Aerosol life cycles: what can we learn from high altitude sites?

Urs Baltensperger
Laboratory of Atmospheric Chemistry
Paul Scherrer Institute, 5232 Villigen PSI, Switzerland

AeroCom Workshop
Hamburg, 23 – 27 September 2013

PAUL SCHERRER INSTITUT

PSI

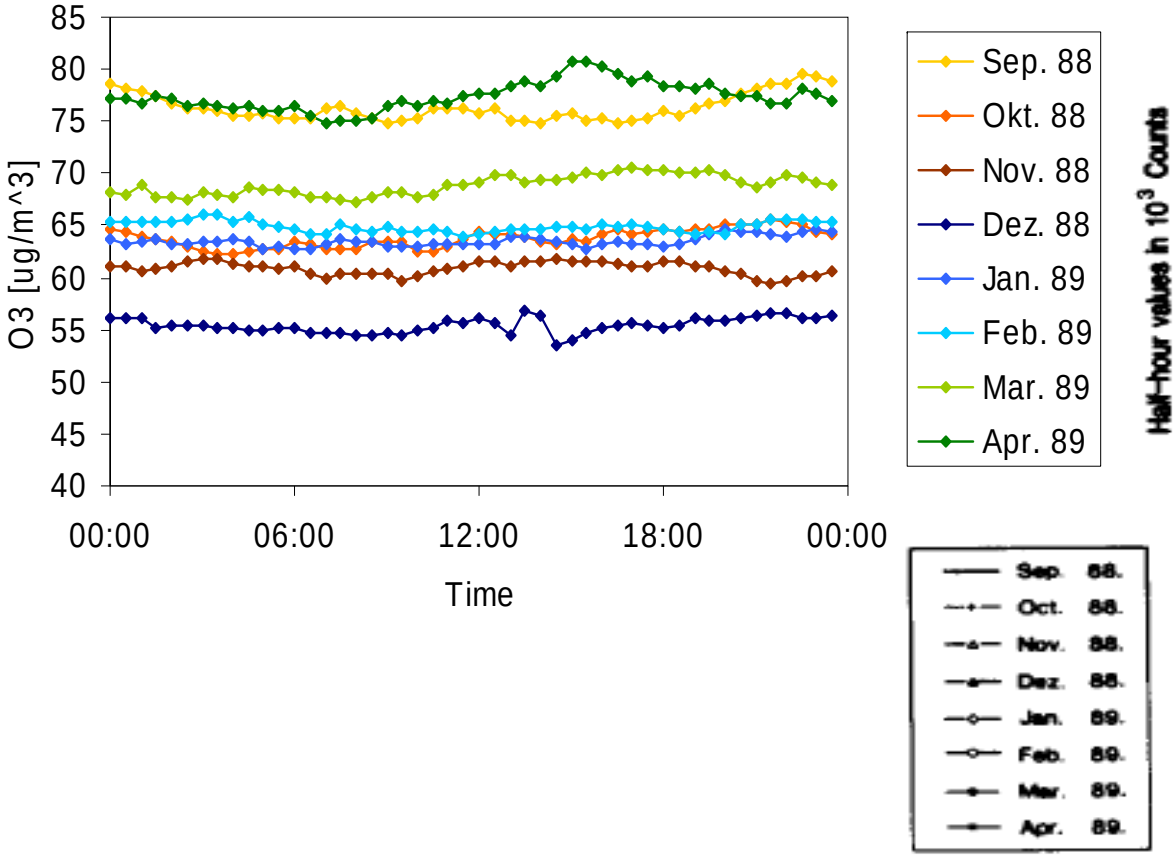
LABOR FÜR ATMOSPHÄREN-CHEMIE

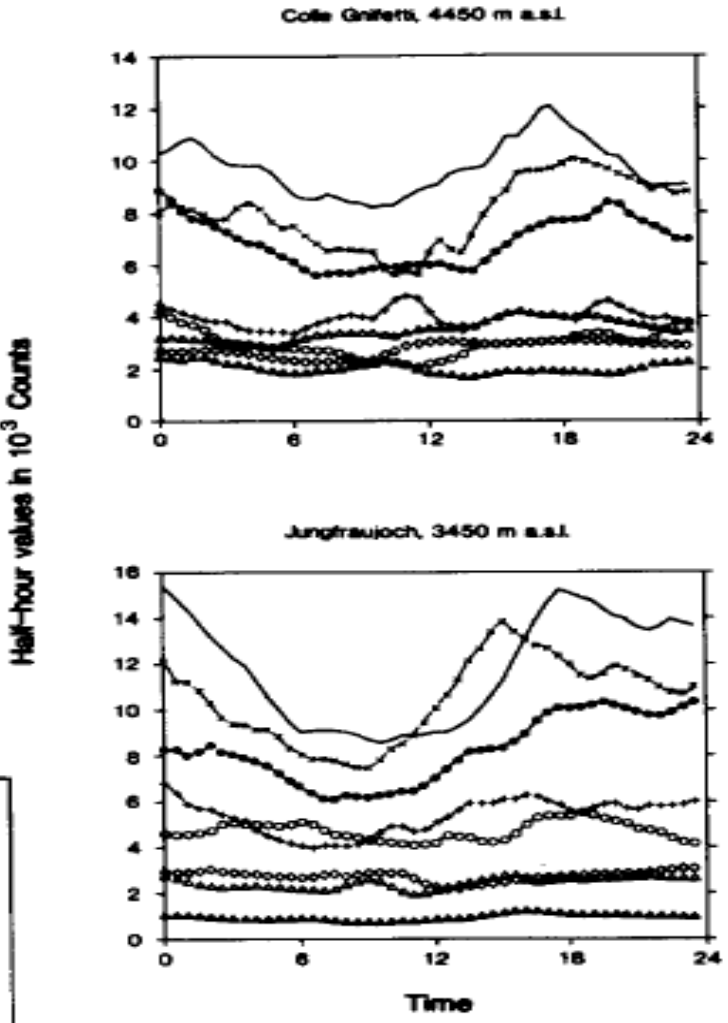
Research questions

- Topography enhanced vertical transport
- Short lifetime, high spatial variability
- Nucleation
- Away from sources, enabling studies of aged aerosols (physical, optical and chemical properties, source apportionment..)
- If station in cloud: aerosol-cloud interaction, liquid and mixed-phase clouds

Vertical transport does reach the highest mountain tops in Europe

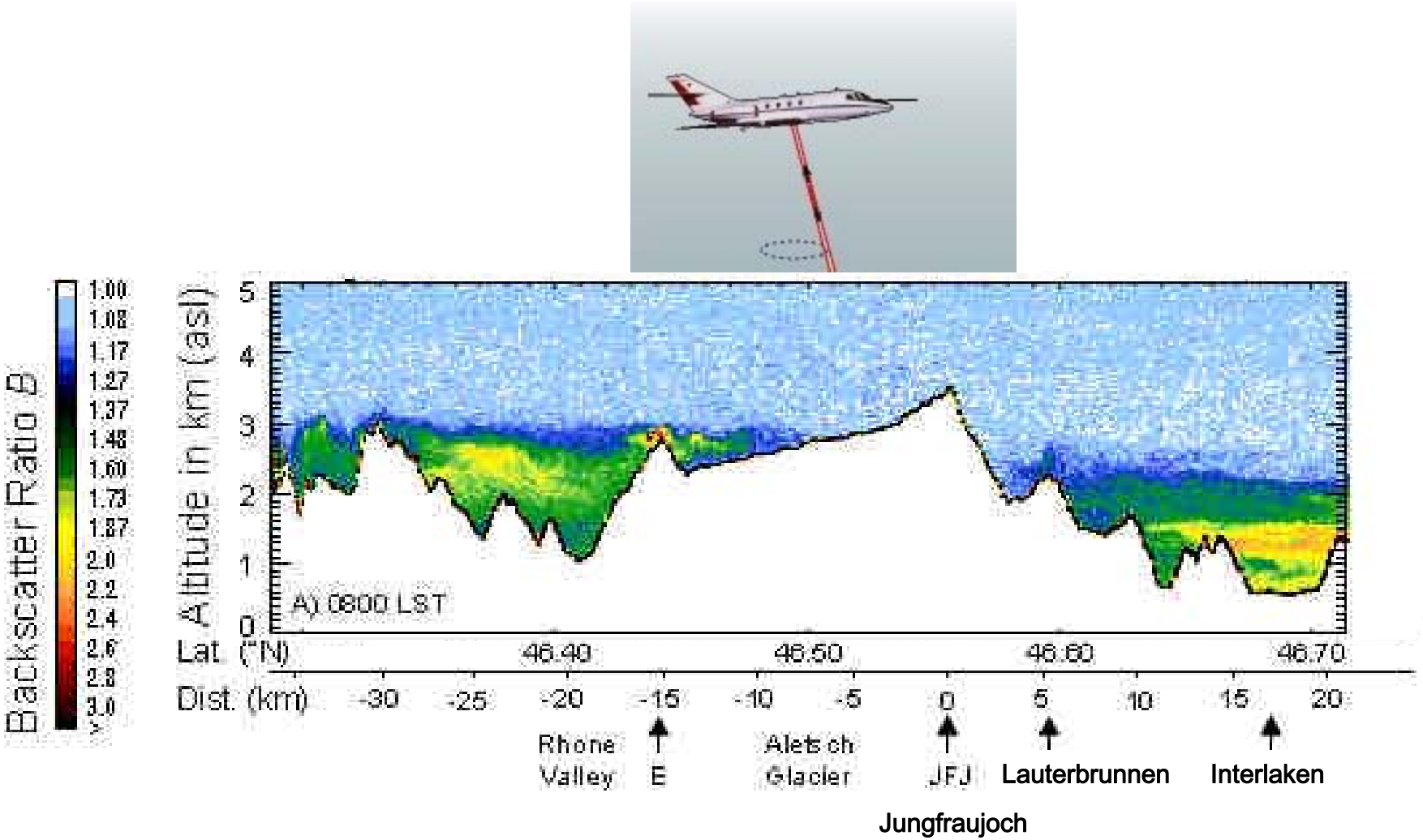
Before, it was believed, based on ozone data, that such sites are always in the free troposphere





Baltensperger et al., 1991

Confirmation by airborne lidar



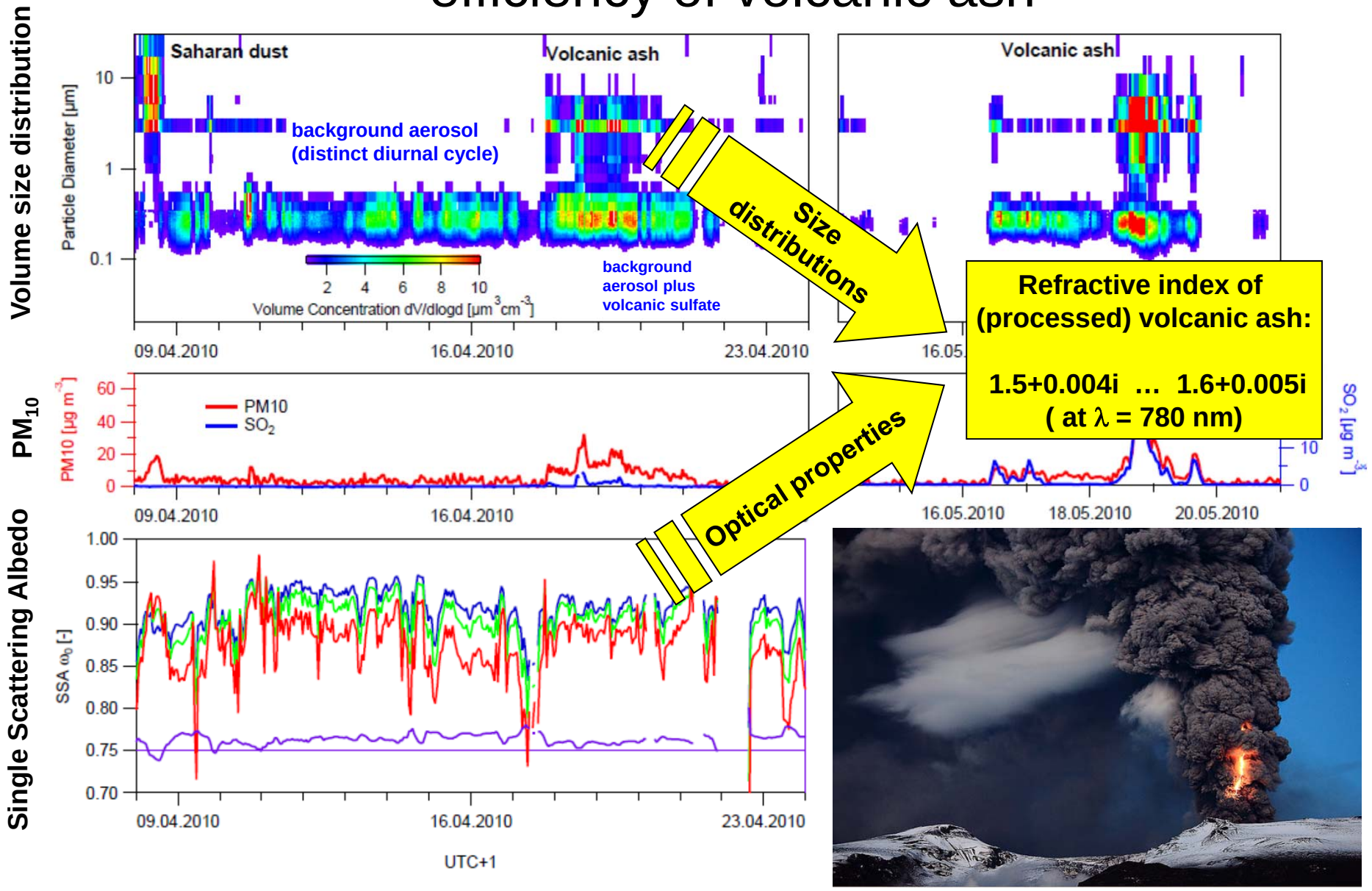
Nyeki et al., GRL, 2000

A wide variety of aerosol variables are needed for a full description of the atmospheric aerosol (Recommendations of the GAW Aerosol SAG)

- Multiwavelength optical depth
- Mass in two size fractions
- Major chemical components in two size fractions
- Scattering and hemispheric backscattering coefficient at various wavelengths
- Absorption coefficient
- Aerosol number concentration
- Cloud condensation nuclei (at various supersaturations)
- Aerosol size distribution
- Detailed size fractionated chemical composition
- Dependence on relative humidity
- Vertical distribution of aerosol properties (e.g. LIDAR)

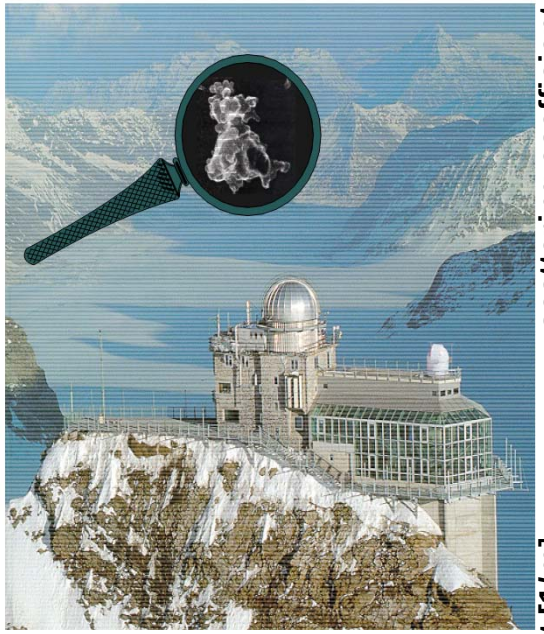
High altitude stations typically provide these properties for an aged aerosol above a continental area, without the influence of a local source

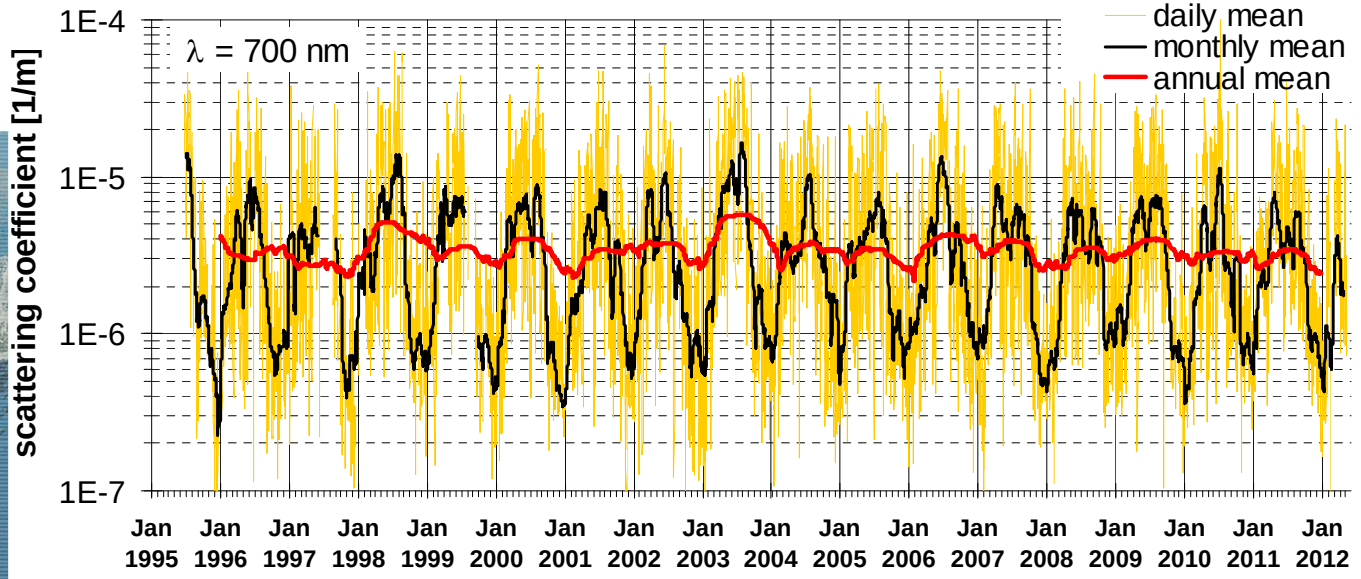
Refractive index and mass extinction efficiency of volcanic ash

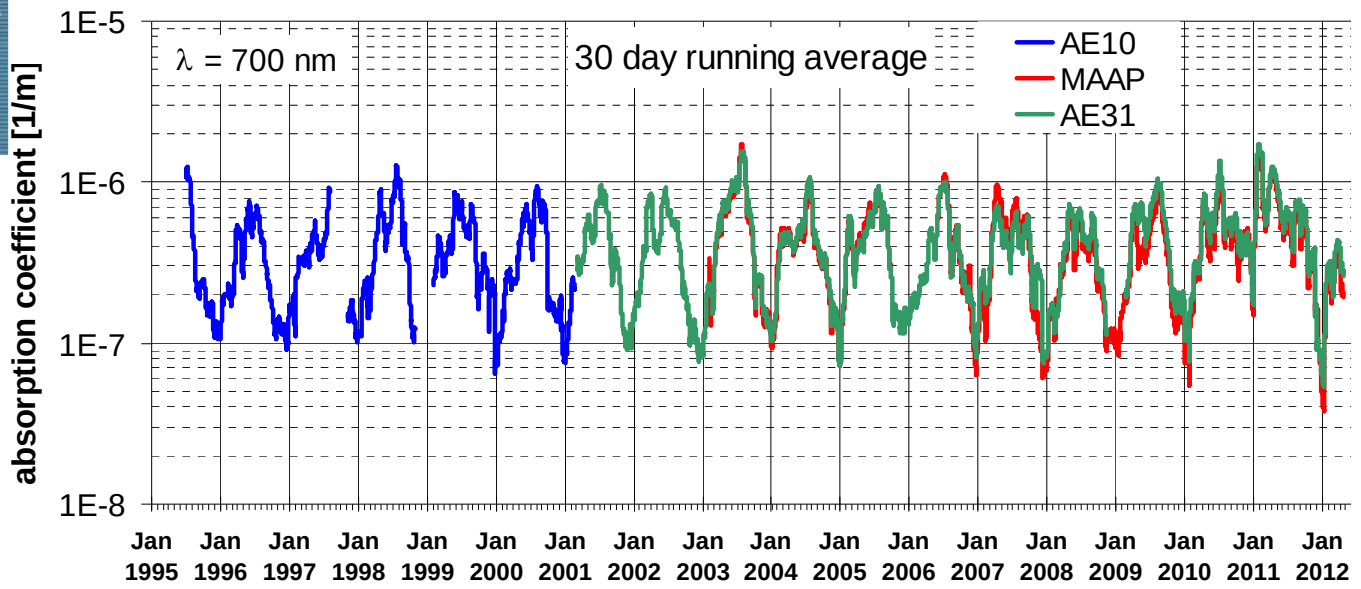


Bukowiecki et al., ACP 2011

18 years of continuous data at the Jungfraujoch (3580 m asl)







PAUL SCHERRER INSTITUT

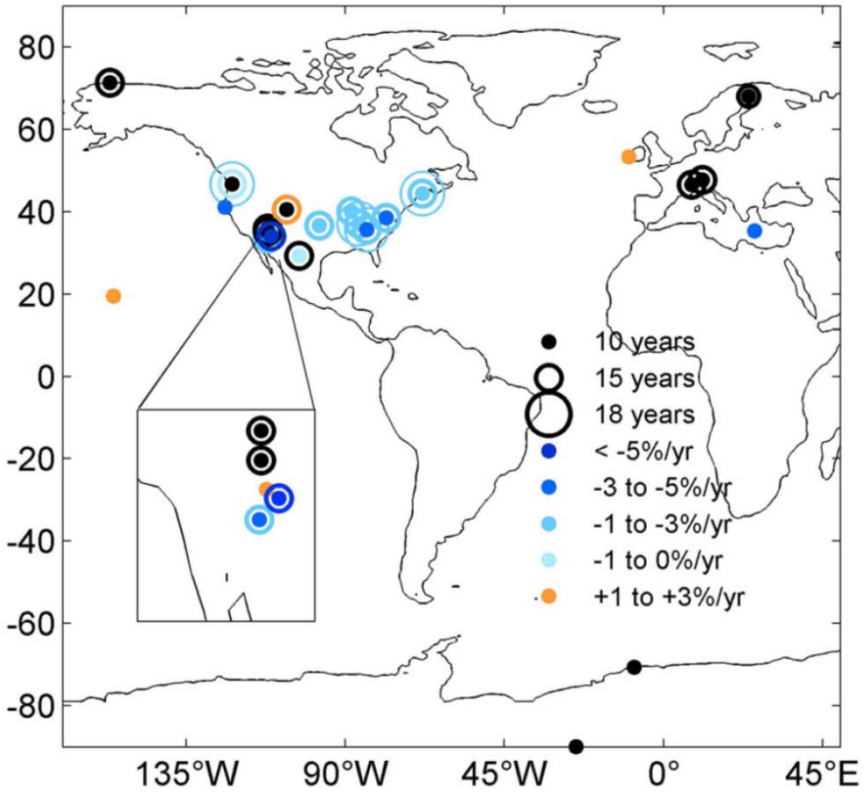
LABOR FÜR ATMOSPHÄREN-CHEMIE

There are only very few stations with long-term measurements of climate relevant properties

➔ we need more stations with long-term vision to better assess the impact of aerosols on climate

The ‚global' stations of the Global Atmosphere Watch program of the World Meteorological Organization

Trends of the aerosol light scattering coefficient

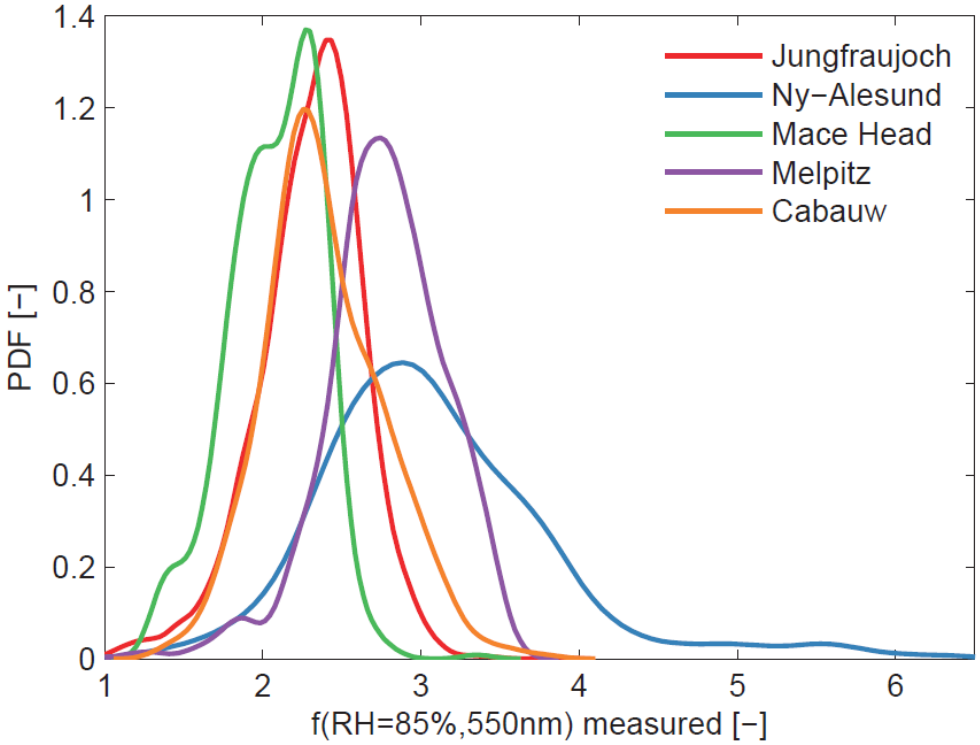


Collaud Coen et al., ACP 2013

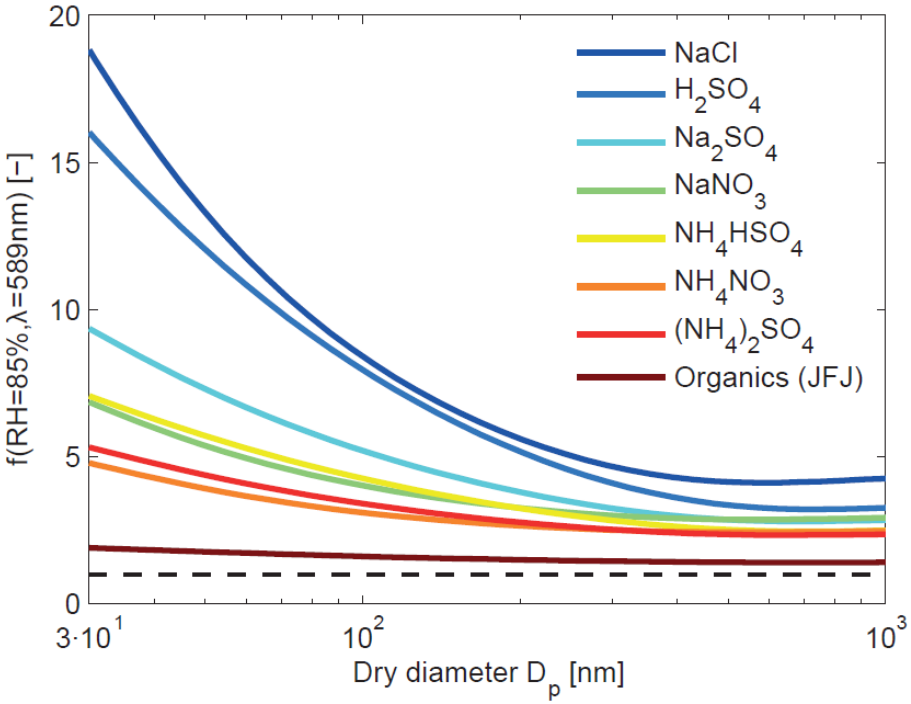
The ambient single scattering albedo requires the ambient scattering coeffcient

The scattering enhancement depends on size and chemistry

Scattering enhancement at different sites (at RH = 85%)



Dependence on size and chemistry

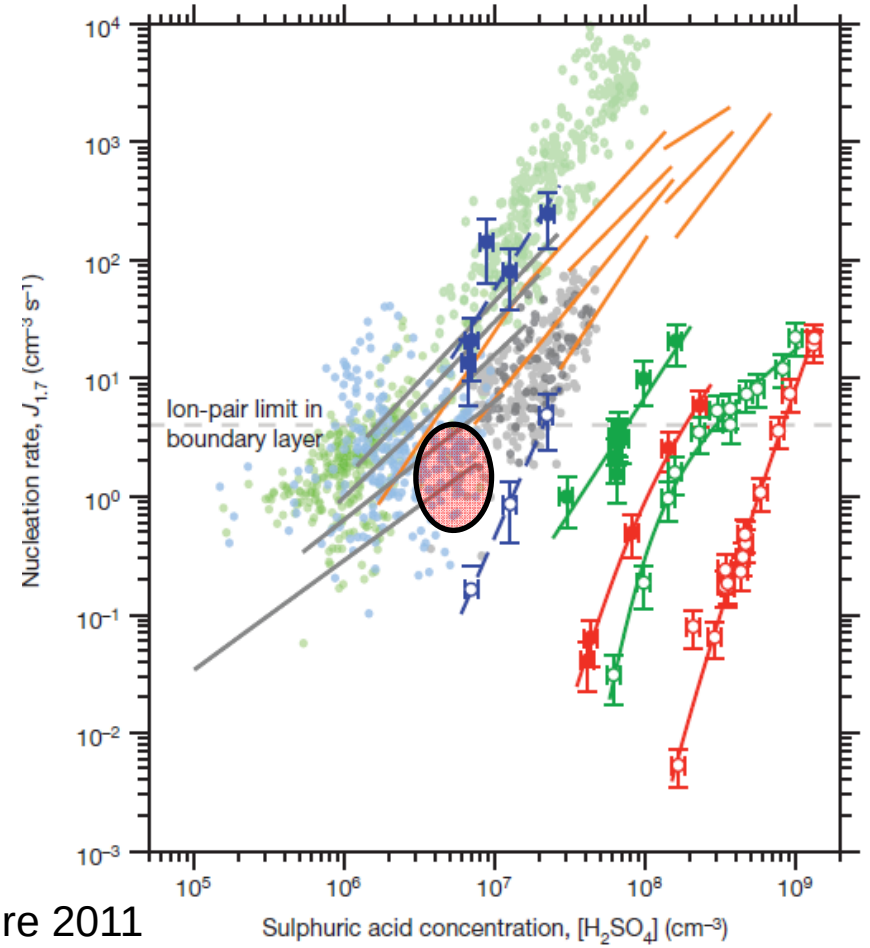


Zieger et al., ACP 2013, in press

Nucleation occurs frequently in the lower free troposphere, mechanisms still largely unknown

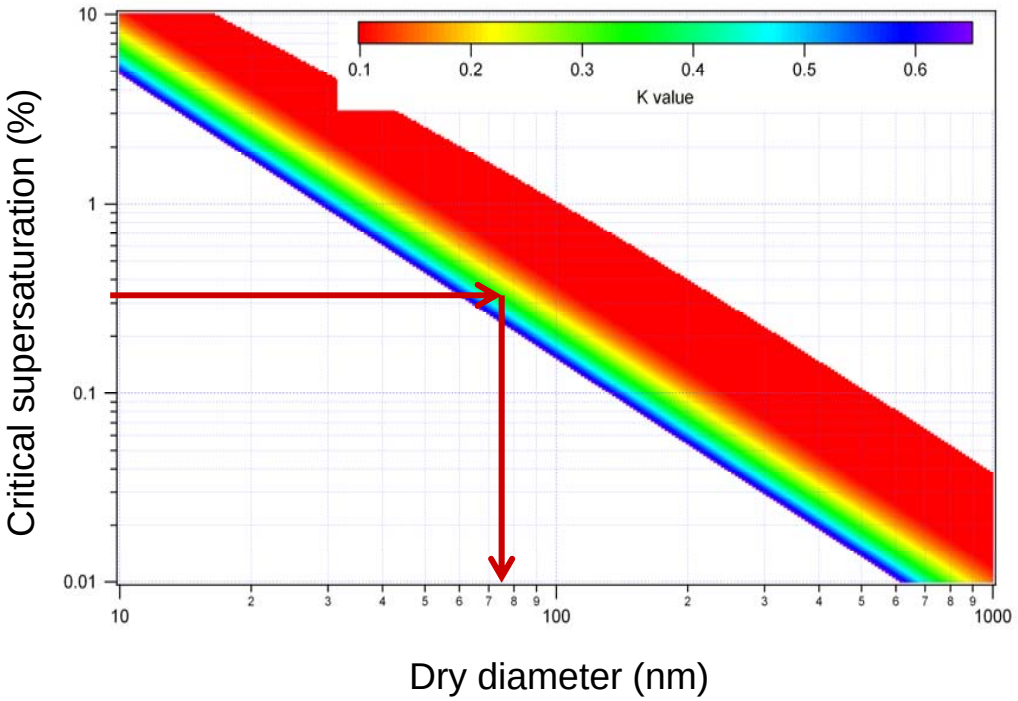
- J_3 nucleation rates around 1 cm^{-3} s^{-1}
- Sulfuric acid around $5 \cdot 10^6$ - 10^7 cm^{-3}
- Nucleation rates cannot be explained by pure sulfuric acid, even at low T
- Also with NH_3 still difficult at Jungfraujoch temperature

Nucleation rates from CLOUD:
red: 292 K, green: 278 K, blue: 248 K
open: pure sulphuric acid; filled: with NH_3

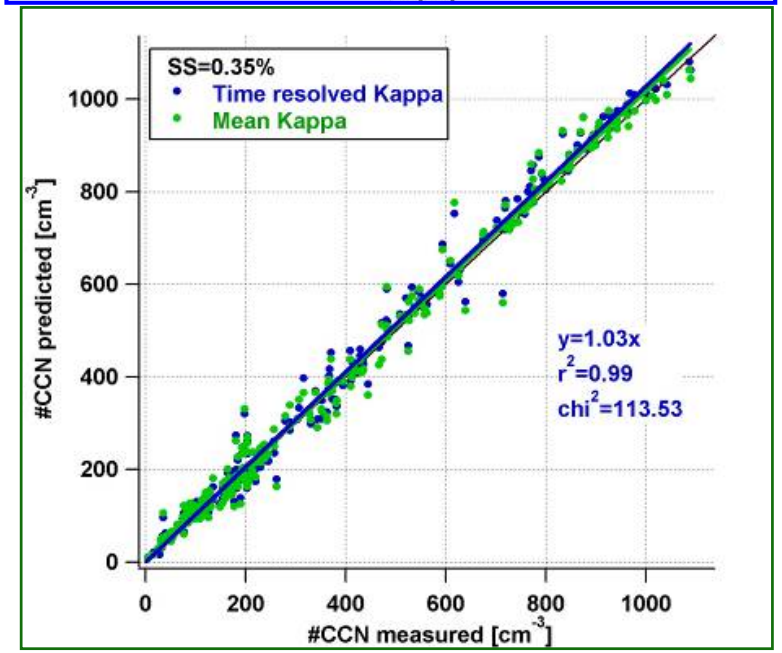


Kirkby et al., Nature 2011

CCN number concentrations by direct measurement and indirectly from size and hygroscopicity measurements

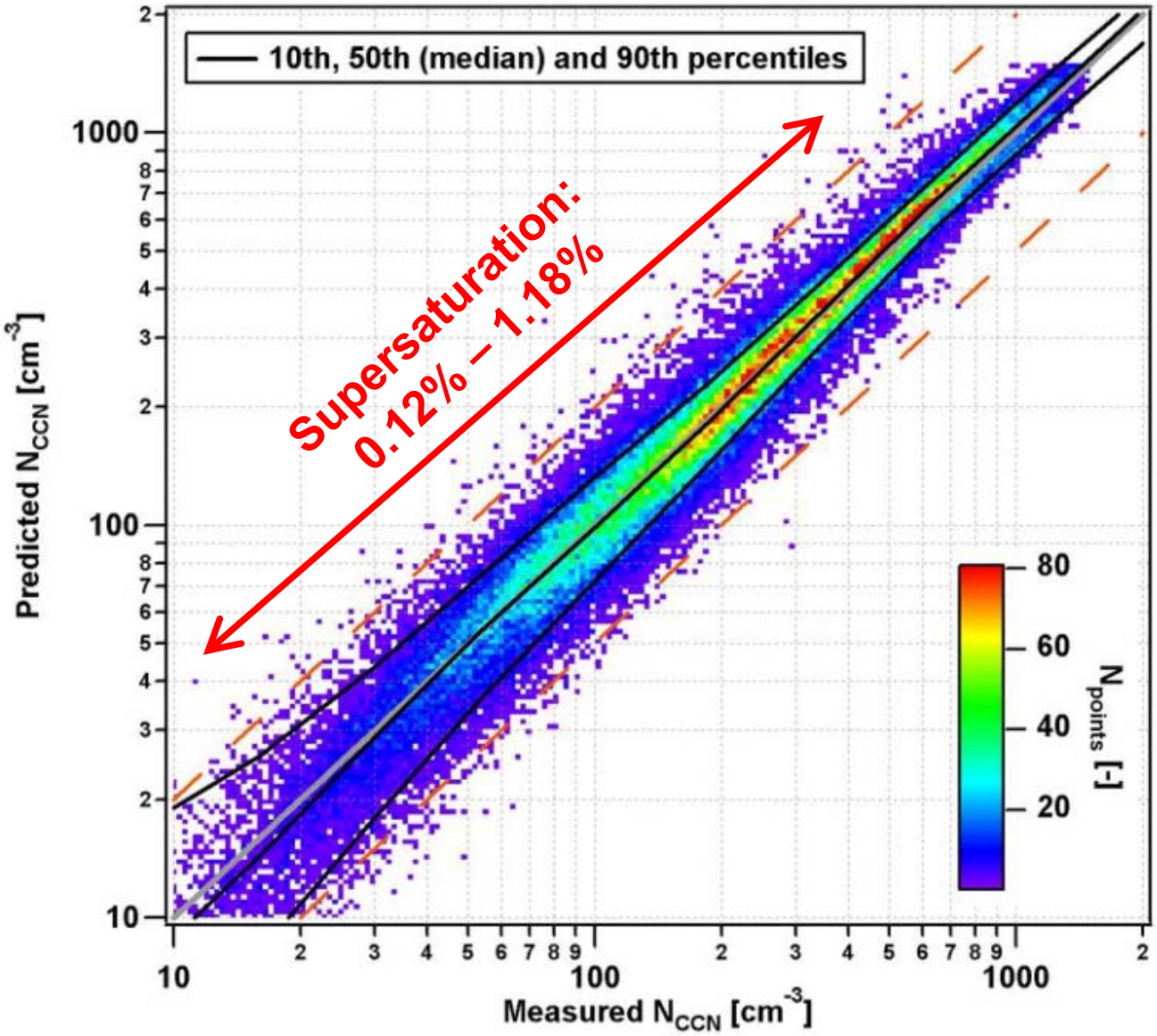


In simple cases, size and chemistry allow to determine CCN number concentration:
Comparison of measured and predicted CCN concentration for the Jungfraujoch



Prediction of the CCN concentration

Prediction only uses *N(D)* and assumes constant chemical composition in time

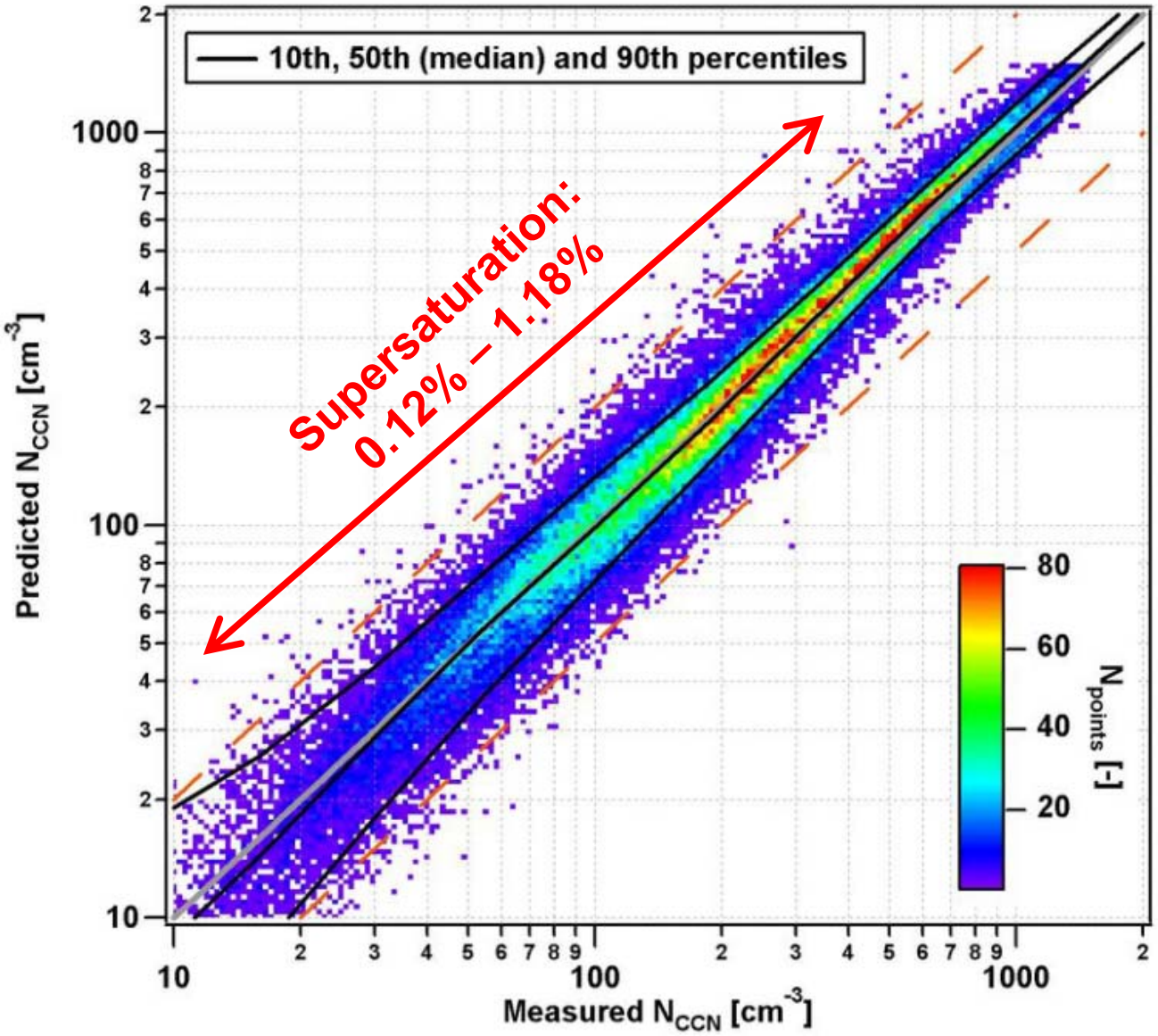


This is great news for the modellers:
With a size distribution and a chemical composition (kappa) we can predict the number of CCN for a wide range of supersaturations

Juranyi et al. JGR 2011

Prediction of the CCN concentration

Prediction only uses *N(D)* and assumes constant chemical composition in time



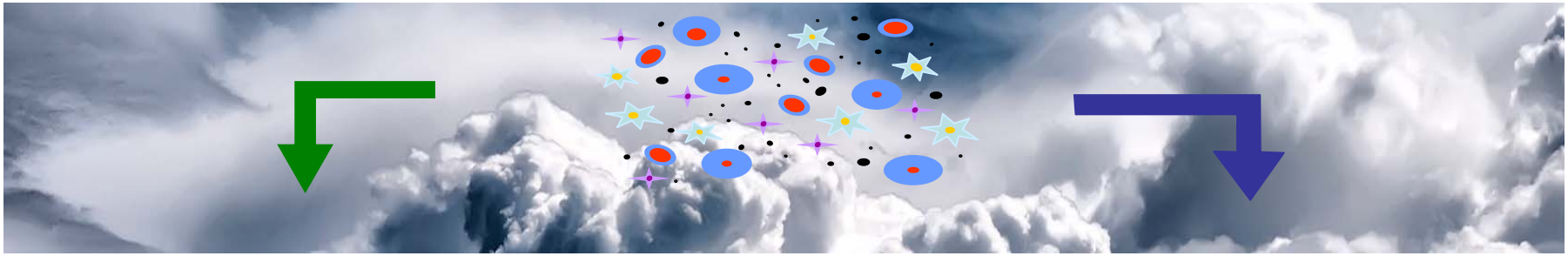
BUT:

We do not know the supersaturation in the ambient cloud

➔ Can we measure it ?

Juranyi et al. JGR 2011

CLACE campaigns



Interstitial inlet:

(no activated particles)

removes :
- droplets
- ice crystals

(Size < 2 μm)

- PVM and/or FSSP/FM
- Meteo (T, RH, P, Wind)

Total inlet :

heated inlet

Laboratory (dry aerosol)

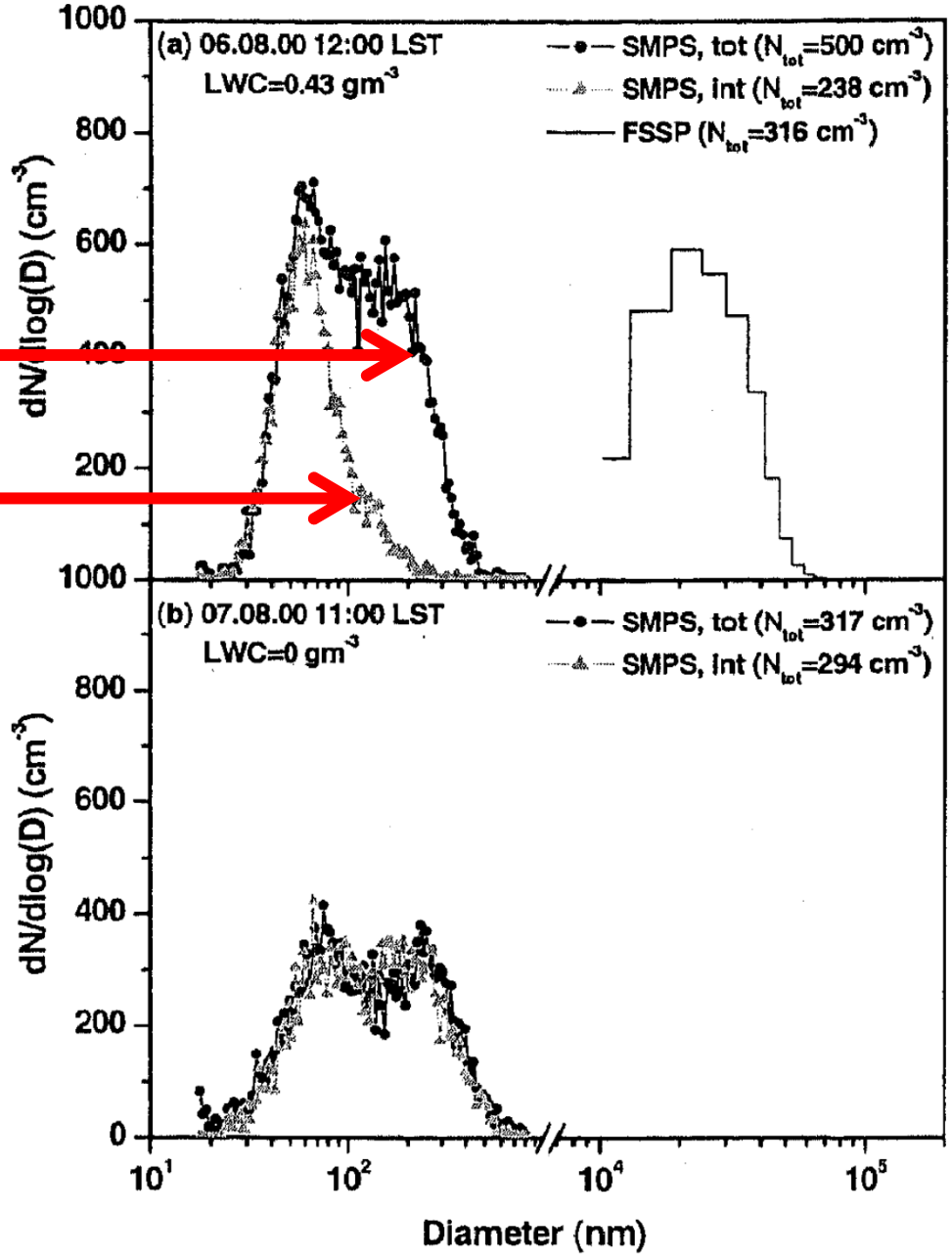
- SMPS

- SMPS
- DPM

Size distributions in and out of cloud

Total

Interstitial

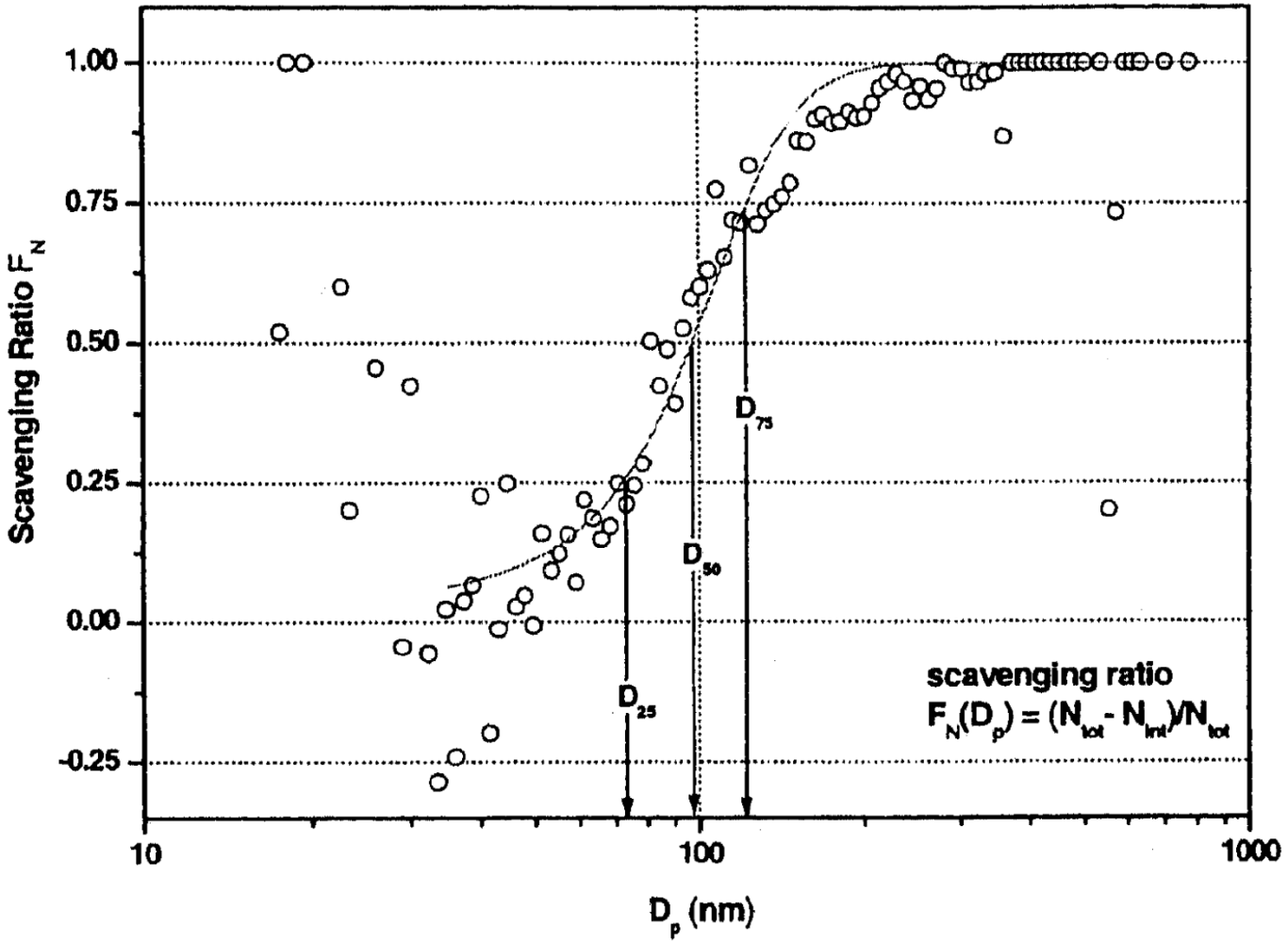


Henning et al., 2002

PAUL SCHERRER INSTITUT

LABOR FÜR ATMOSPHÄREN-CHEMIE

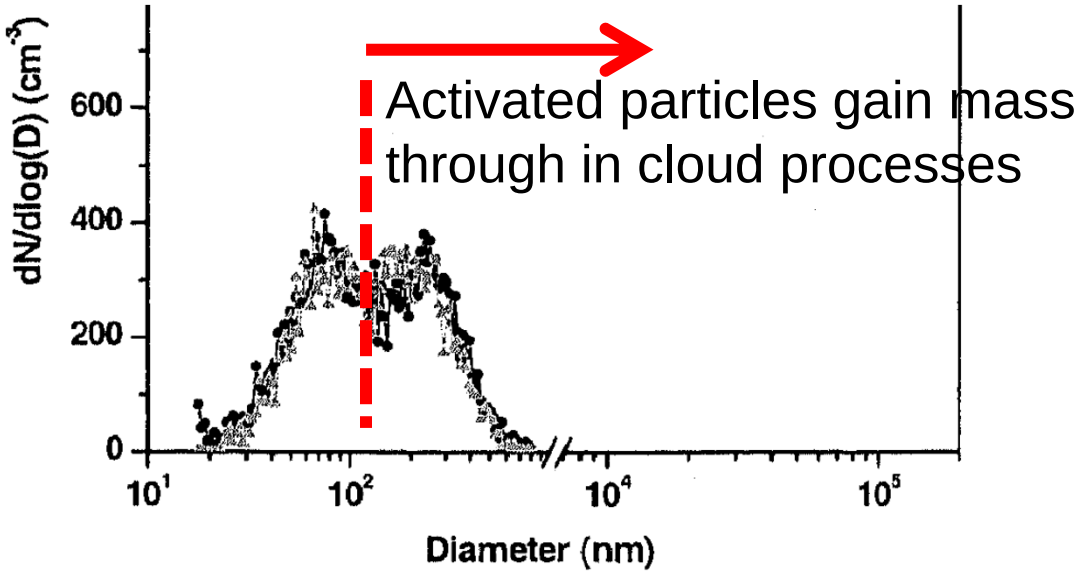
Activated fraction as a function of particle diameter in the real cloud



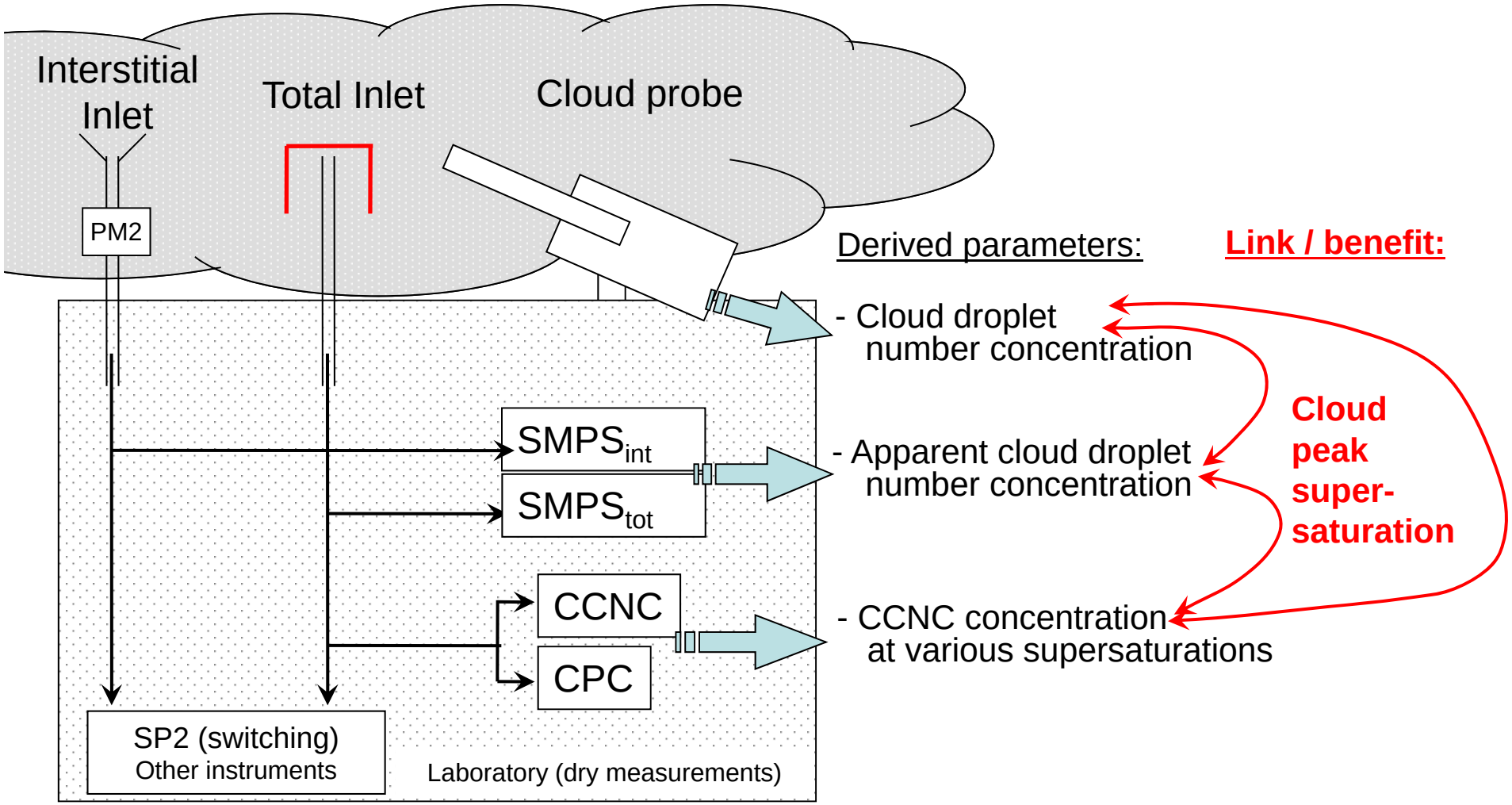
Henning et al., 2002

BTW: bimodal size distribution

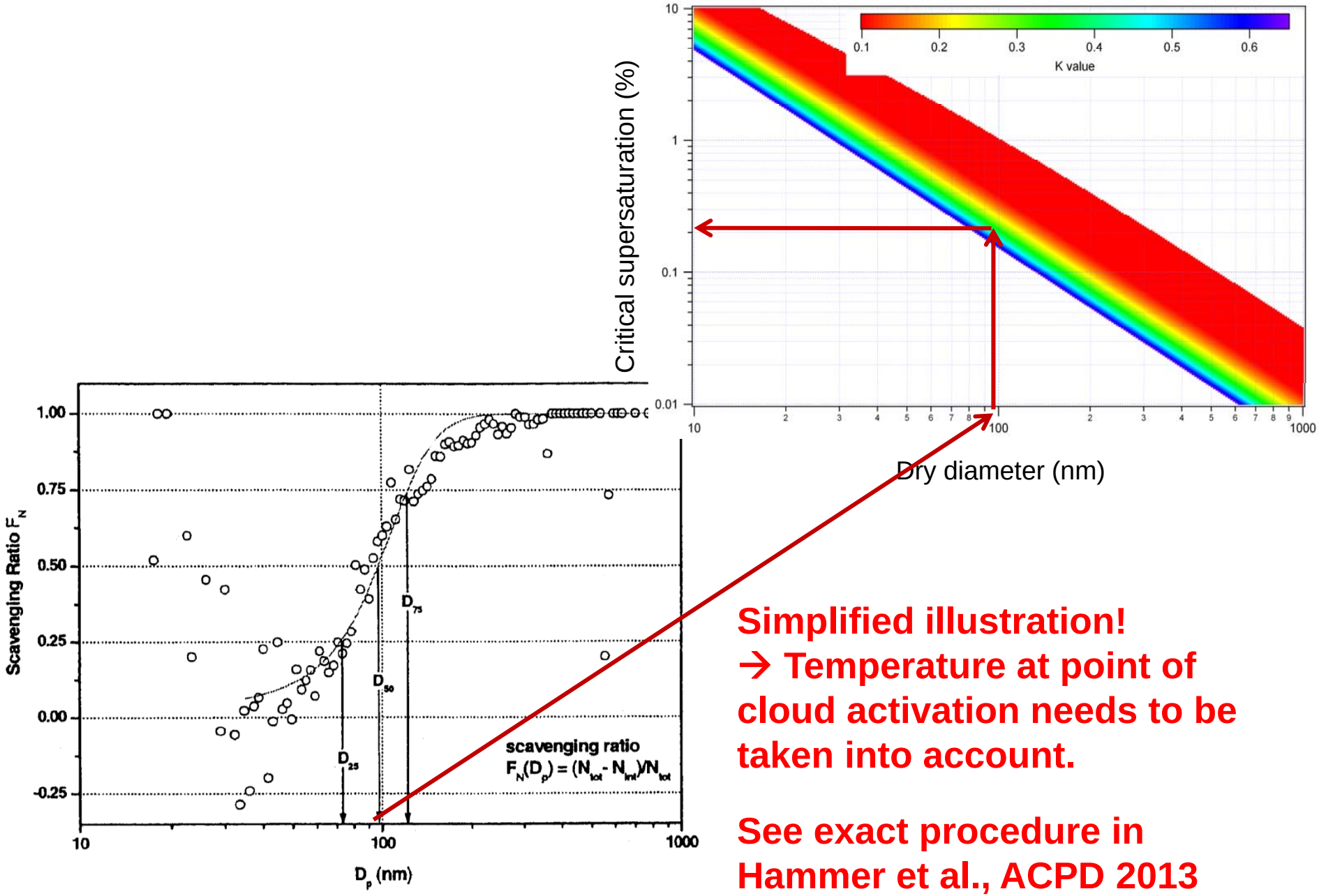
(Hoppel minimum) in the fine mode explained by this preferential activation of larger particles followed by mass gain through in cloud oxidation of water soluble gases (such as SO_2 and oxidized organics)



Determination of the actual supersaturation in clouds



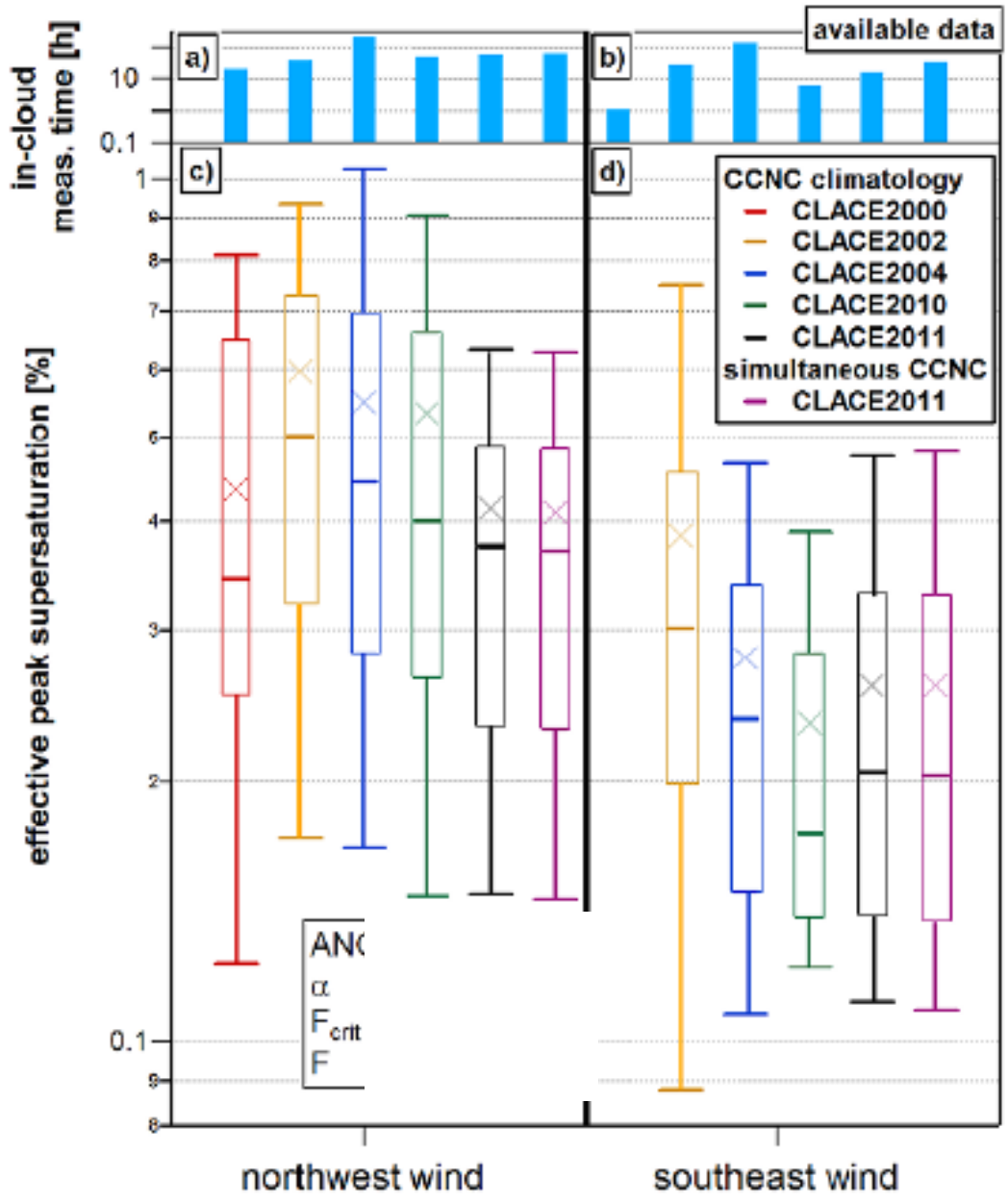
Comparison of real cloud and CCN counter



Simplified illustration!
→ Temperature at point of cloud activation needs to be taken into account.

See exact procedure in Hammer et al., ACPD 2013

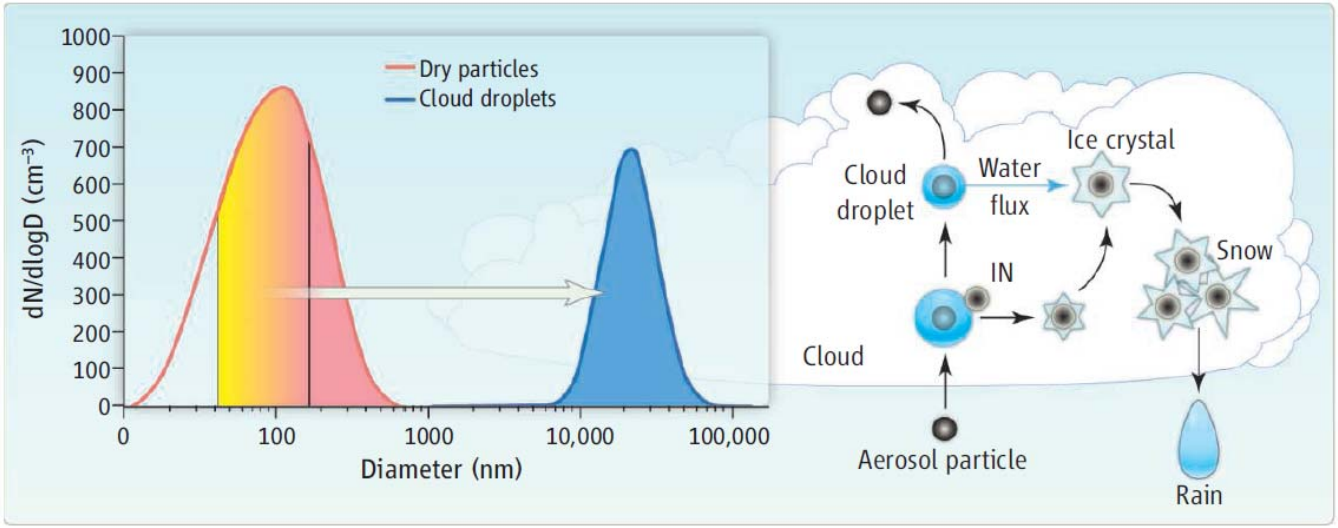
Retrieved ambient peak supersaturation



Higher for
north wind than for
south wind conditions
because of steeper
North slopes

Hammer et al., ACPD 2013

Which particles act as ice nuclei?



Baltensperger, Science 2010

In an ice cloud, cloud droplets evaporate while few, but large ice crystals grow on ice nuclei, changing cloud radiative properties and enhancing precipitation.

Therefore it is important which particles can act as ice nuclei.

Installation of the new ice selective inlet at the Jungfraujoch

Conclusions

- A large number of aerosol properties needs to be determined for a full characterization
- High-altitude stations can provide highly valuable information on an aged aerosol above a continental area
- Variables need to be measured dry, but for comparison with ambient data their transformation to wet conditions is required
- Nucleation is thought to be important in the free troposphere but very few data exist on the ingredients contributing to nucleation
- High-altitude stations, when in clouds, provide highly valuable information on aerosol-cloud interaction. Even more important: characterization of ice clouds, including the determination of ice nuclei (e.g., are BC particles IN at low temperature or not?)


Thank you for your attention
And thanks to
Ernest Weingartner, Martin Gysel, Nicolas Bukowiecki,
Emanuel Hammer, Chris Hoyle, Zsofi Juranyi, Julie Cozic,
Rahel Fierz, Bart Verheggen, Silvia Henning, Paul Zieger,
Piotr Kupiszewski, Günther Wehrle, ……