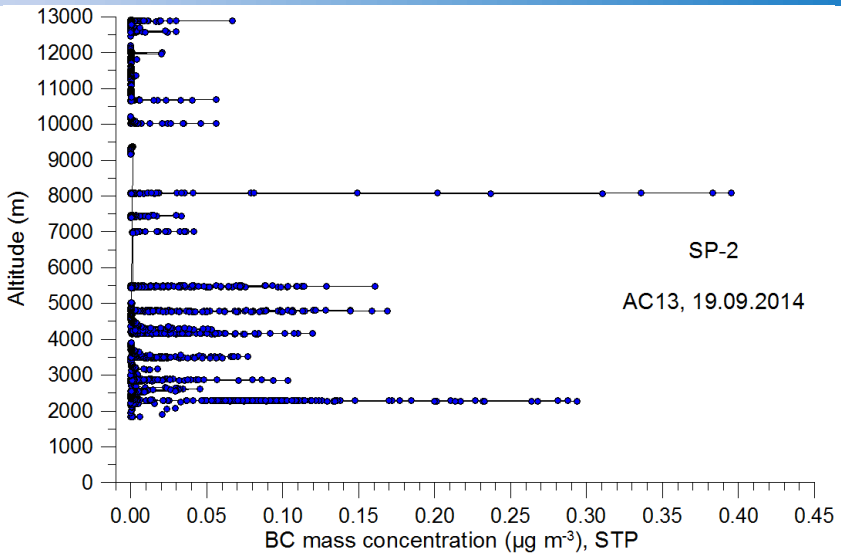


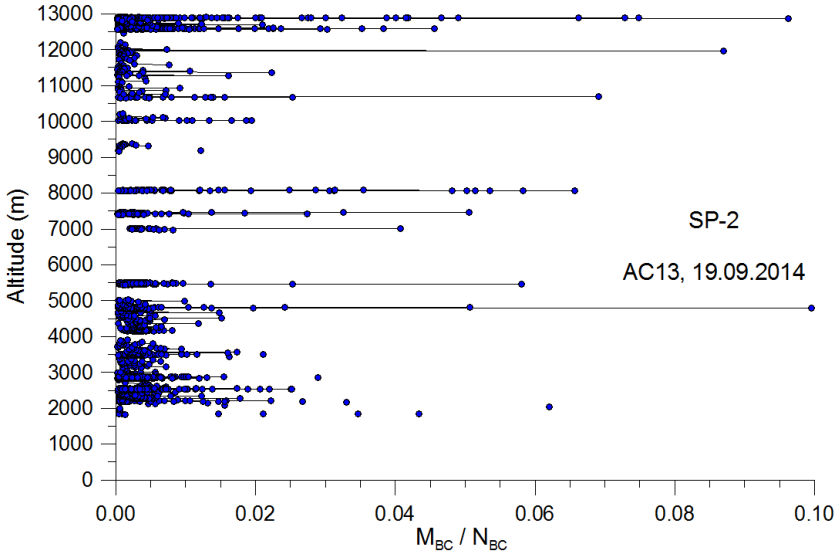
- Good absolute agreement between PSAP and SP-2 for BC mass
- BC number fraction: 10 %; BC mass per BC particle increases with height

TROPOS

HALO-CVI measurements: black carbon







- BC mass per BC particle increases with height

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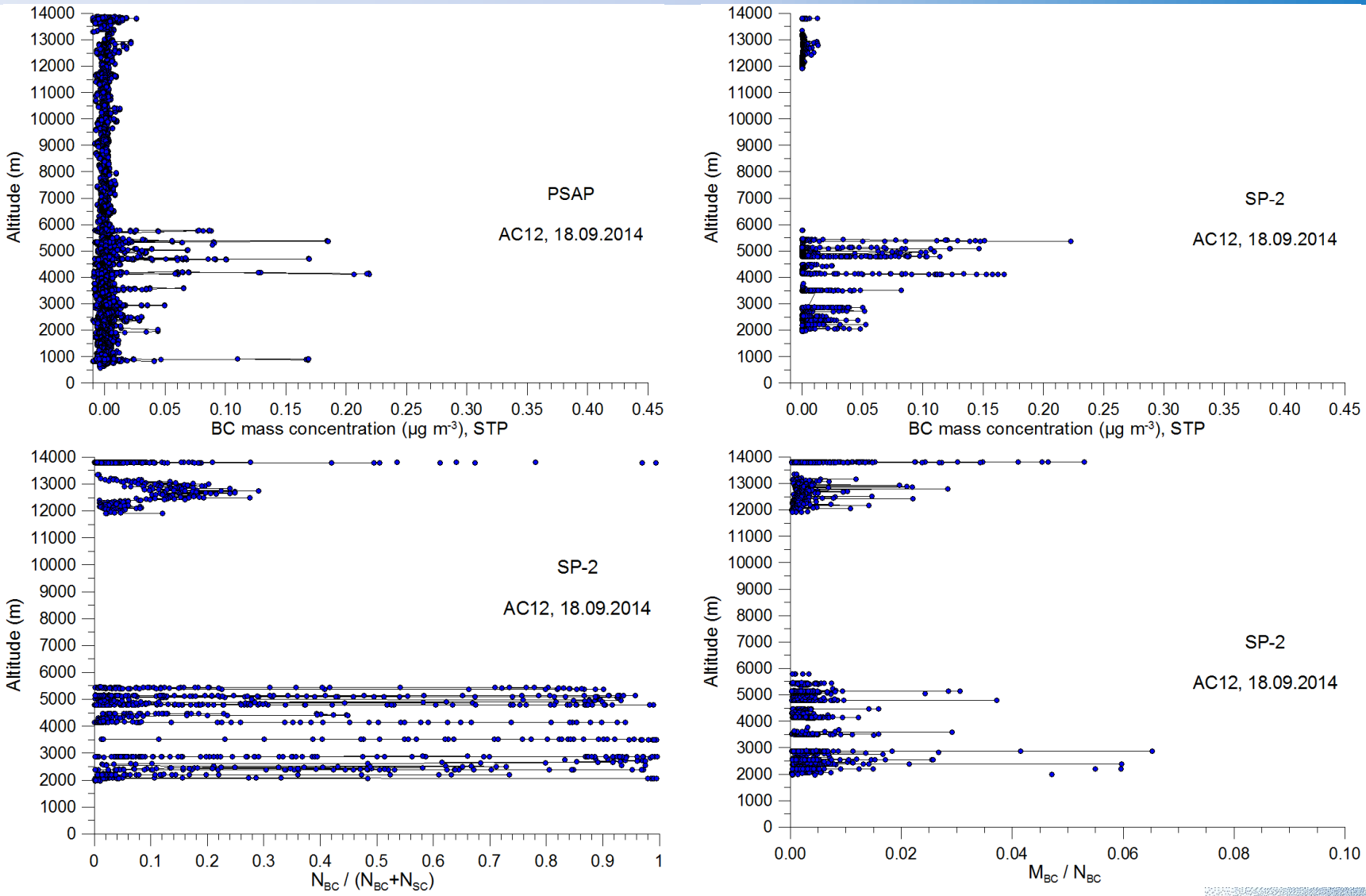
HALO-CVI measurements: black carbon



- BC number fraction varies greatly at lower level; in-situ cirrus 20 – 30 %
- BC mass per BC particle does not increase with height

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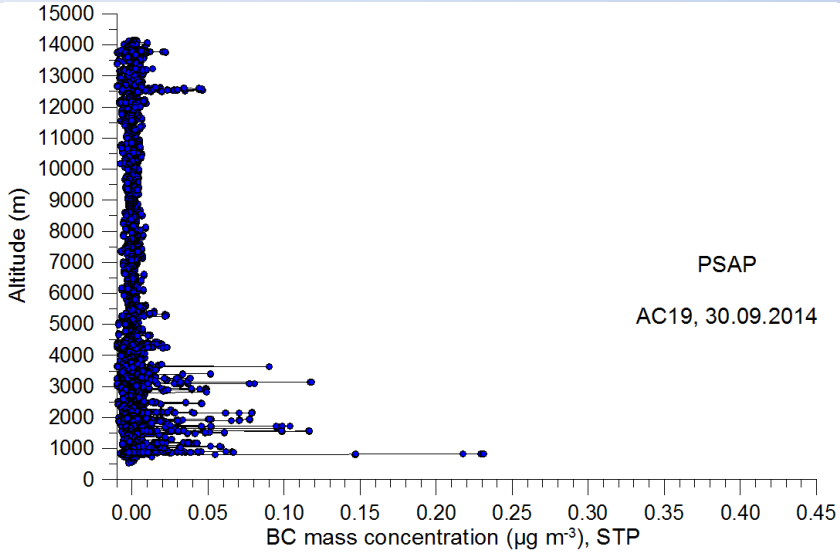
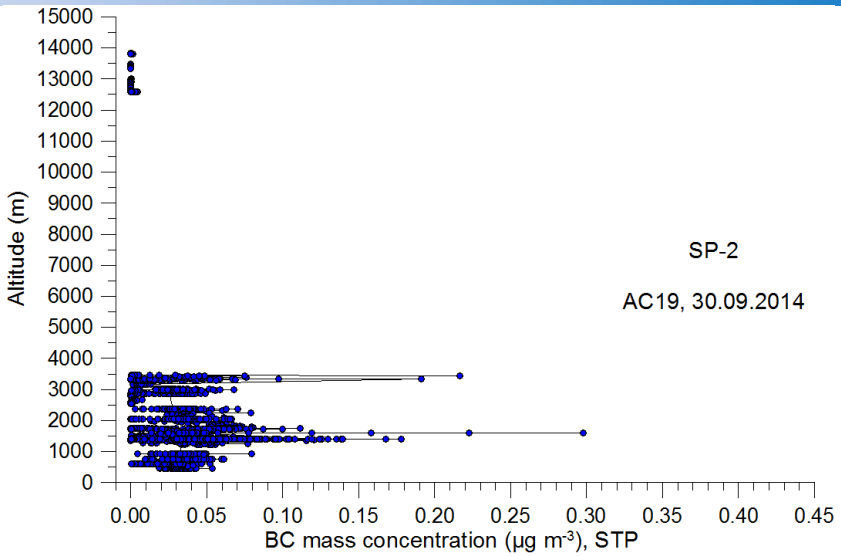
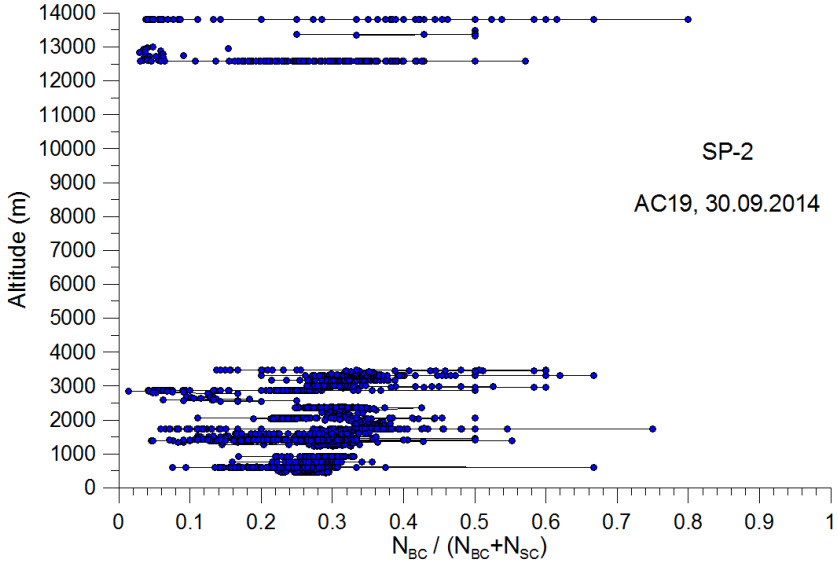
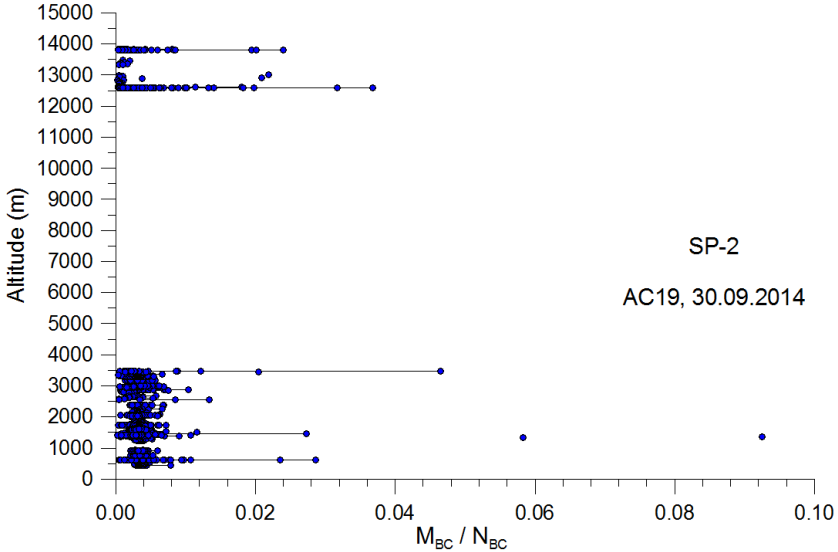
HALO-CVI measurements: black carbon









- BC number fraction: 30 %
- BC mass per BC particle deccreases with height

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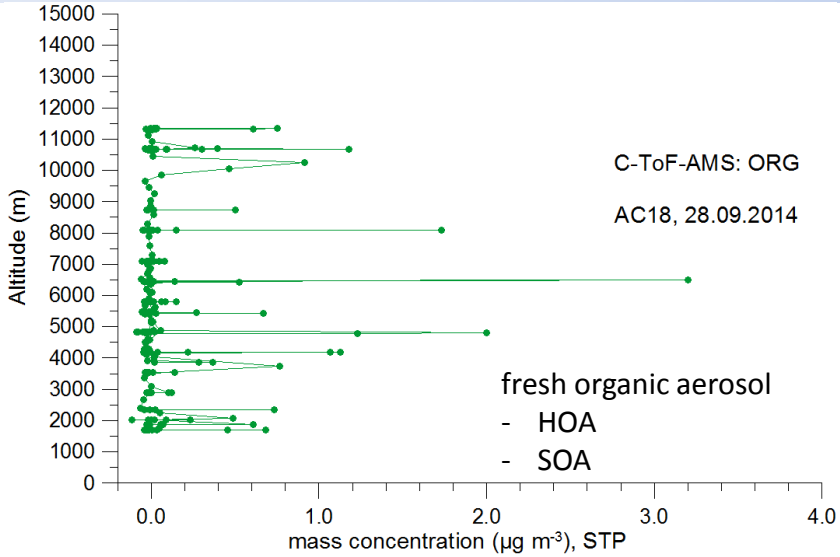
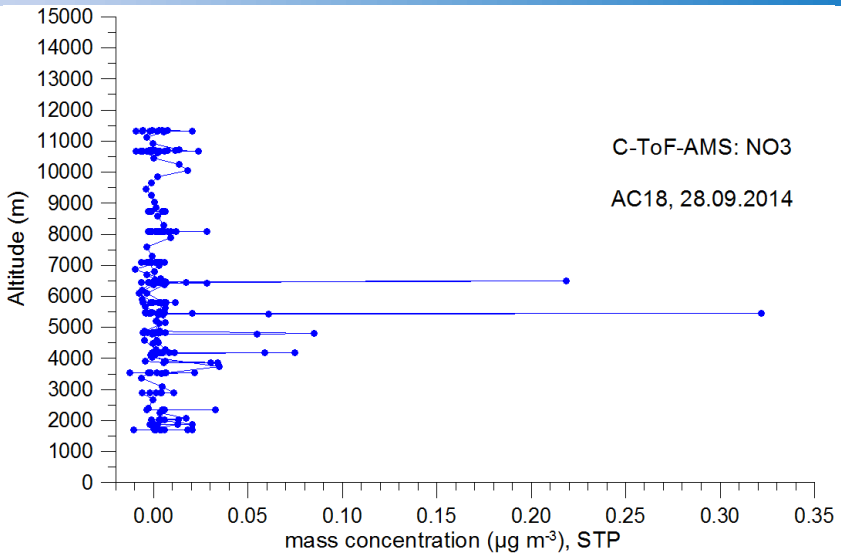
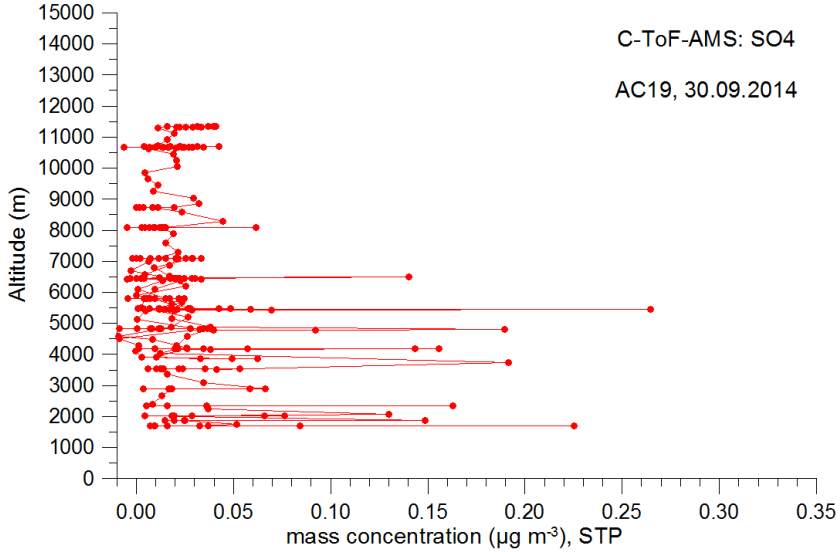
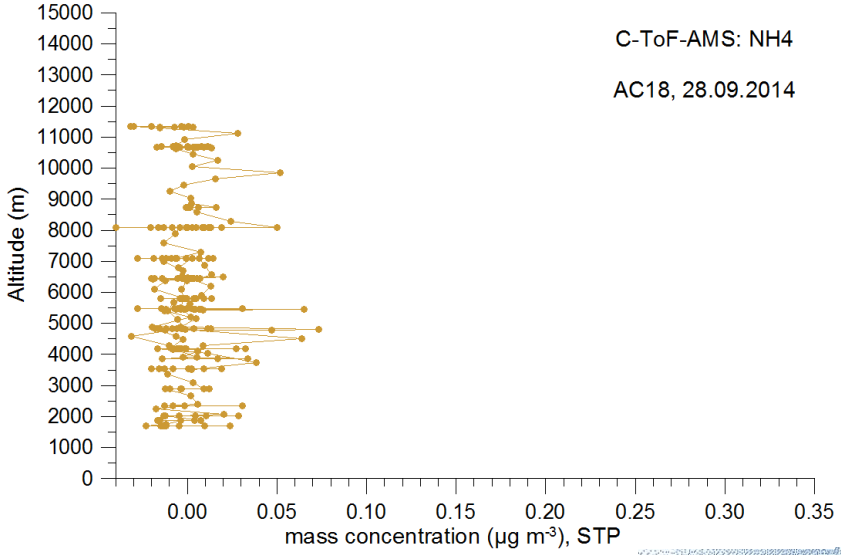
HALO-CVI measurements: chemical composition









- Derived absolute mass concentrations are too low; needs to be checked
- NO3 and SO4 with similar mass concentration; NH4 has lower mass

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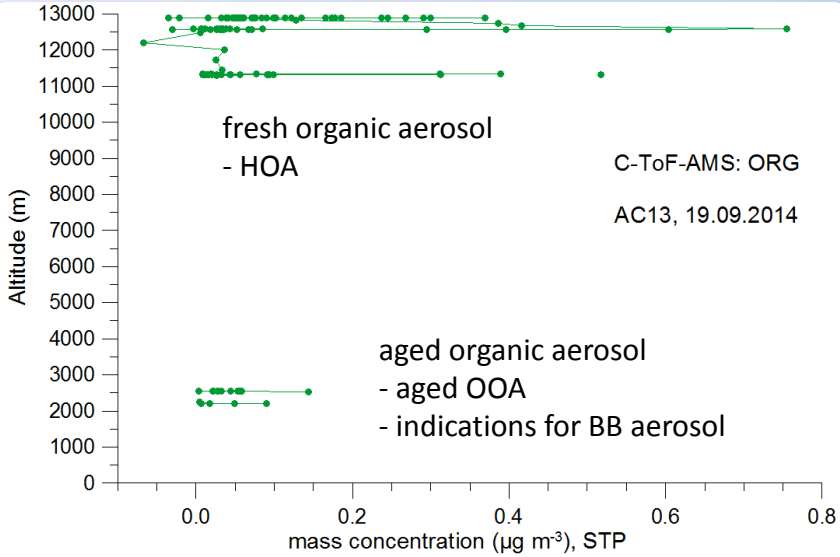
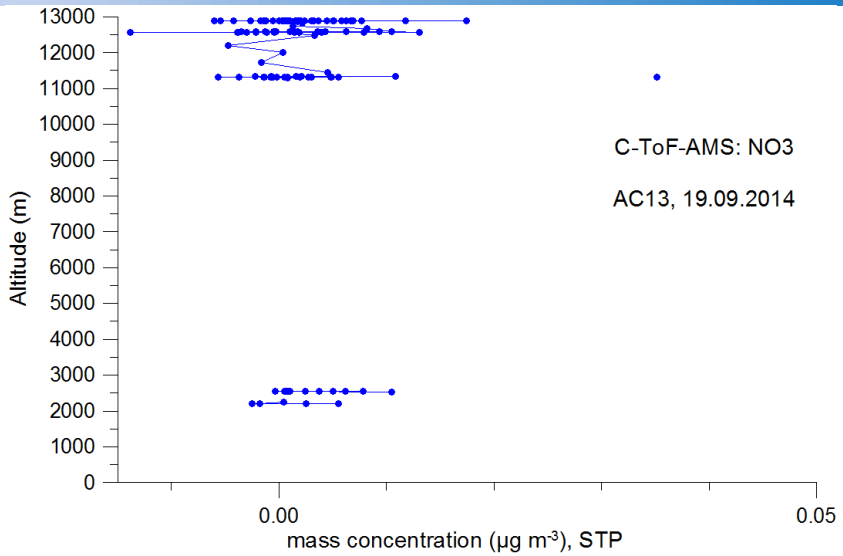
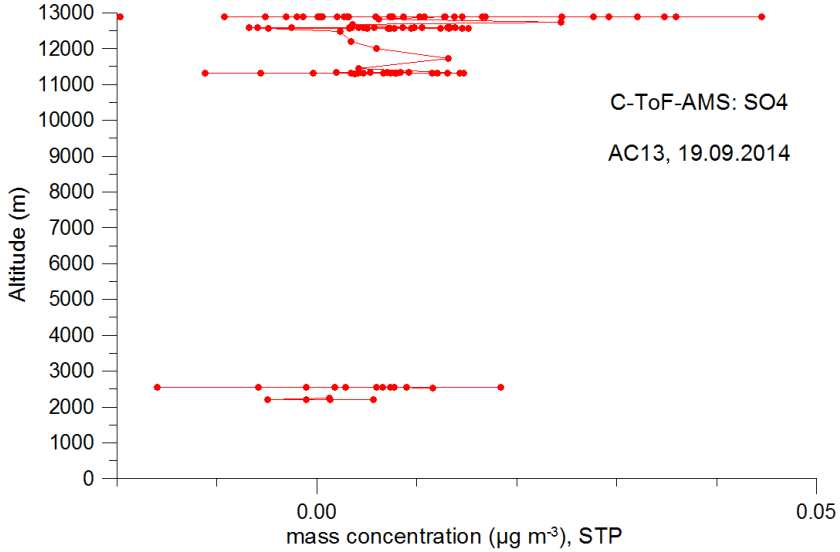
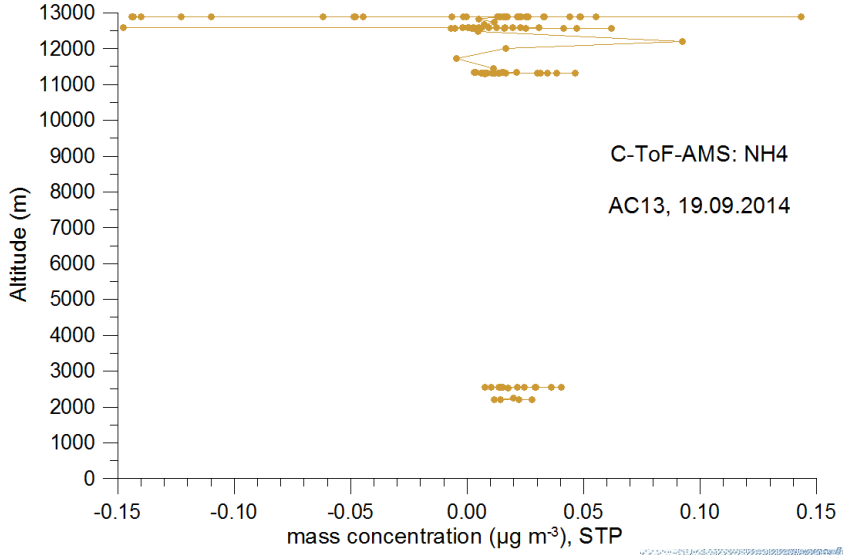
HALO-CVI measurements: chemical composition









- NO3 and SO4 with similar mass concentration; NH4 has higher mass

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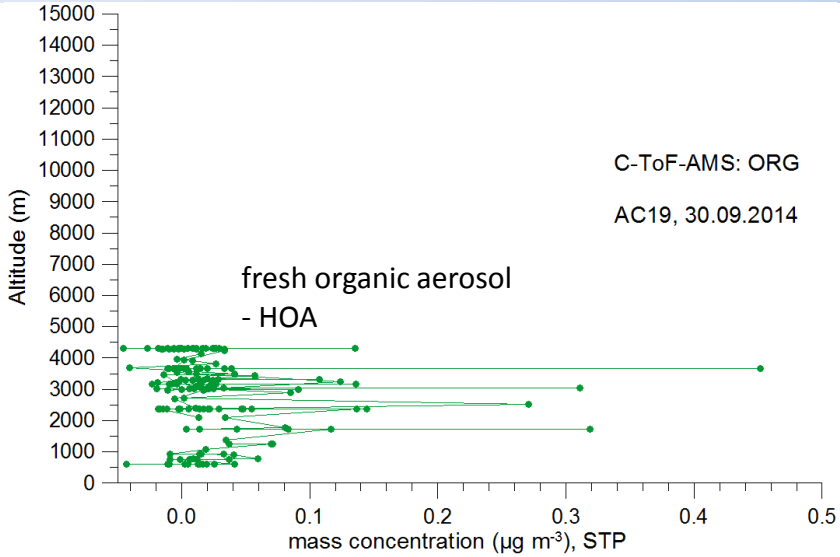
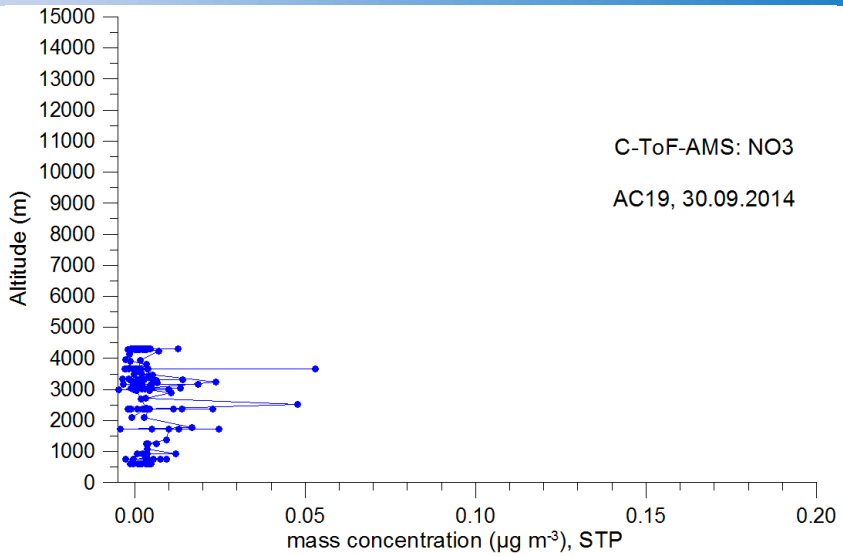
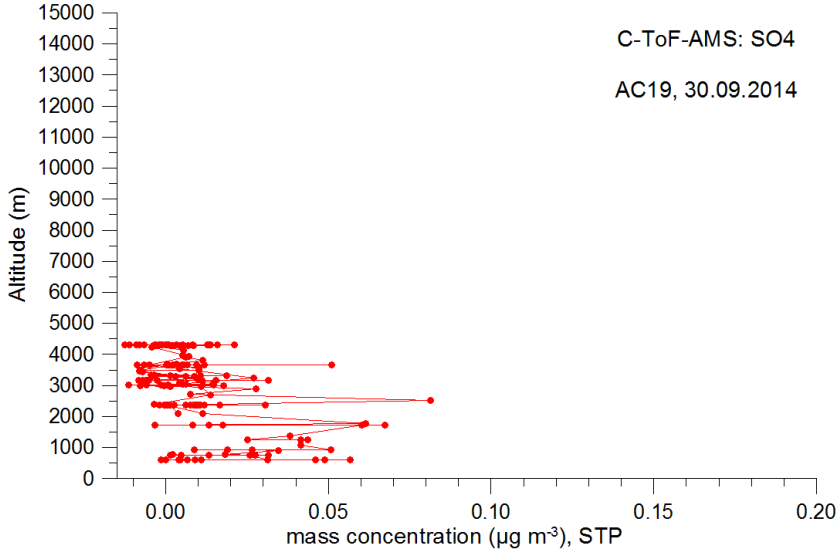
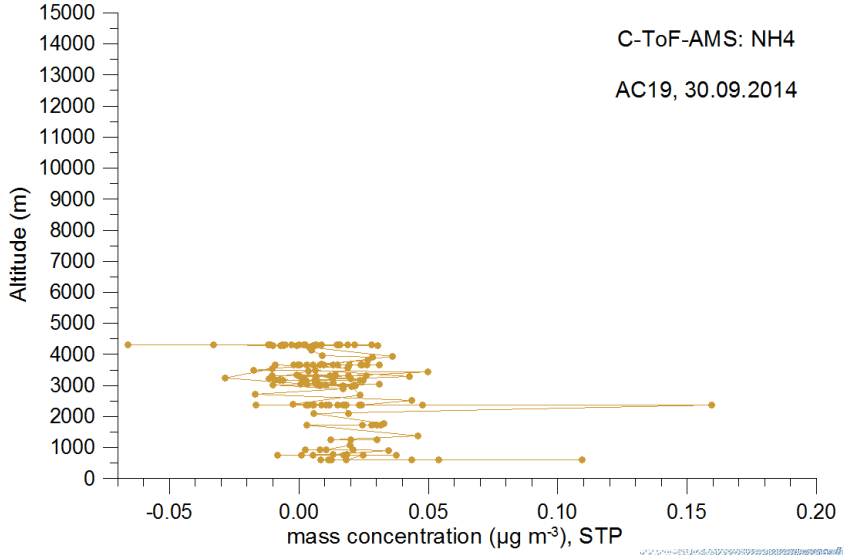
HALO-CVI measurements: chemical composition









- NO3, SO4 and NH4 with similar mass concentration

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HALO-CVI measurements: drop charges

Electrometer: current I (fA)

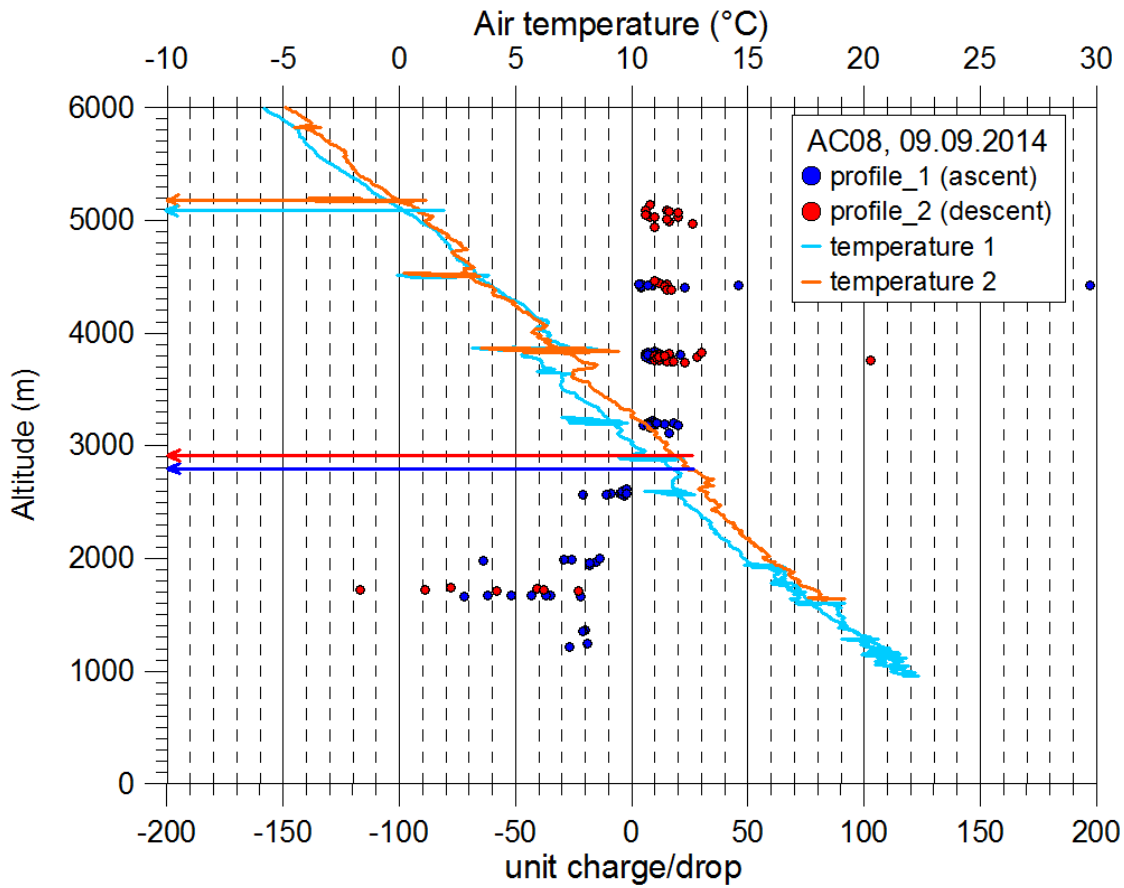
CPC: N_{res} (cm^{-3})

Flow: $F_{electro}$ ($L\ min^{-1}$)

e: $1.602*10^{-19}$ C

$$\frac{charge}{drop} = \frac{I}{e * Felectro * Nres}$$

Net charge measurement:
Charge of single drops might be much larger



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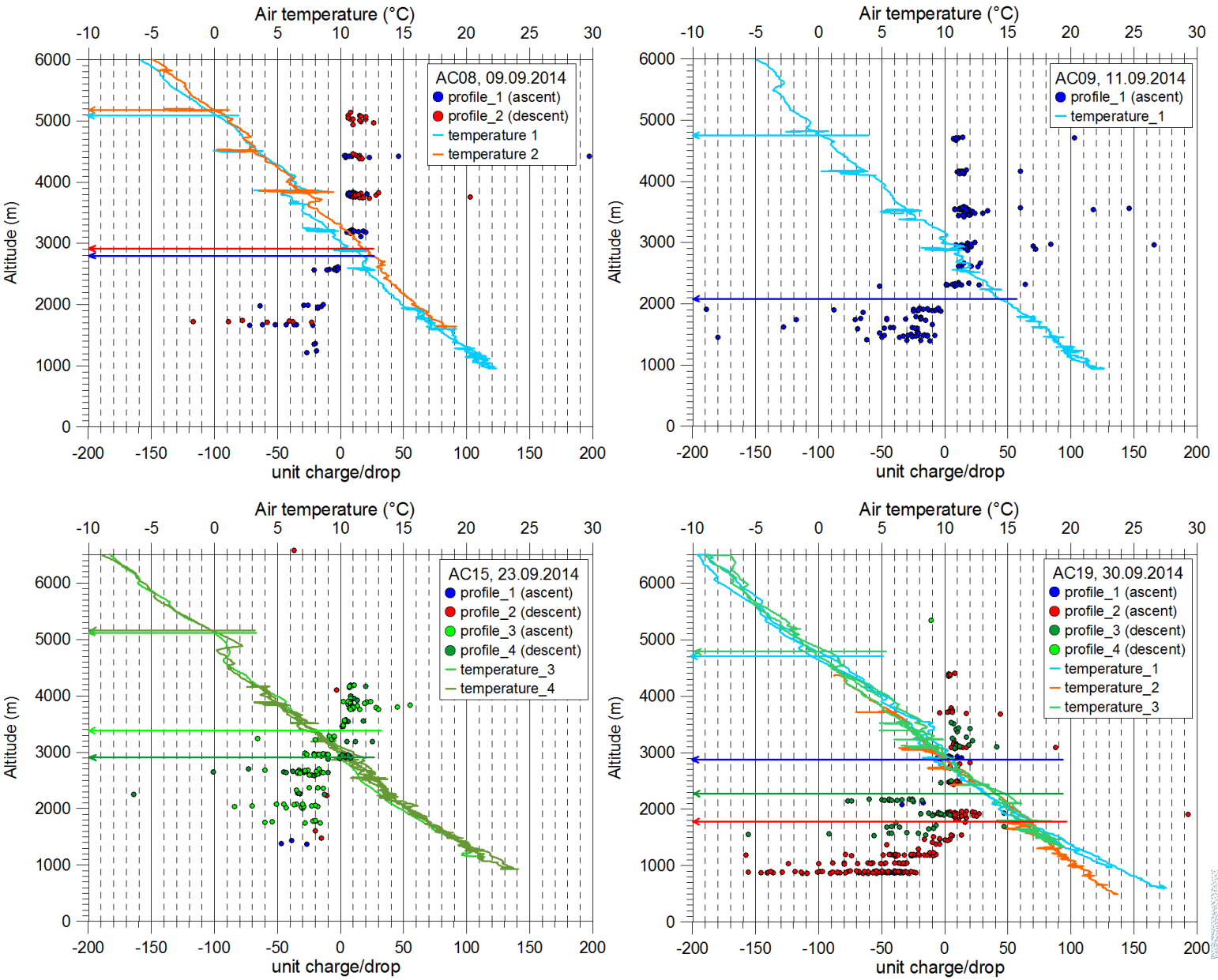
HALO-CVI measurements: drop charges



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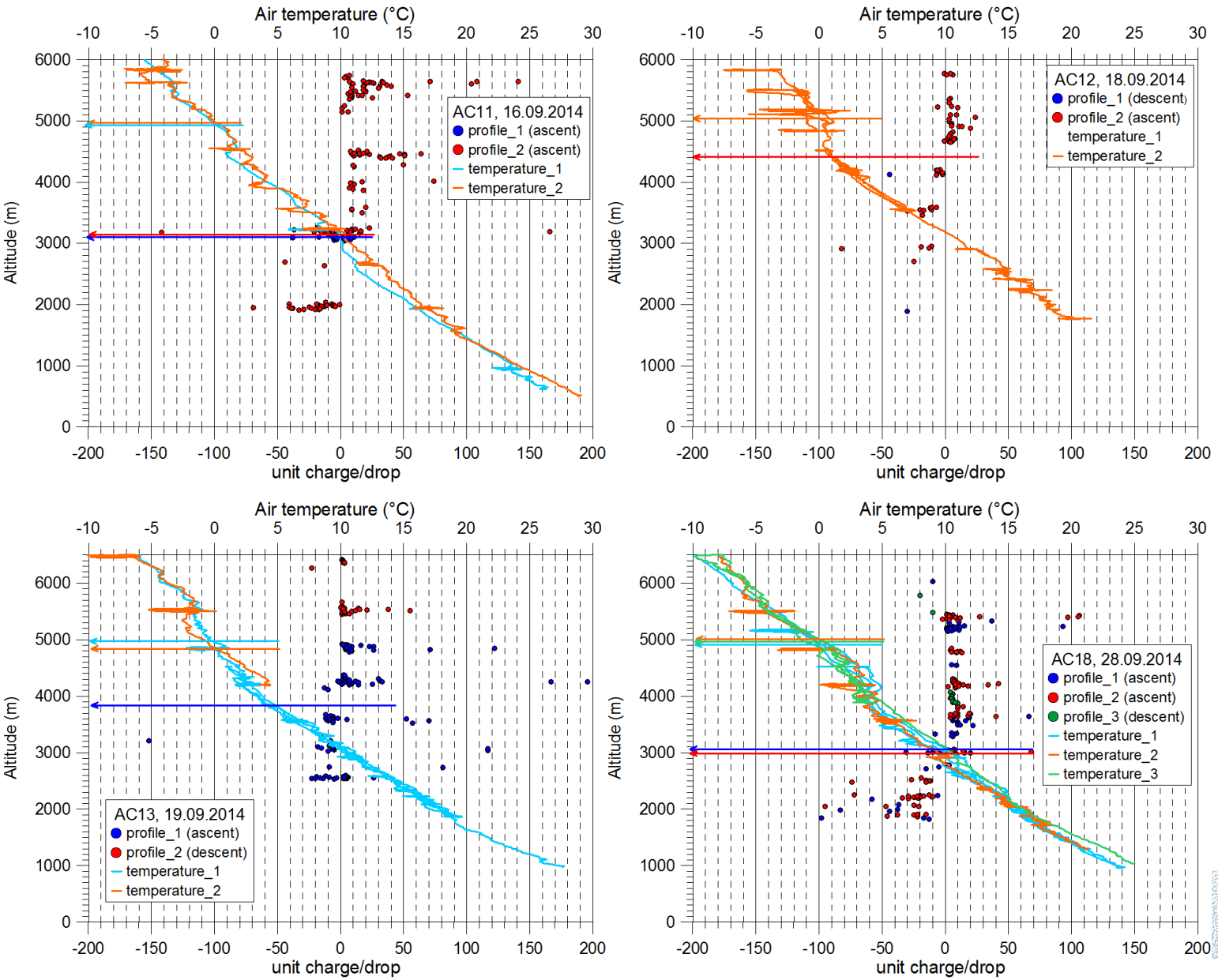
HALO-CVI measurements: drop charges



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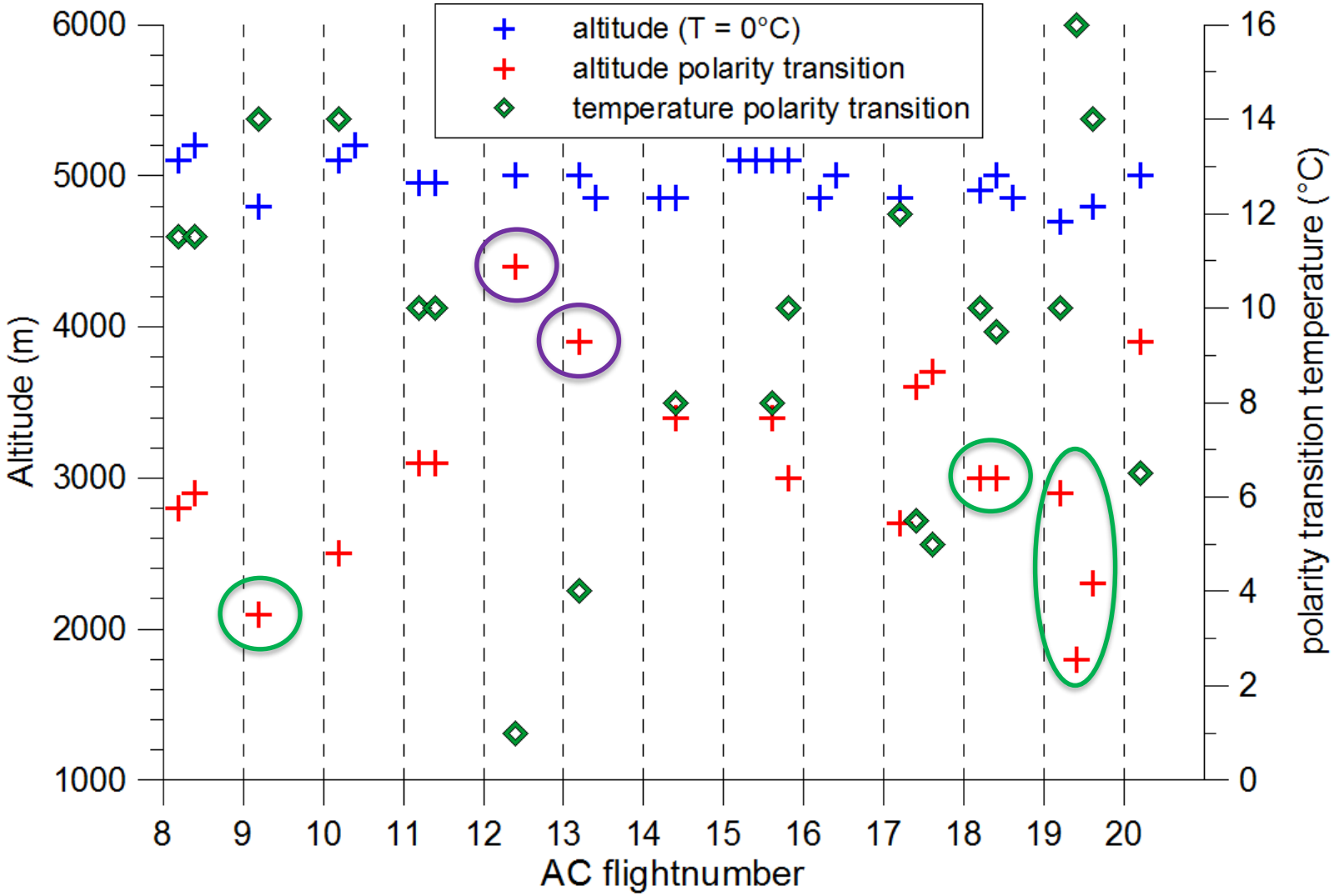
HALO-CVI measurements: drop charges



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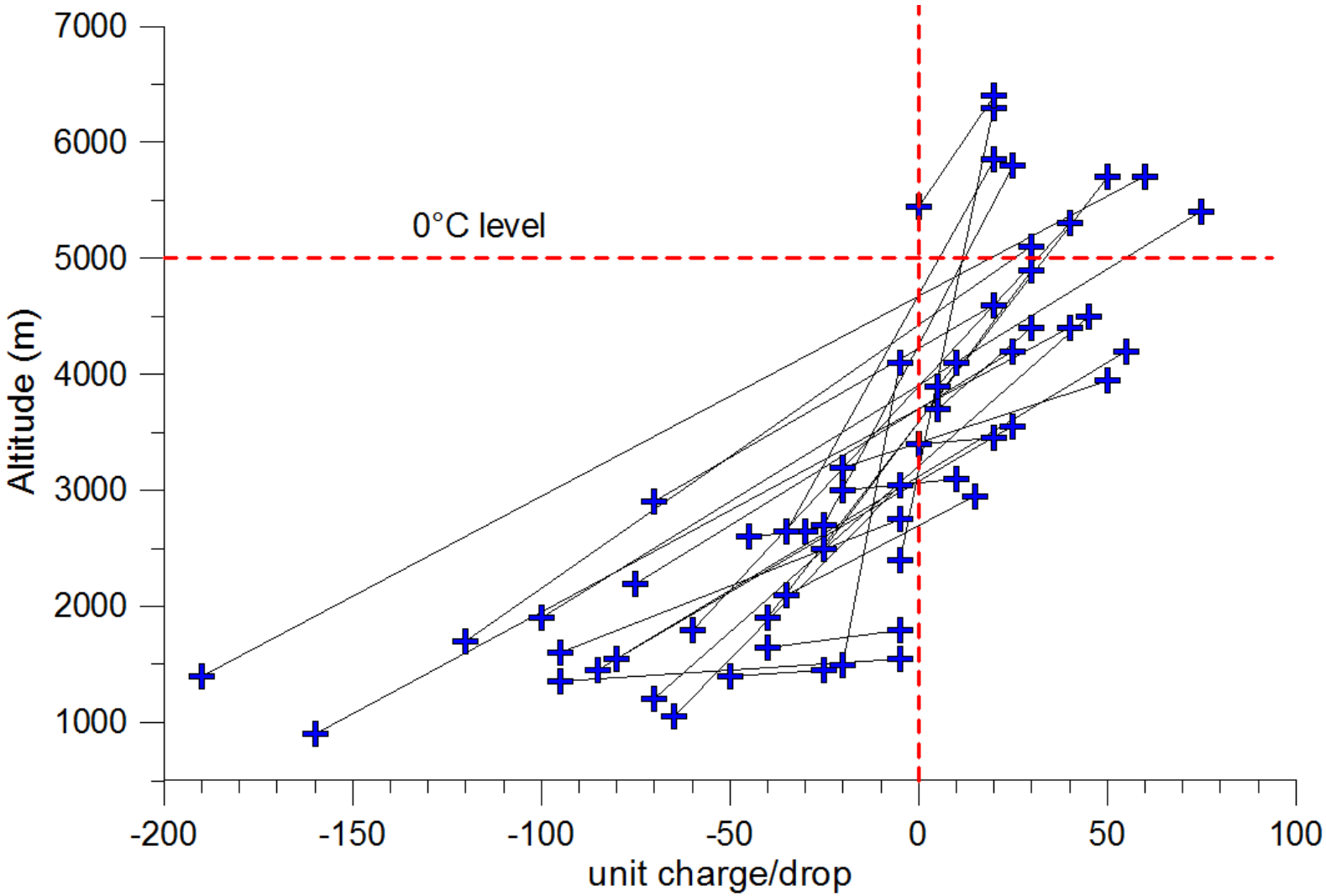
HALO-CVI measurements: drop charges



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HALO-CVI: summary and outlook

- <u>Residual particle concentration: CVI sampling characteristics on the upper fuselage</u>
  - Folding of oversampling due to hydrometeor enrichment “by HALO” at all flight levels and undersampling due to an increased cut-off diameter at lower flight levels, due to the non-ideal sampling position at HALO
  - ➢ Comparison to other cloud probes and for all mission flights
  - ➢ Looking for dependencies on TAS and mean volume diameter of the hydrometeor size distribution in order to search for a correction scheme

TROPOS

HALO-CVI: summary and outlook

- <u>Residual particle size distribution (preliminary)</u>
  - Lower levels: typical CCN distributions
  - Mode diameter between 200 nm and 300 nm, slightly smaller for clean conditions
  - Second mode at 500 nm or artefact?
  - ➢ Look on residual particle distributions for all flights and in mixed-phase and totally iced cloud regions
  - ➢ Comparison to residual size distributions measured with the SP-2
  - ➢ Relation to UHSAS size distributions measured at the wing below cloud base

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HALO-CVI: summary and outlook

- <u>Chemical composition of residual particles</u>
  - Higher time averaging of data (difficult since cloud transects were short in lower levels)
  - Eventually working with “relative parameters” due to changing CVI sampling efficiency: mass and number fractions, mass per residual particle
  - BC_{RES}: - differences between clean and polluted air masses
    - AC12: different BC particles at lower level and in-situ cirrus
  - Organics: - differences between clean and polluted air masses
    - AC13: aged organics at lower level and fresh primary organics in the outflow region: own exhaust?

➢ Comparison with identical measurements at HASI below cloud base and in the outflow

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HALO-CVI: summary and outlook

- <u>Droplet charges</u>
  - Similar pattern for all mission flights:

    - negatively charged below 2000 m, transition region 2000 m – 4000 m, positively charged above 4000 m
  - Charge transition at cloud temperatures above 0°C.
  - few data points of an altostratus transect at 3000m (Beard et al, 2004)
  - ➢ How do these results fit into general cloud electrification processes ?

    - Charging: Convective charging or collisional charging? (charging at cloud boundaries by ion currents outside cloud and consecutive mixing)
    - Macroscale charge separation: needs ice particles !
    - Observations are most likely not relevant for thunderstorm development but maybe for warm rain formation

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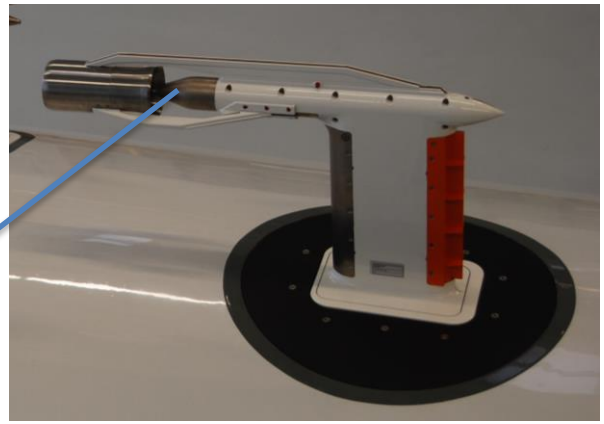
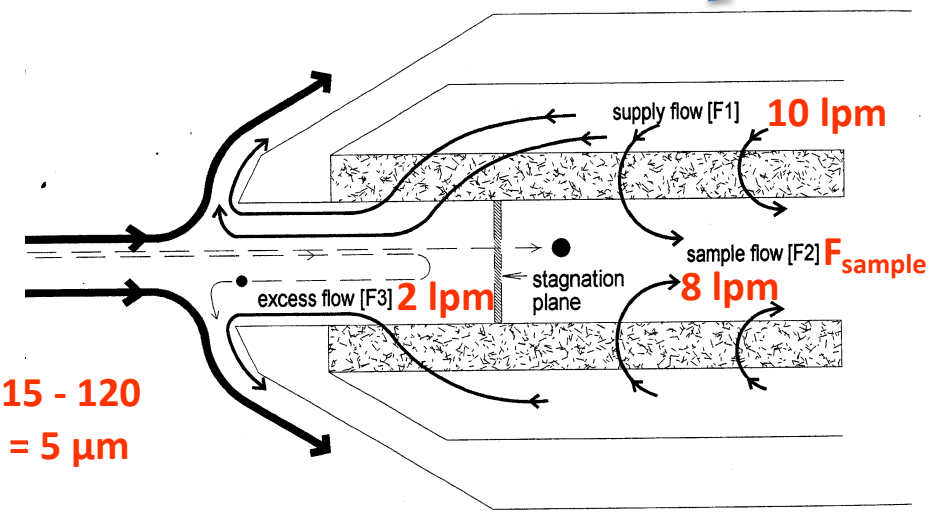
Sampling of cloud particles

- Inside cloud the Counterflow Virtual Impactor (CVI) samples drops and ice particles and simultaneously pre-segregates the interstitial particles and gases.
- The condensed phase of the collected cloud particles is driven into the gas phase in order to measure aerosol properties of the released residuals (CDR and IPR).





F_{air} = 220 m s^{-1}

enrichment = 15 - 120

lower cut size = 5 µm

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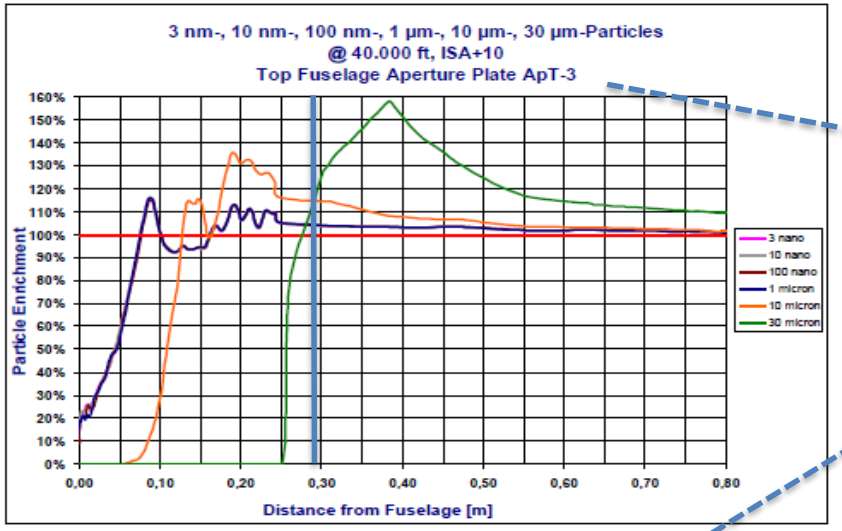
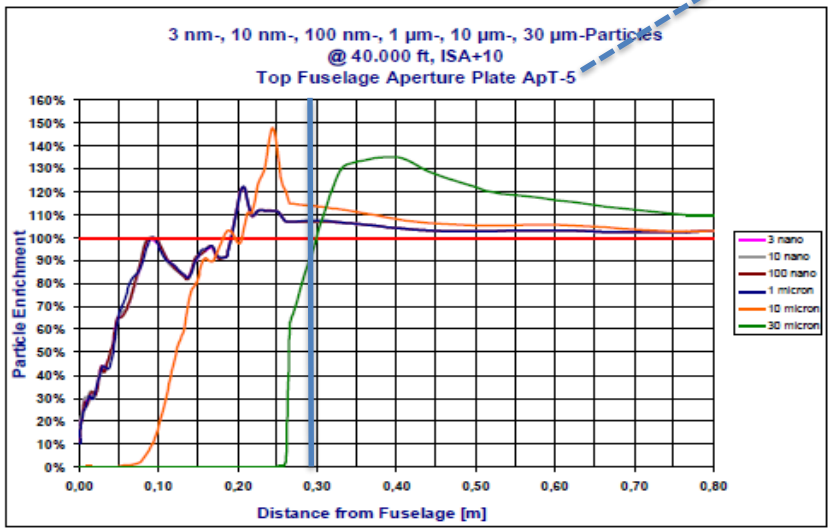
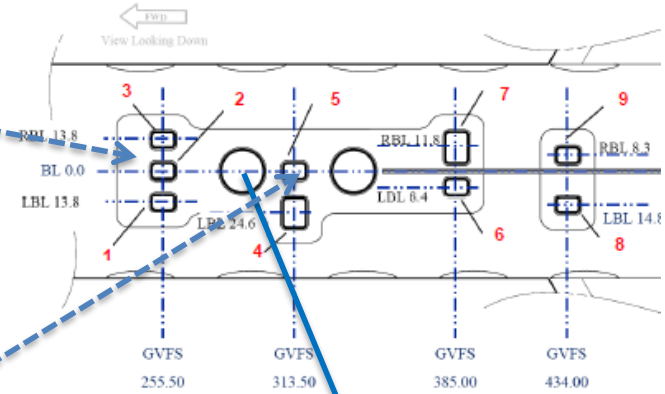
Sampling of cloud particles

- CVI installation at upper front viewport with an intake height of about 290 mm:







(HALO-TN-2008-003-A, by K. Witte, DLR-FX)

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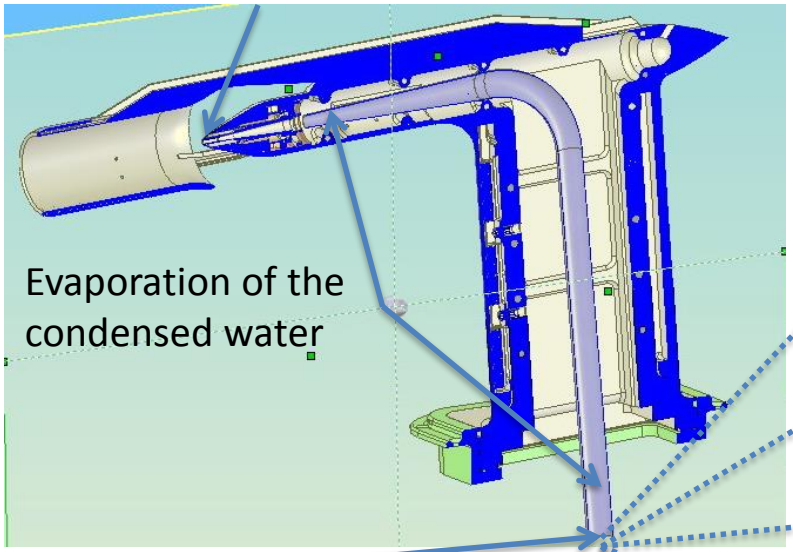
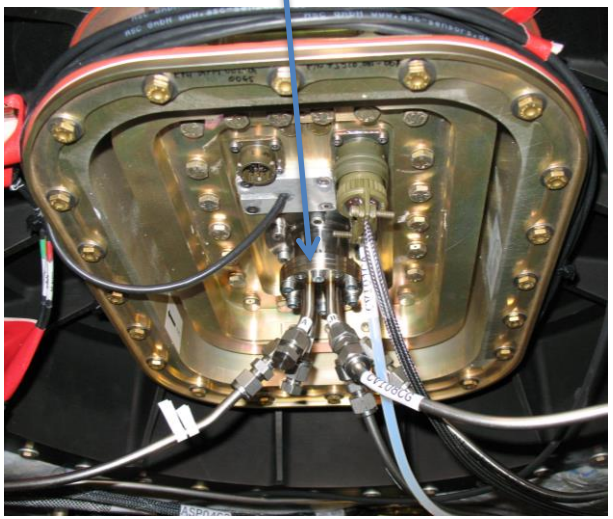
Distribution of cloud particle residues

Sampling of cloud particles



Distribution of ice particle residues



- C-ToF AMS (MPI Mainz)
- SNOOPY (DLR OP)
- FINCH (U Frankfurt)
- CCN-Rack (MPI Mainz)
- HALO-CVI-RACK (TROPOS)

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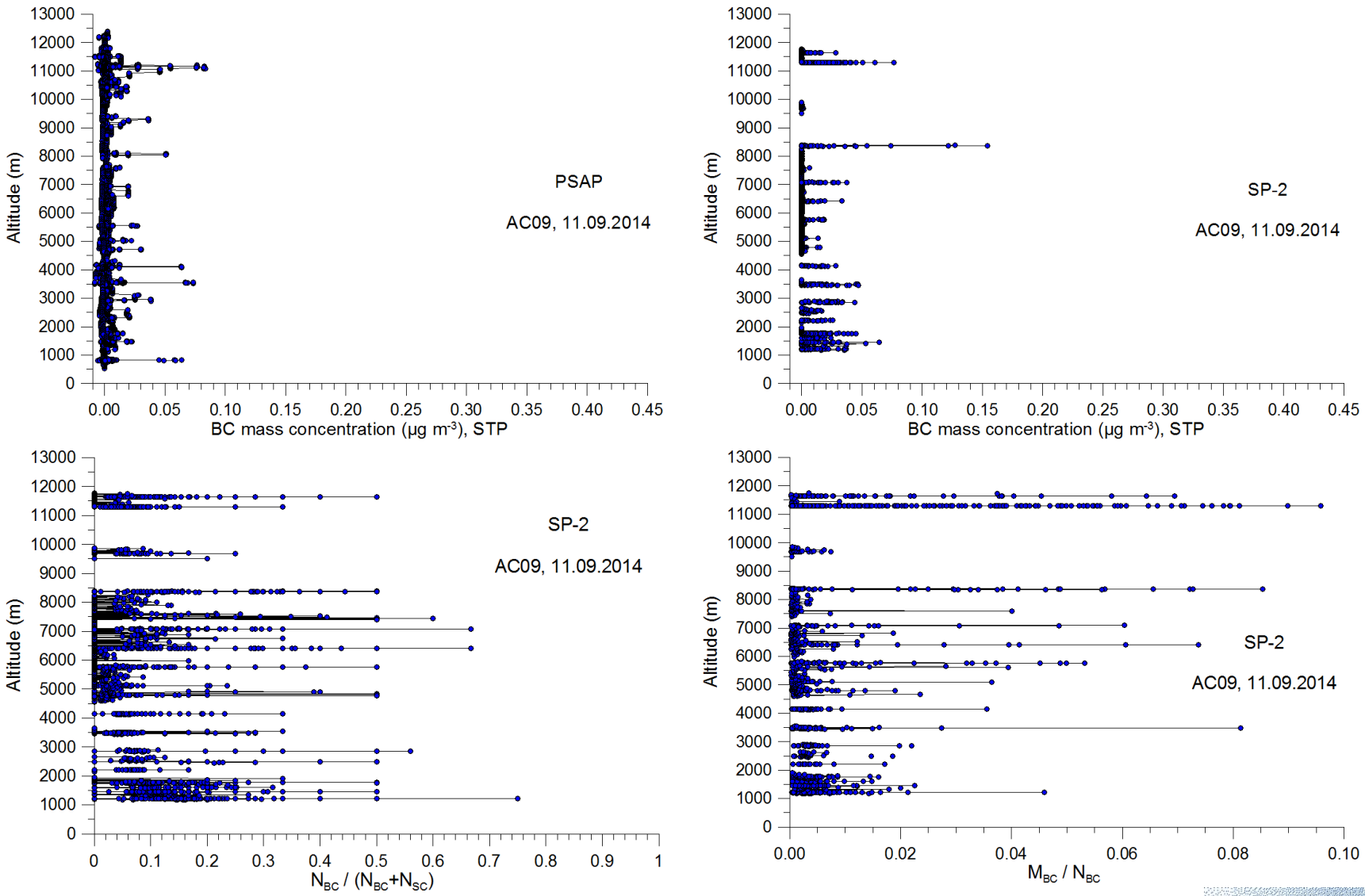
HALO-CVI Rack for ACRIDICON

- Flow preparation and regulation of the HALO-CVI inlet system
- CPC TSI-3010: number concentration all flights
- UHSAS: size distribution (70 – 1000 nm) all flights
- PSAP: absorption coefficient, BC all flights
- Electrometer: cloud particle charge not on AC07, off when p < 500 mbar

TROPOS

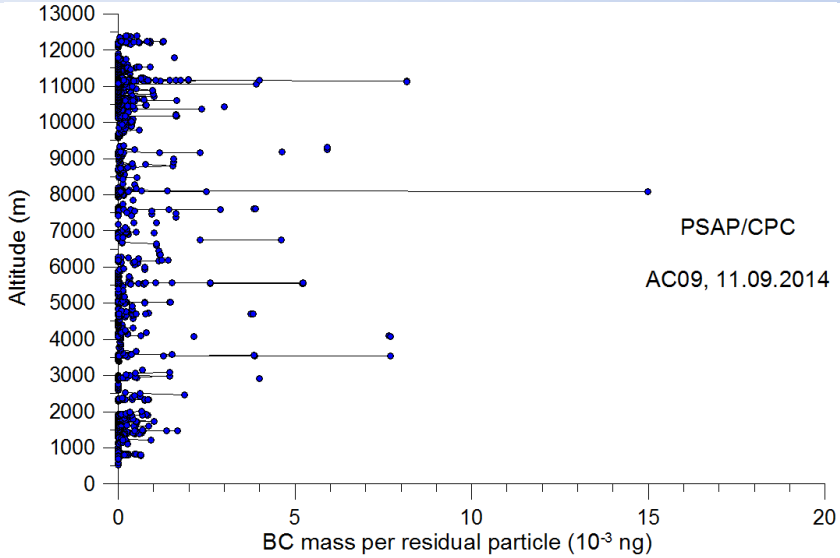
HALO-CVI measurements: black carbon

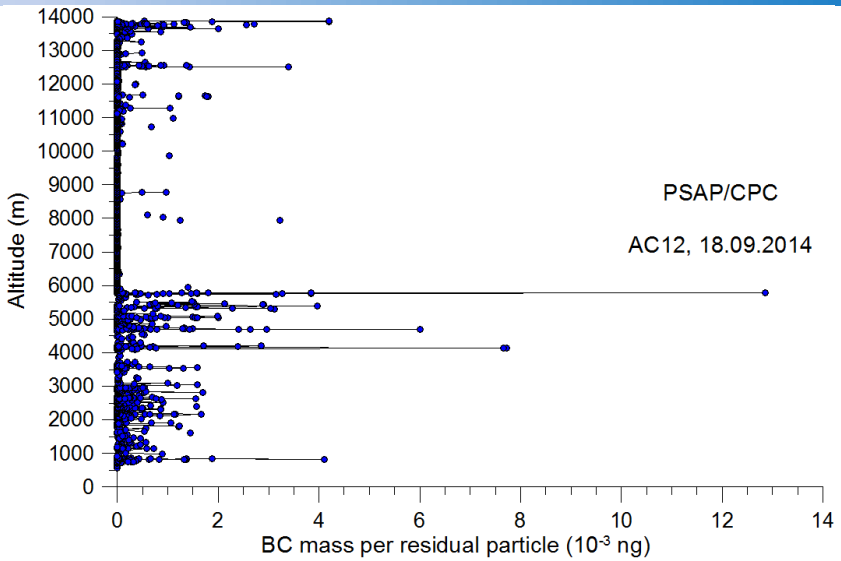


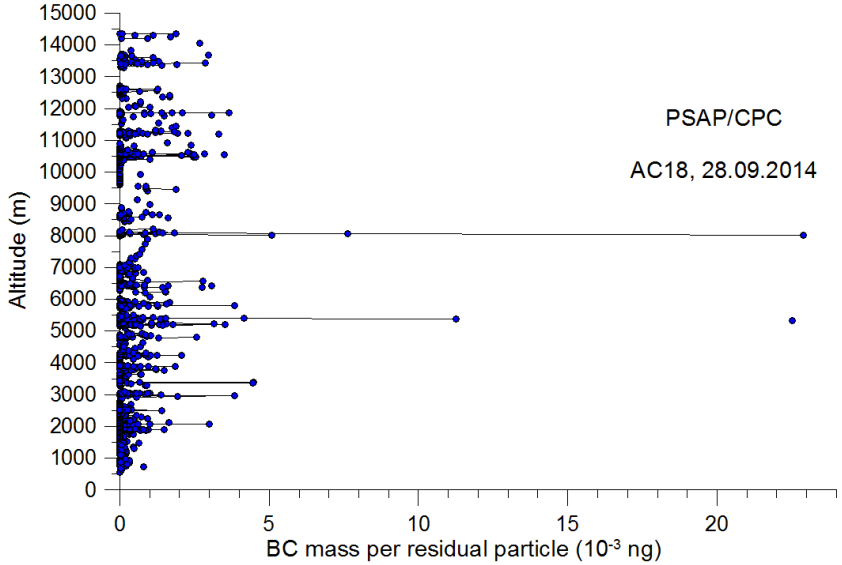
- Good absolute agreement between PSAP and SP-2 for BC mass
- BC number fraction: 10 %; BC mass per BC particle increases with height

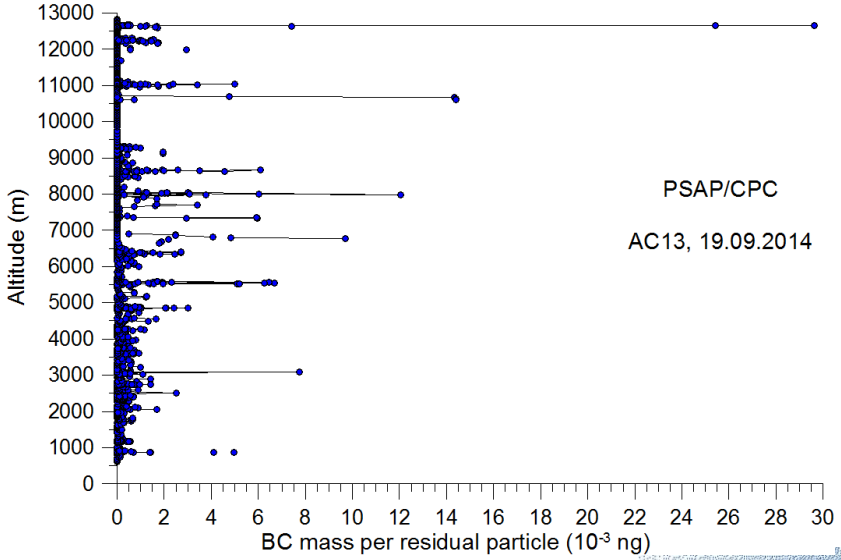
TROPOS

HALO-CVI measurements: Black Carbon



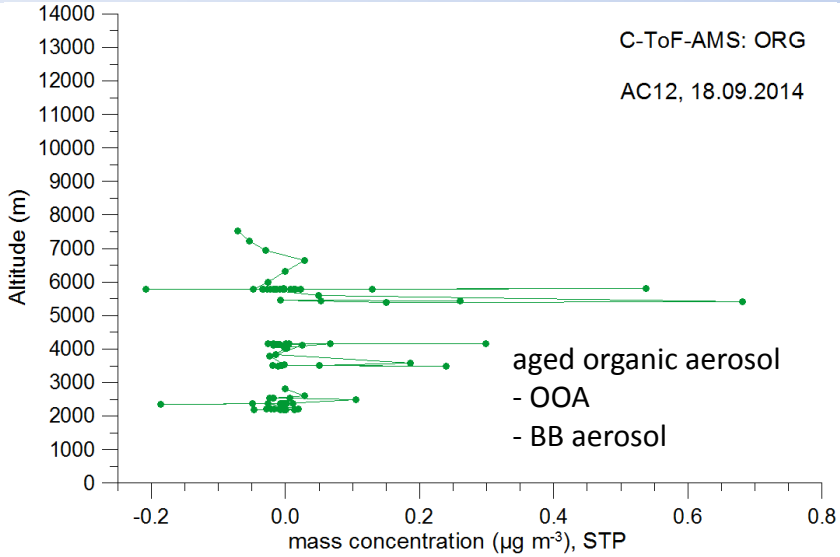


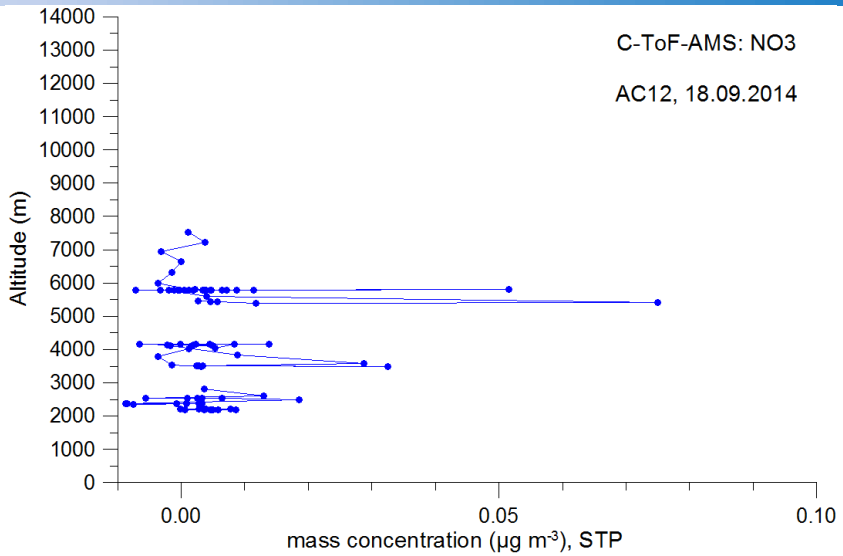


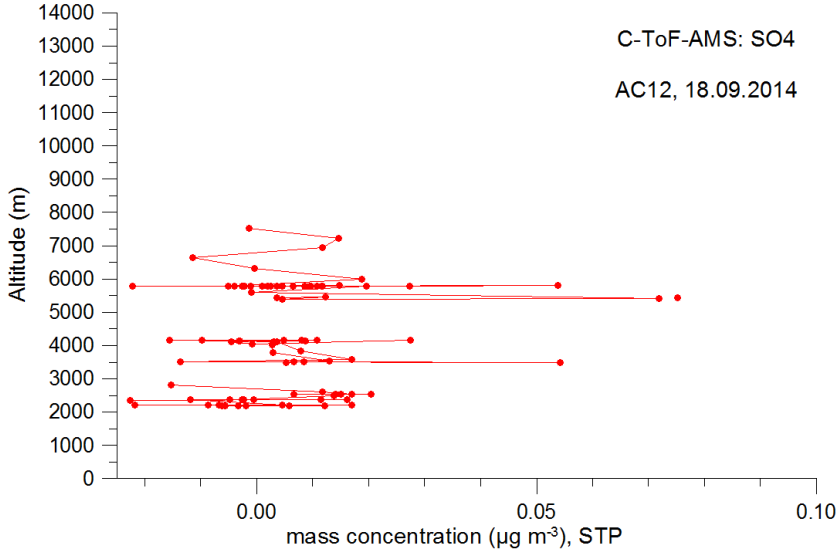


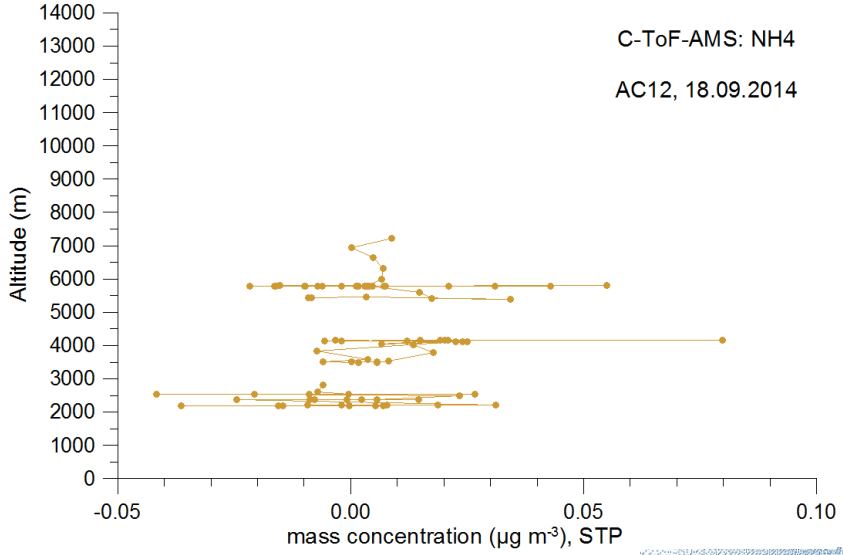
TROPOS

HALO-CVI measurements: chemical composition





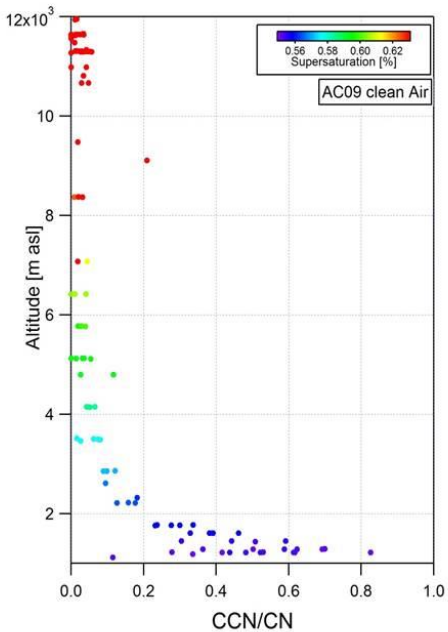


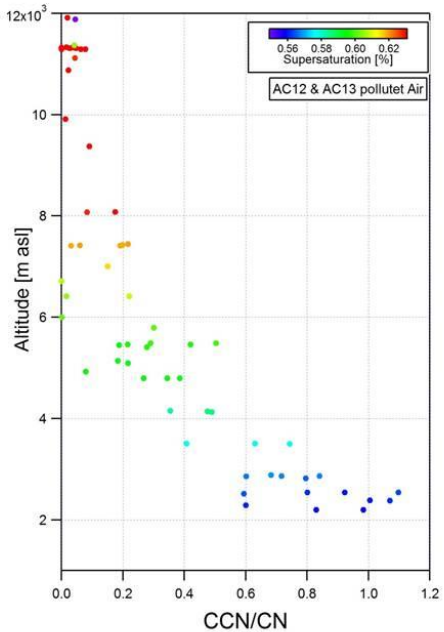


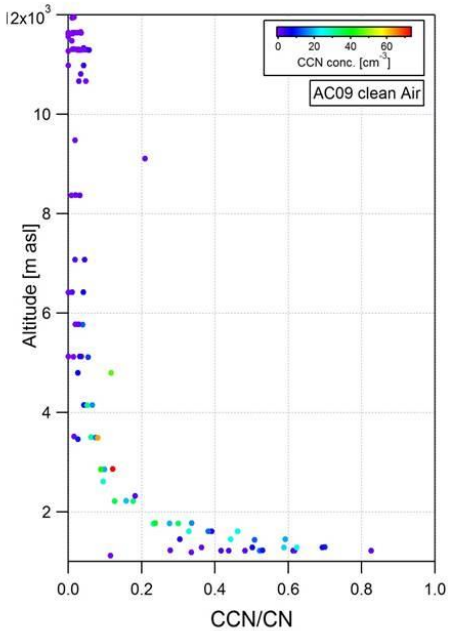
- NO3, SO4 and NH4 with similar mass concentration

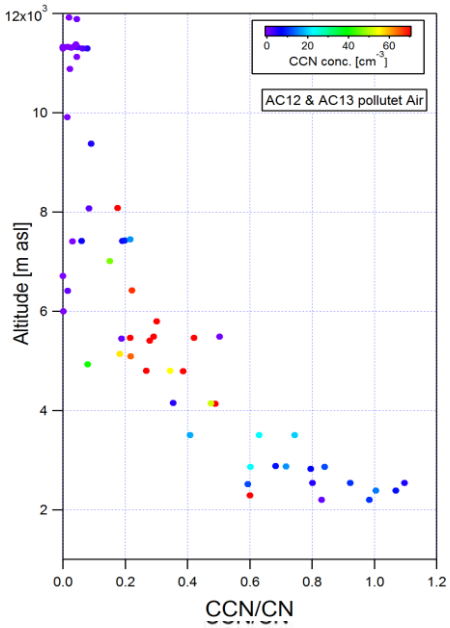
TROPOS

HALO-CVI measurements: CCN









TROPOS

Status

- Uploaded on HALO-DB: Mission flight AC07 – AC20:
  - CPC: ambient residual particle concentration (cm^{-3})
  - PSAP: ambient residual particle absorption coefficient (m^{-1})
    (BC mass concentration applying a mass absorption coefficient, 10 m^2/g)
  - Electrometer: charge per cloud particle
  - HALO-CVI enrichment factor: needed to calculate ambient residual phase concentrations for ALABAMA, SNOOPY, FINCH and CCN
  - Time periods during mission flight when the counterflow was off

- Not yet uploaded on HALO-DB:
  - UHSAS: ambient residual particle size distribution ($dN/dlogd_p$)

TROPOS