APPLICATION-SPECIFIC CALIBRATION OF CONDENSATION PARTICLE COUNTERS FOR USE AT REDUCED PRESSURE CONDITIONS

O.F. Bischof [1,2], P. Weber[1], U. Bundke[1], A. Petzold[1] and A. Kiendler-Scharr[1 †]

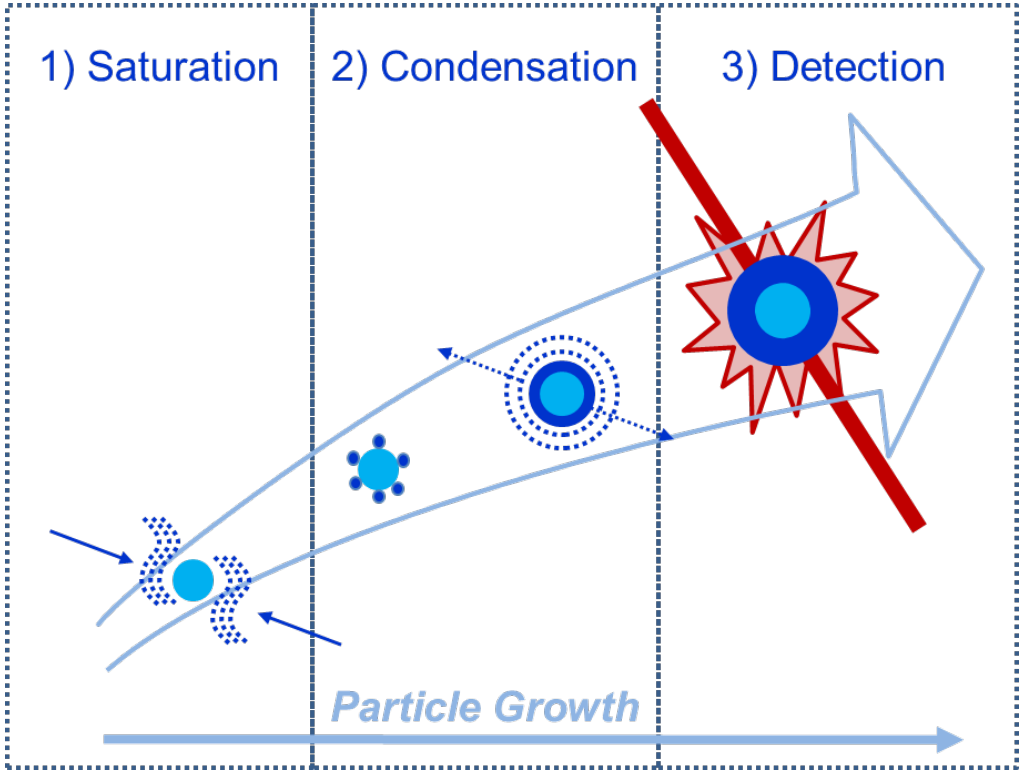
[1] Forschungszentrum Jülich GmbH, IEK-8: Troposphere, Germany

[2] TSI GmbH, Aachen, Germany

26th ETH Nanoparticles Conference 2023 (#ethnpc23)
June 20-22, 2023
ETH Zurich, Switzerland

OVERVIEW

- Introduction
  - Motivation & Prior research
- Modelling of CPC performance
- Experimental work
  - Setup
  - Calibration results
    - Material dependence
    - Humidity
- Conclusions



INTRODUCTION

Motivation: Applications of Condensation Particle Counters (CPCs) at Reduced Pressue

- In scientific research and for Particle Number (PN) regulations

Atmospheric research

- Measurements onboard aircraft
  - Aerosol Package P2c in IAGOS must work up to 10,700 m (245 hPa)
- High-altitude research stations
  - Jungfraujoch, CH, at 3,580 m (651 hPa)

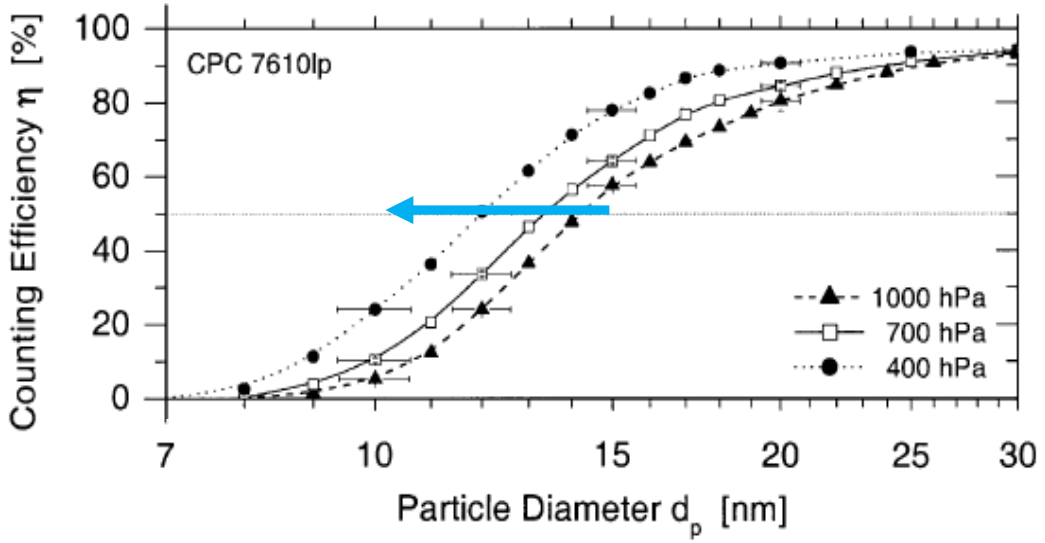
Regulatory use

- Vehicle emissions
  - Type approval of vehicles at engine test rigs at high-altitudes up to 2,400 m (750 hPa)
- PN concentration in ambient air at higher altitude (e.g. acc. to CEN/TS 16976)

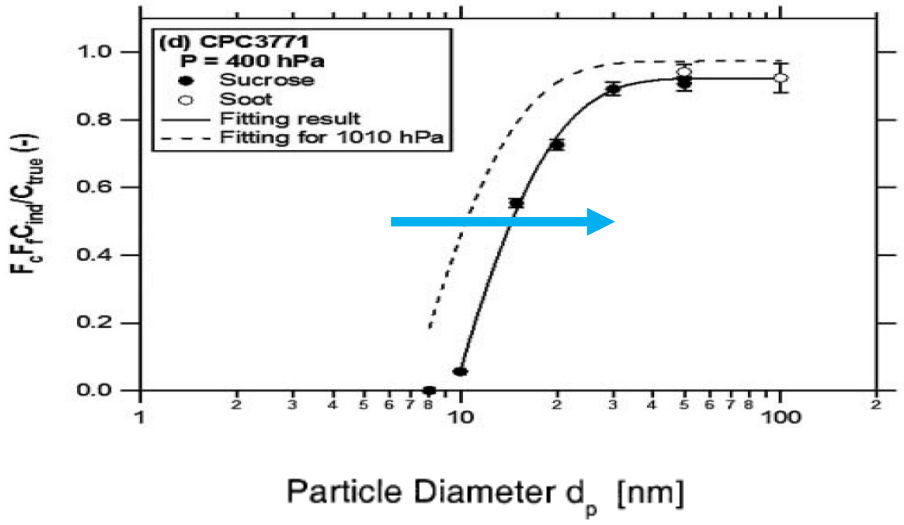
INTRODUCTION

Prior Research

- Literature study of 60+ peer-reviewed publications from past ~50 years
  - No consensus on how CPC's can be expected to perform at reduced pressure!
  - Some show shift in cut-off to smaller diameters (left), others display change to larger sizes (right)



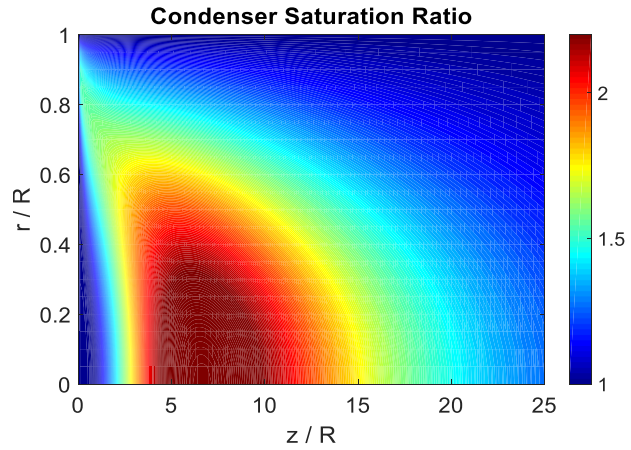
Hermann & Wiedensohler (J. Aerosol Sci., 2001)



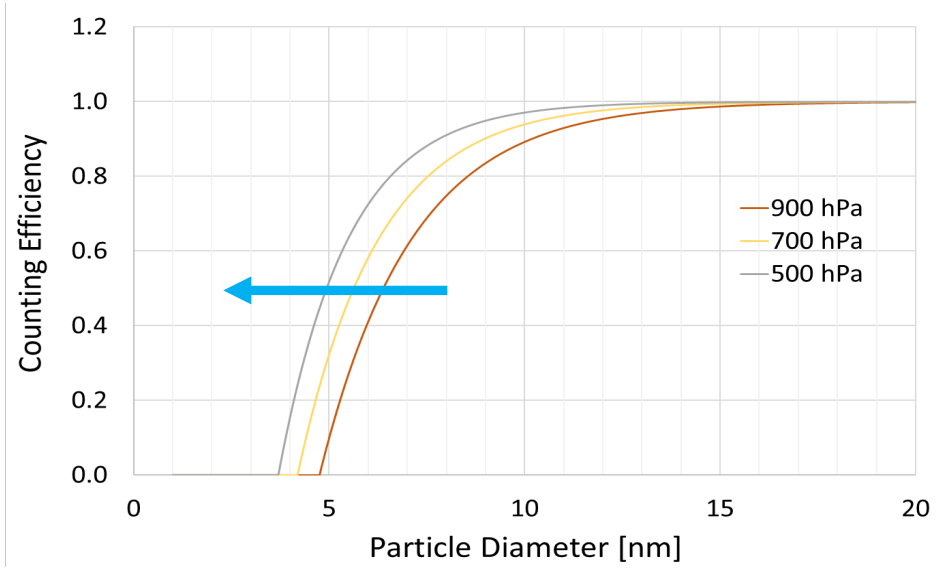
Takegawa & Sakurai (Aerosol Sci. Tech., 2011)

NUMERICAL WORK

Modelling of CPC Performance at Reduced Pressure



- Based on two-dimensional model of Stolzenburg (1991)
  - Determines activation efficiency based on sample flow going through saturator and condenser
  - Implemented in MATLAB by Dr. Ryan Han (TSI), who also ran it
  - Delivered efficiency curves and cut-sizes
- Three effects predicted (for 3772 CPC)
  1. Counting efficiency curve shifts to smaller size
  2. Little change in slope of curves
  3. No major decrease in maximum asymptotic counting efficiency



EXPERIMENTAL SET-UP

(1) “Atmospheric Background” Aerosol (represented by Ammonium Sulfate)

- Custom-designed at FZ Jülich
- Allows precise & stable control of
  - Monodisperse particle size by DMA
  - Ambient pressure
  - Relative humidity
  - Flow rates

AEM = Aerosol Electrometer

DMA = Differential Mobility Analyzer

CPC = Condensation Particle Counter

WCPC = Water-based CPC

EXPERIMENTAL SET-UP

CPC Models

- Two different continuous-flow CPCs, operated side-by-side

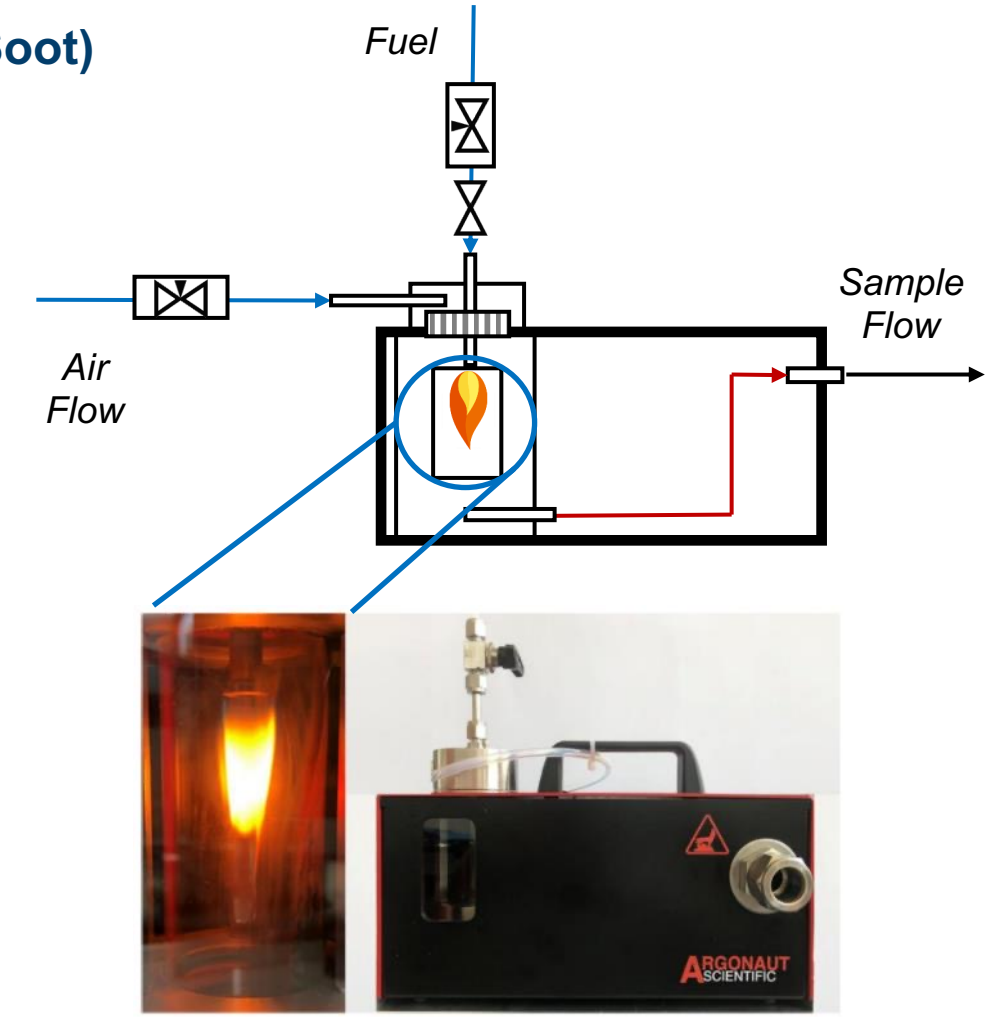
	Sky-CPC 5.411 (Grimm)	CPC 3772-CEN (TSI)
Nominal detection limit (d_{50})	4 nm	7 ± 0.7 nm
Maximum concentration	100,000 P/cm^3	50,000 P/cm^3
Nominal flow rate	0.6 L/min	1.0 ± 0.05 L/min
Absolute pressure range	125 to 1,100 hPa	750 to 1,050 hPa

According to the manufacturer, the Sky-CPC is a “custom-made CPC-core… optimized for low pressure conditions”

EXPERIMENTAL SET-UP

(2) “Combustion Emission in Urban Air” (represented by Flame Soot)

- Largely same set-up
  - Miniature Inverted Soot Generator (Argonaut Scientific Corp.) replaced atomizer and its diffusion drier
    - Two co-annular tubes provide fuel and air flows
    - Downward-flowing diffusion flame inside burner
  - Promises
    - Increased flame stability & more constant soot production
    - Generation of *larger* fraction of nanometer-sized particles
      - Calibration aerosol for CPC requires sufficient particle concentration in sub-20nm range to determine counting efficiency

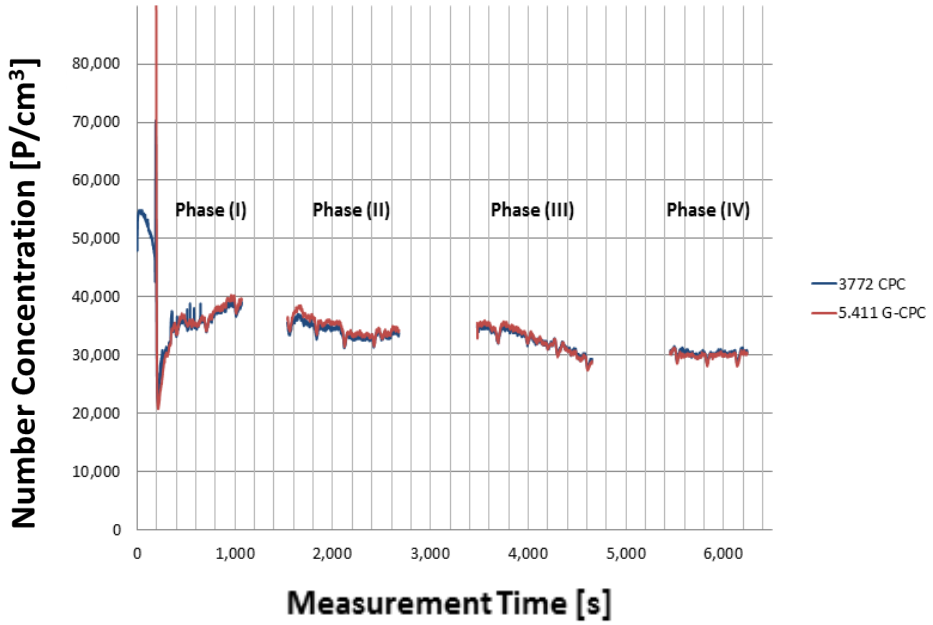


EXPERIMENTAL SET-UP

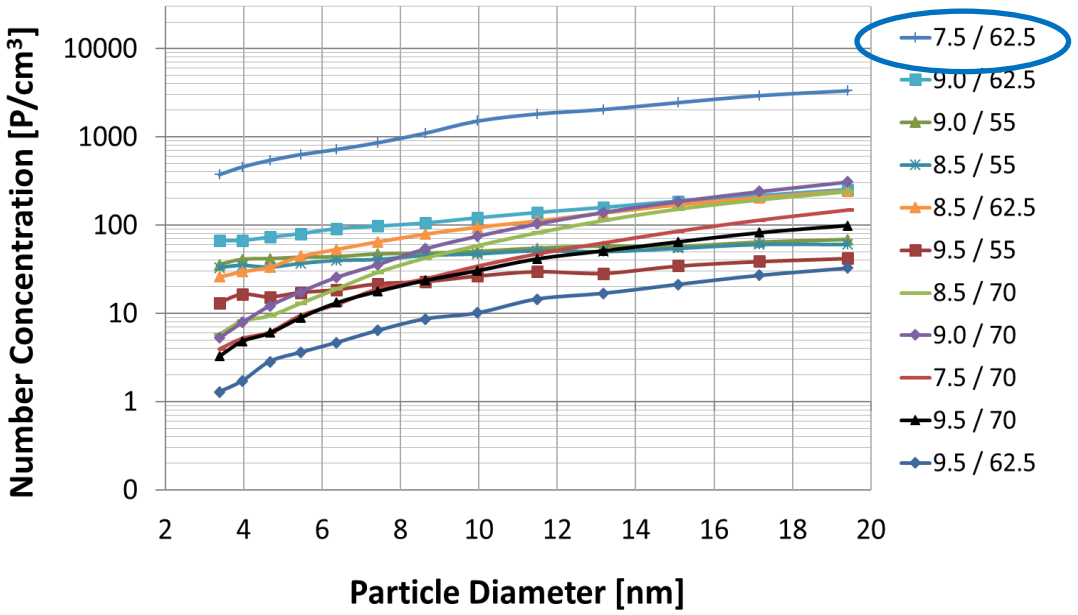
Soot Generator Characterization

- Initial characterization of Miniature Inverted Soot Generator

Warm-up time of soot generator



Particle size and concentration as function of air flow and fuel flow rates



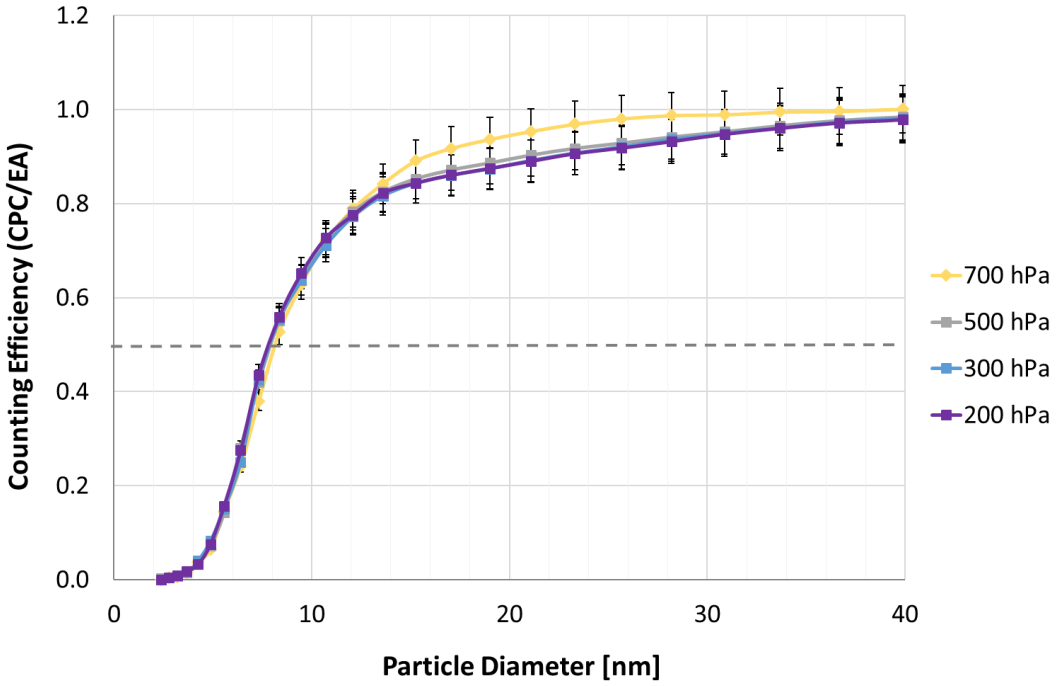
Bischof, Weber, et al. (Emiss. Control Sci. Technol., 2019)

CALIBRATION RESULTS

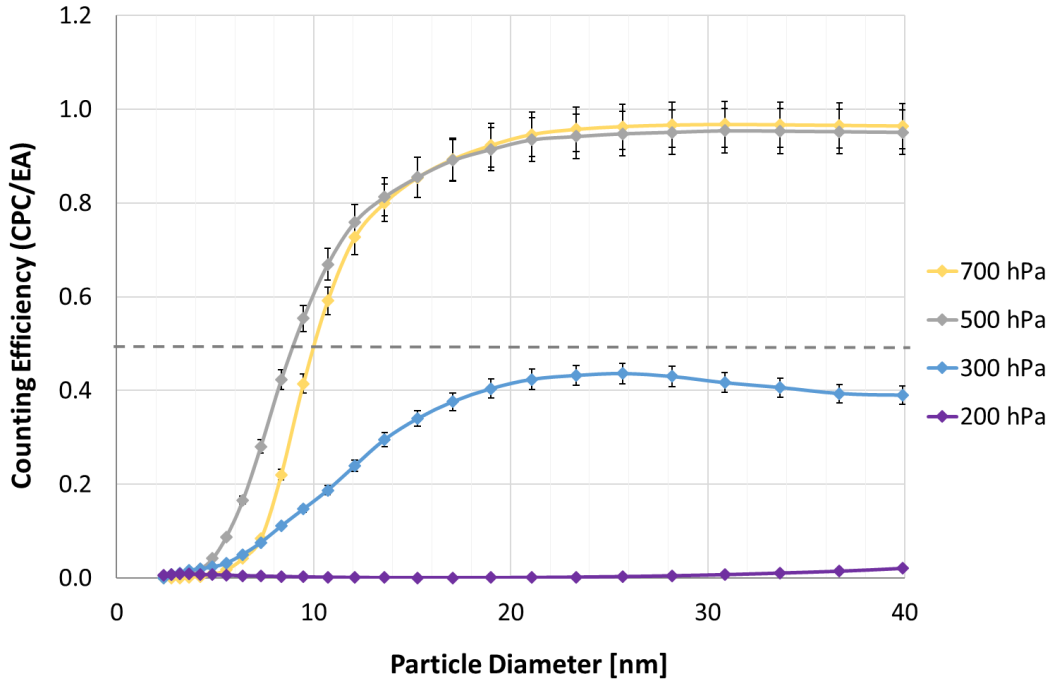
(1) “Atmospheric Background” Aerosol (represented by Ammonium Sulfate)

- Counting efficiency curves for AS for 700 hPa down to 200 hPa

Sky-CPC 5.411 (Grimm)



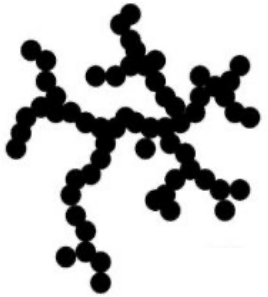
CPC 3772-CEN (TSI) *



* Operated with default temperatures

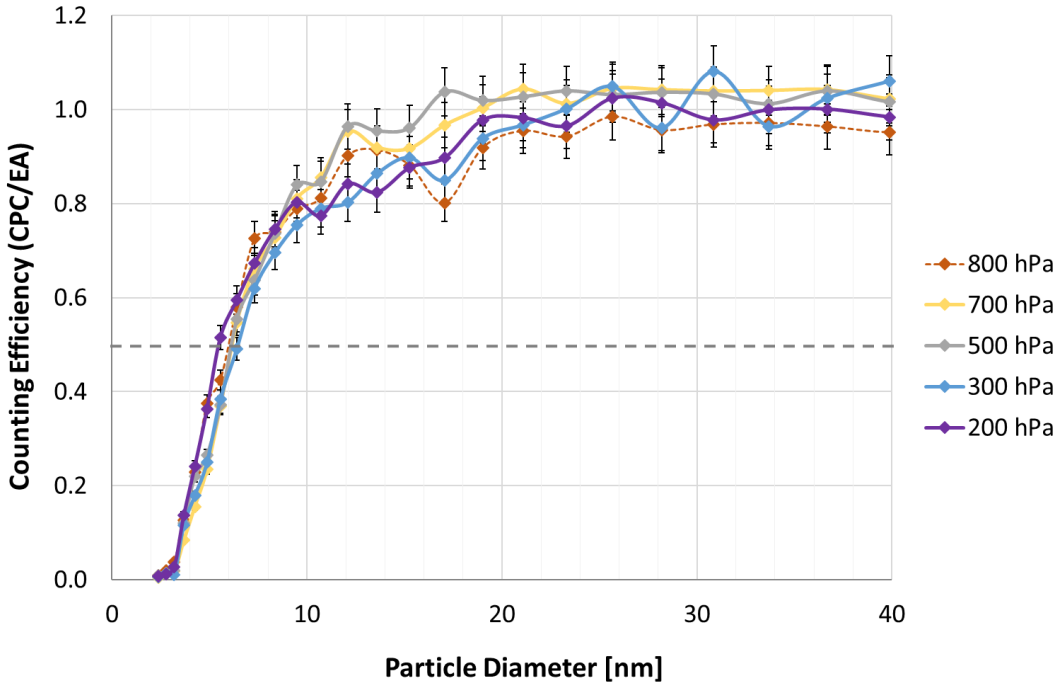
CALIBRATION RESULTS

(2) “Combustion Emission in Urban Air” (represented by Flame Soot)

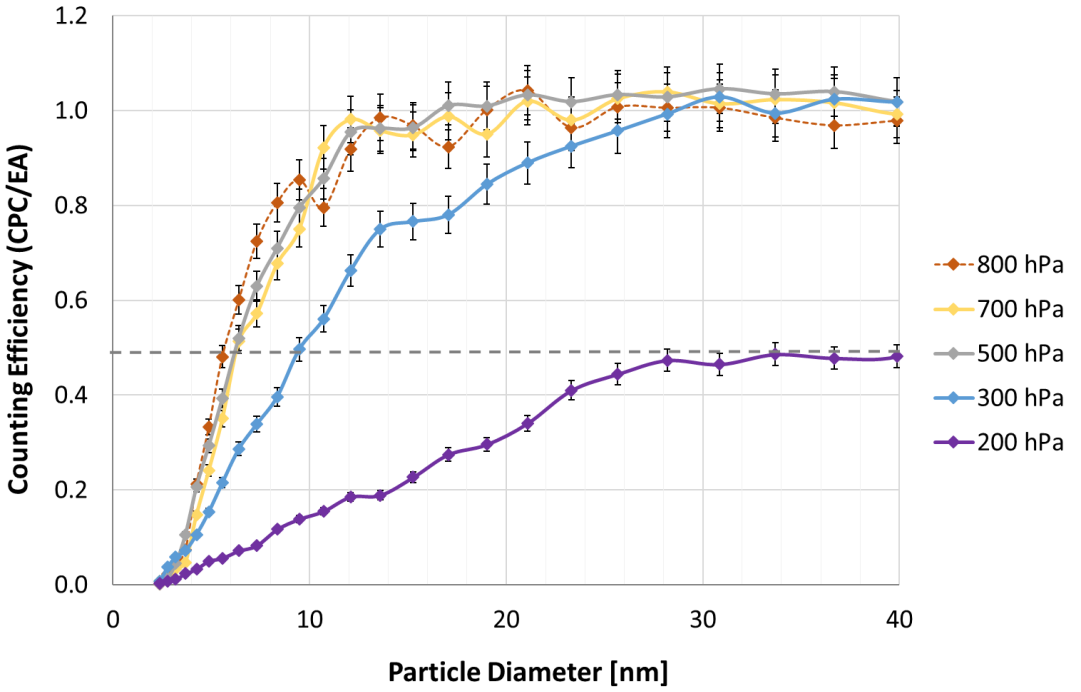


- Counting efficiency curves for Soot for 800 hPa down to 200 hPa

Sky-CPC 5.411 (Grimm)



CPC 3772-CEN (TSI) *



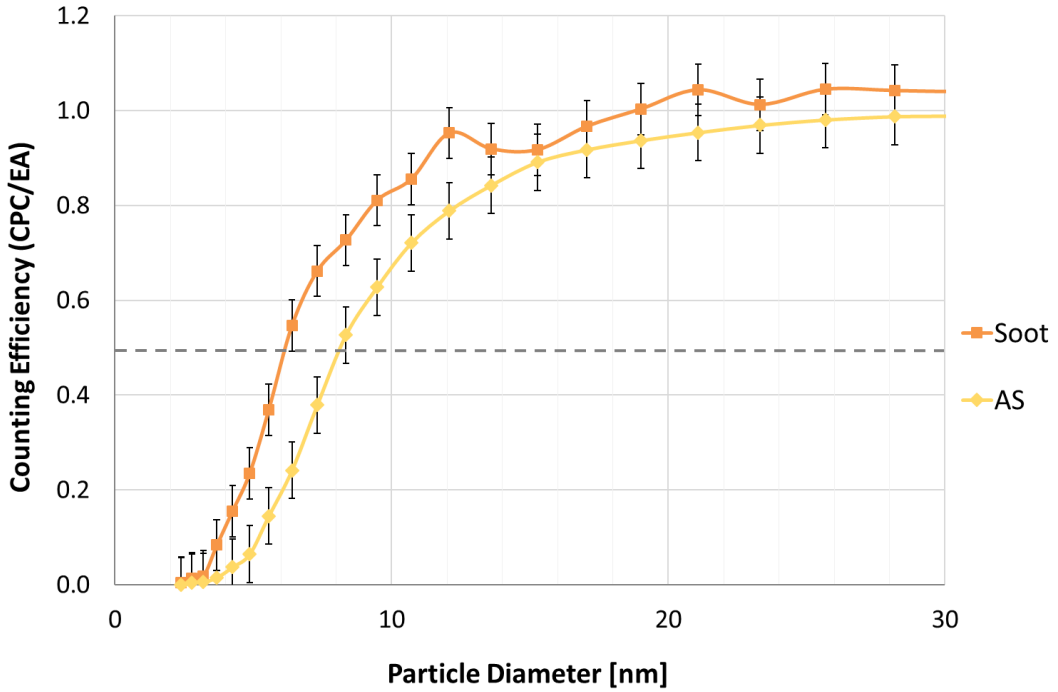
* Operated with default temperatures

CALIBRATION RESULTS

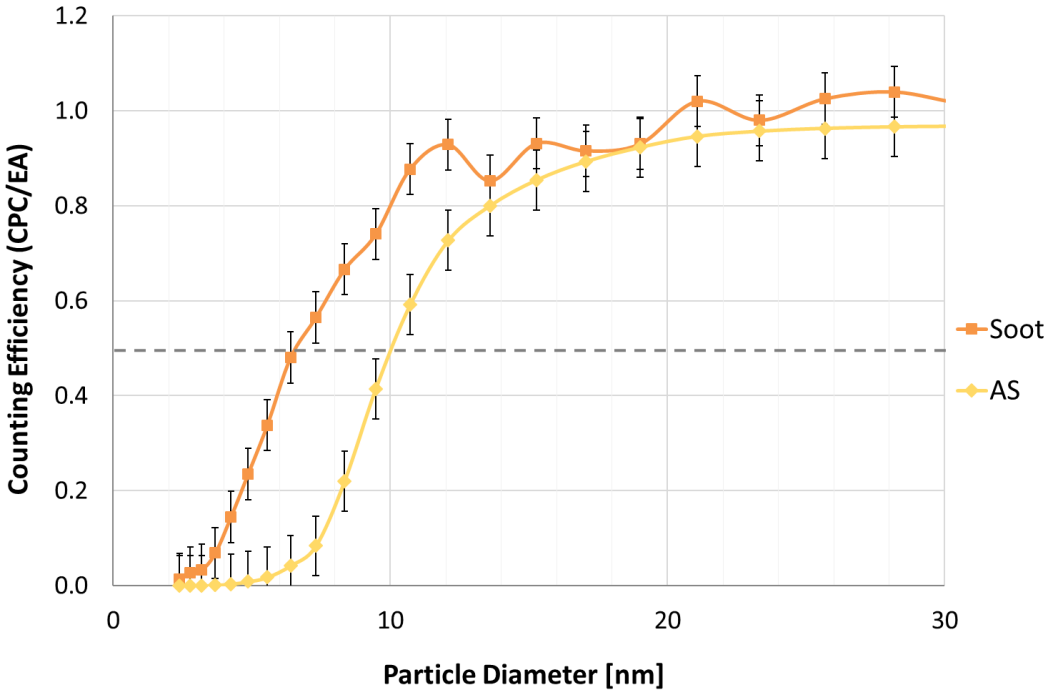
(3) Impact of Material Dependence

- Counting efficiency comparison, AS with Flame Soot at 700 hPa

Sky-CPC 5.411 (Grimm)



CPC 3772-CEN (TSI) *



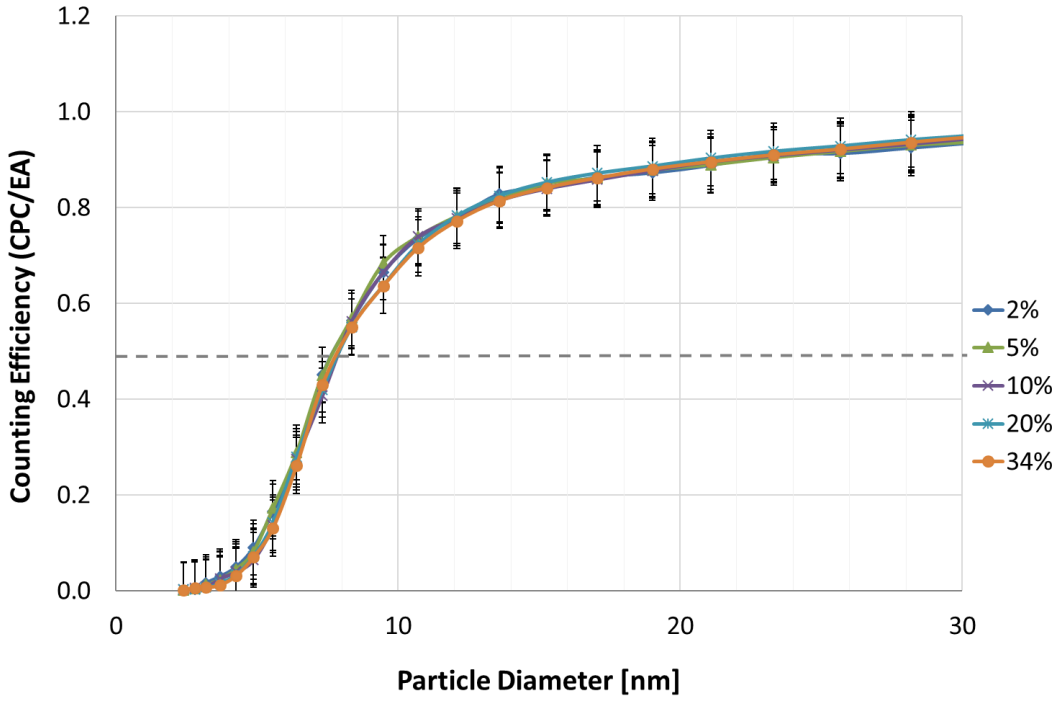
* Operated with default temperatures

CALIBRATION RESULTS

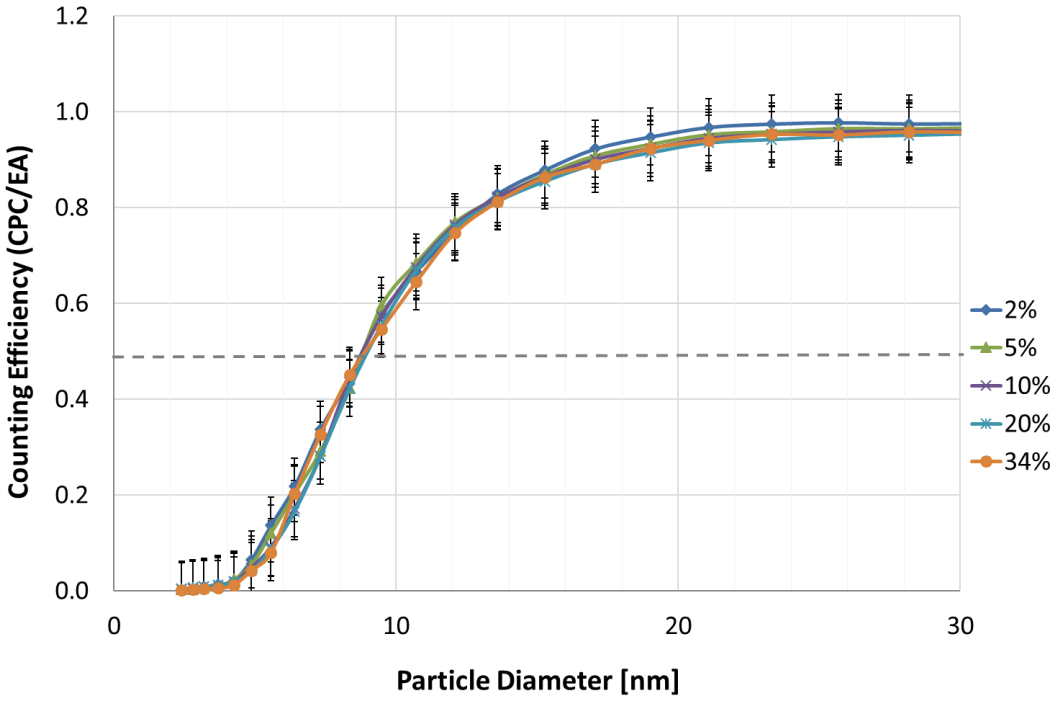
(4) Impact of Low Levels of Relative Humidity

- Counting efficiency comparison, for AS at varied RH at 500 hPa

Sky-CPC 5.411 (Grimm)



CPC 3772-CEN (TSI) *



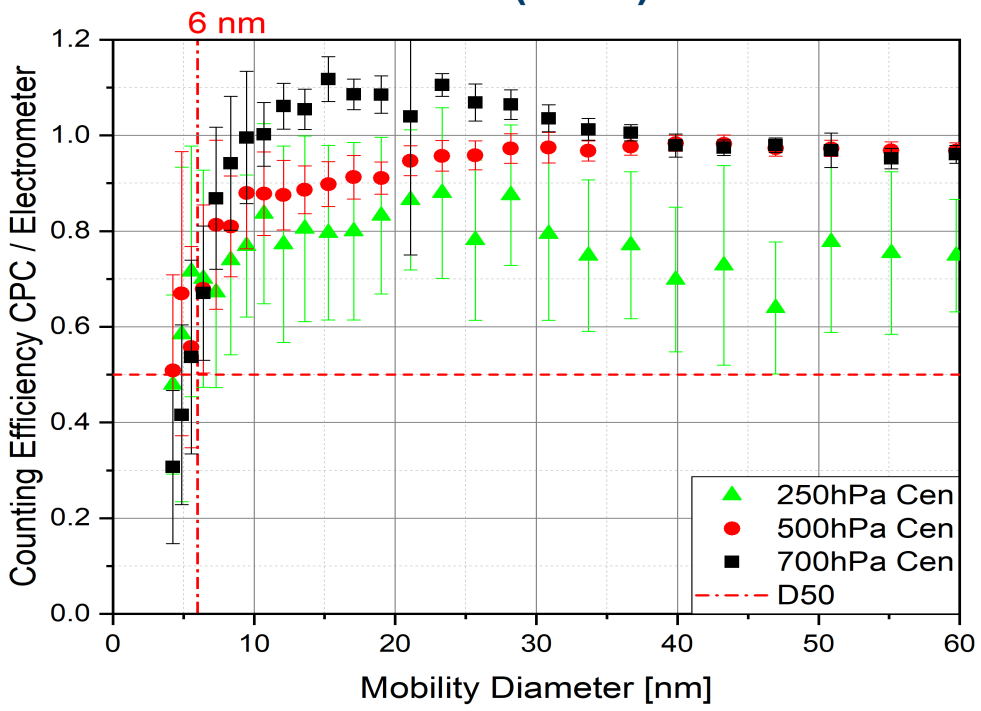
* Operated with default temperatures

CALIBRATION RESULTS *

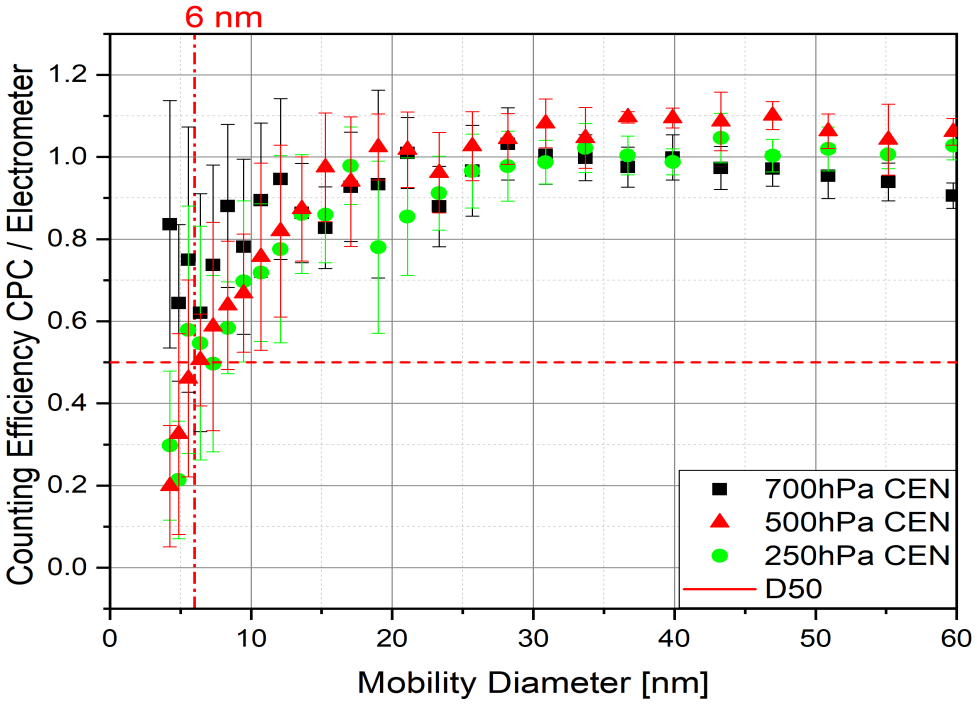
Impact of Modified Operating Temperatures (5°C and 40°C) - CPC 3772-CEN only

- Counting efficiency curves for 700 hPa, 500 hPa and 250 hPa

Salt (NaCl)



Combustion Soot



* Later work conducted by Patrick Weber in our group

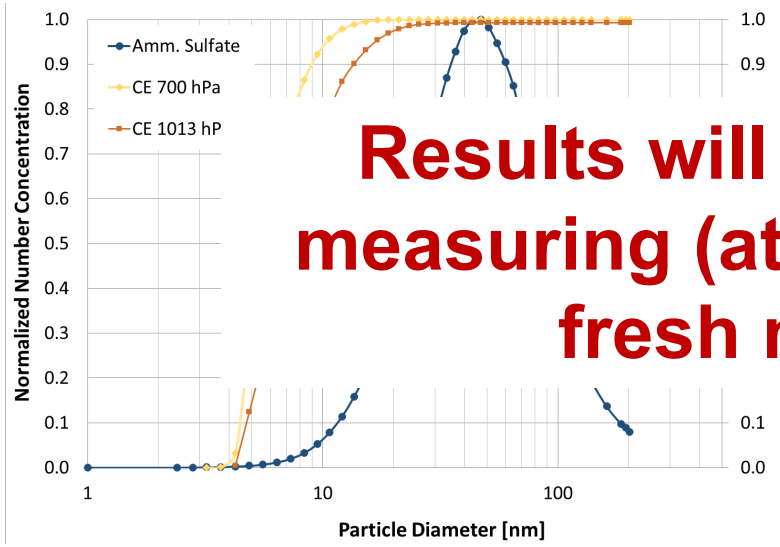
IMPACT ON TOTAL PN CONCENTRATION

Estimation

$$\eta_{CPC,Tot} = \frac{\sum_{i=0}^{n} (N_{norm,i} * \eta_{CPC,i})}{\sum_{i=0}^{n} (N_{norm,i})}$$

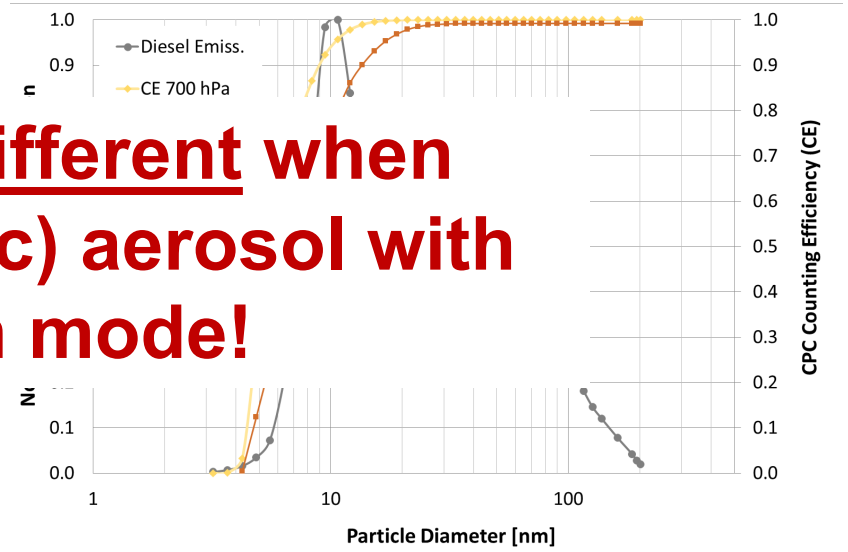
- Convolute known size distributions with efficiency data

Ammonium Sulfate



- 1,013 hPa, $\eta_{CPC,Tot}$ = 98.4%
- 700 hPa, $\eta_{CPC,Tot}$ = 99.8%
- Delta is 1.4% in total concentration

Diesel Emission



- 1,013 hPa, $\eta_{CPC,Tot}$ = 90.8%
- 700 hPa, $\eta_{CPC,Tot}$ = 97.0%
- Delta is 6.2% in total concentration

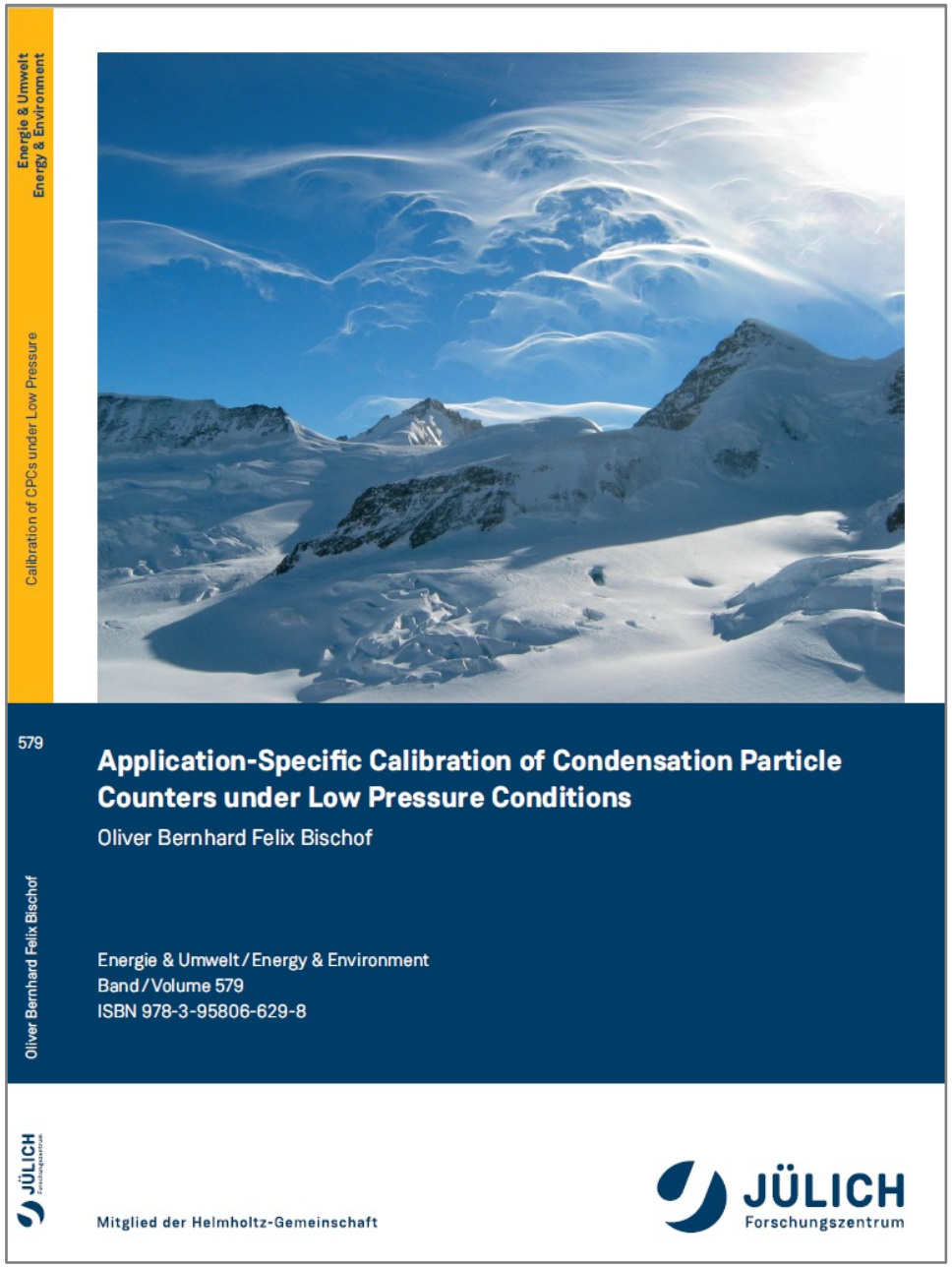
Results will be very different when measuring (atmospheric) aerosol with fresh nucleation mode!

SUMMARY

- Characterized counting efficiency of two CPC models
- Effect of low pressure depends on exact conditions, CPC design & operating parameters
  - Sky-CPC 5.411, custom-designed for reduced pressure, worked well down to 200 hPa
  - CPC 3772-CEN, specified down to 750 hPa, worked until 400 hPa but collapsed below that
    - If modified operational temperatures are used, recent work has shown it works down to 250 hPa
- Aerosol sources revealed only slight material dependence
- Low to moderate levels of RH (1 to 40%) had no apparent influence
- For highest accuracy (legislative purposes), CPCs should be calibrated for specific applications when these include use at reduced pressure

THANK YOU FOR YOUR ATTENTION!

Q&A


Energie & Umwelt
Energy & Environment
Calibration of CPCs under Low Pressure
579
Application-Specific Calibration of Condensation Particle Counters under Low Pressure Conditions
Oliver Bernhard Felix Bischof
Energie & Umwelt / Energy & Environment
Band / Volume 579
ISBN 978-3-95806-629-8
Oliver Bernhard Felix Bischof
JÜLICH
Mitglied der Helmholtz-Gemeinschaft
JÜLICH
Forschungszentrum