~~Adaptation of Ground-based and Airborne Cloud Spectrometers to Wind Tunnel and Cloud Chamber Applications Challenges and Opportunities~~

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Workshop on laboratory facilities for cloud research
September 24, 2021

Adaptation of Cloud Condensation Nuclei (CCN) Spectrometers for Laboratory Applications Challenges and Opportunities

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BEIJING CLOUD FACILITIES WORKSHOP
SEP 22-25, 2021, ONLINE

Laboratory Studies vs Natural Cloud Processes

Unless the facility is a “natural” laboratory like a mountaintop site, most cloud microphysical processes involving ensembles of droplets and ice crystals are too complex to simulate in a cloud chamber, wind tunnel, flow tubes or electrodynamic balances.

Such facilities are needed to probe specific microphysical processes:

- Activation of specific aerosol types as cloud condensation nuclei (CCN) or ice nuclei (IN)
- Hypothesis testing with respect to theories of condensational or diffusional growth of water droplet or ice crystals, e.g. importance of the accommodation coefficient, contact angle, etc.
- Collision, coalescence and breakup.
- Aggregation and secondary ice production.
- Aerosol cloud interactions

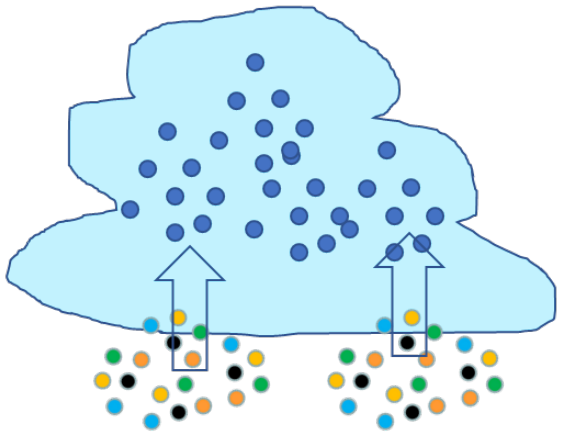
Still Limited Understanding of Aerosol and Cloud Interactions

Aerosol particles and clouds have a symbiotic relationship:

- Without aerosol particles (CCN) there can be no clouds.
- Clouds transform aerosol properties (number, mass, size, chemistry, optical).
- Theoretical studies have shown that some fraction of aerosols are processed by clouds 8-10 times during their lifetime.
- Some aerosols become more active CCN due to cloud processing.

A conceptual picture:
Impact of Aerosol-cloud interactions on Cloud formation and evolution

Initial cloud forms in T_0 min. Droplets formed never grow to raindrops

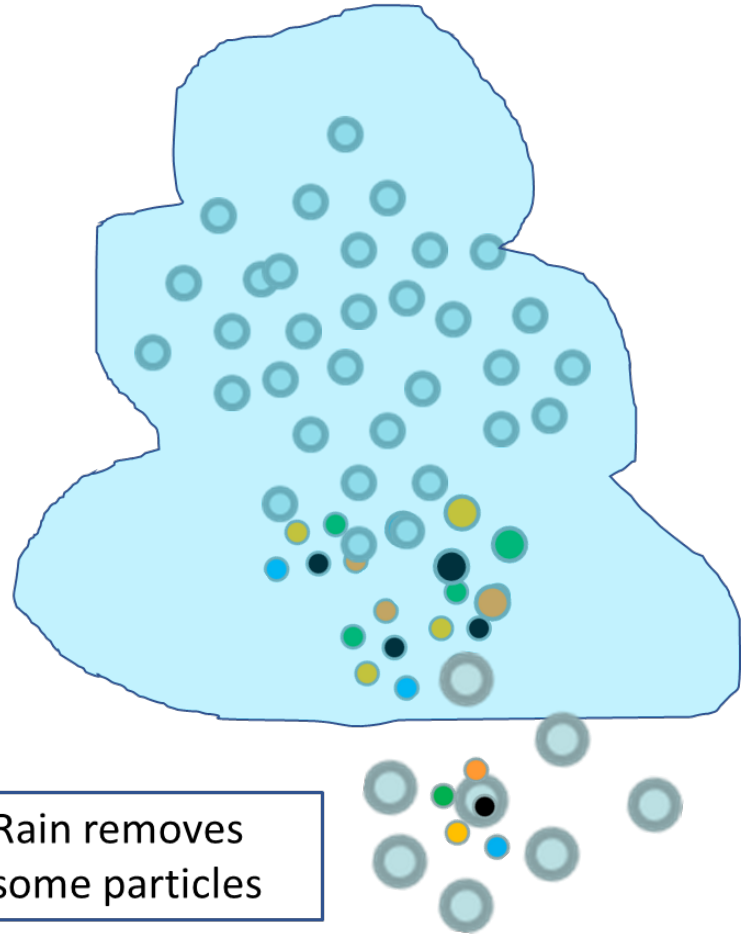


Initial aerosol population with average diameter of D_0

Cloud dissipates leaving behind processed aerosol – some larger and chemically changed.

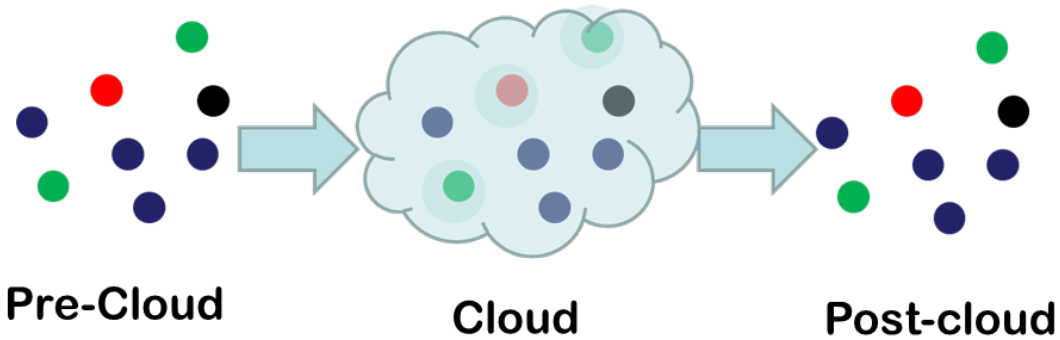
New aerosol population with average diameter of $D_1 >> D_0$

New cloud forms in $T_1 << T_0$ min. Larger droplets are formed on the larger CCN and grown to raindrop sizes.

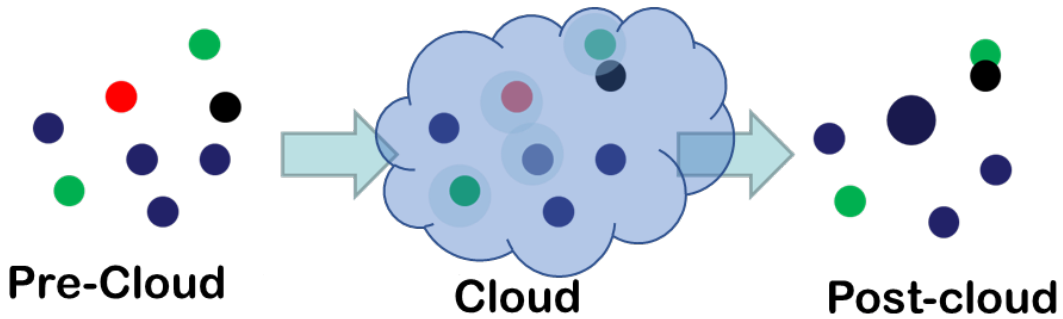


Rain removes some particles

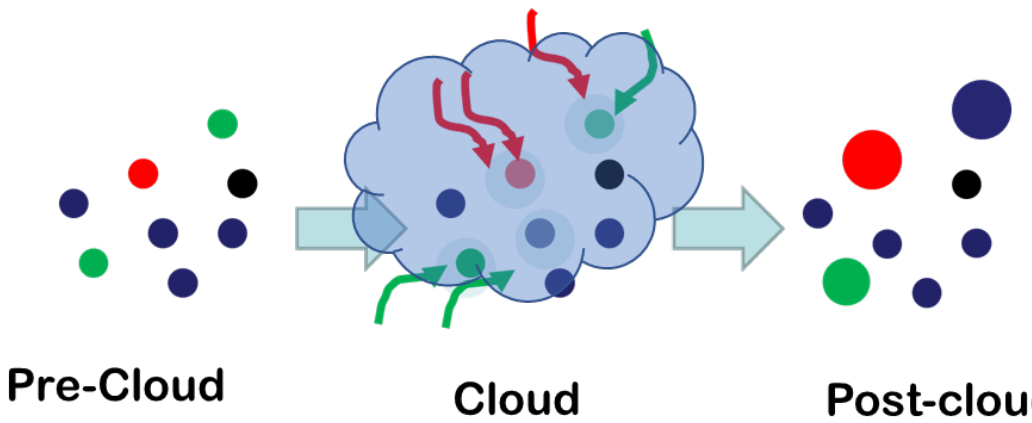
Possible Types of Aerosol Processing



No cloud processing occurs when cloud lifetime is too short.



Inertial scavenging and droplet coalescence lead to changes in number and mass concentration and changes in composition.



Uptake of precursor gases and aqueous processing leads to changes in mass concentration and composition.

These Types of Aerosol/Cloud Interactions are Difficult to Study with Airborne, In Situ Measurements

But Lend Themselves to Laboratory Studies

Mobile Cloud Chambers

Ottmar Möhler introduced the Portable Ice Nucleus Experiment

A Mobile Cloud Chamber for Ice Activation

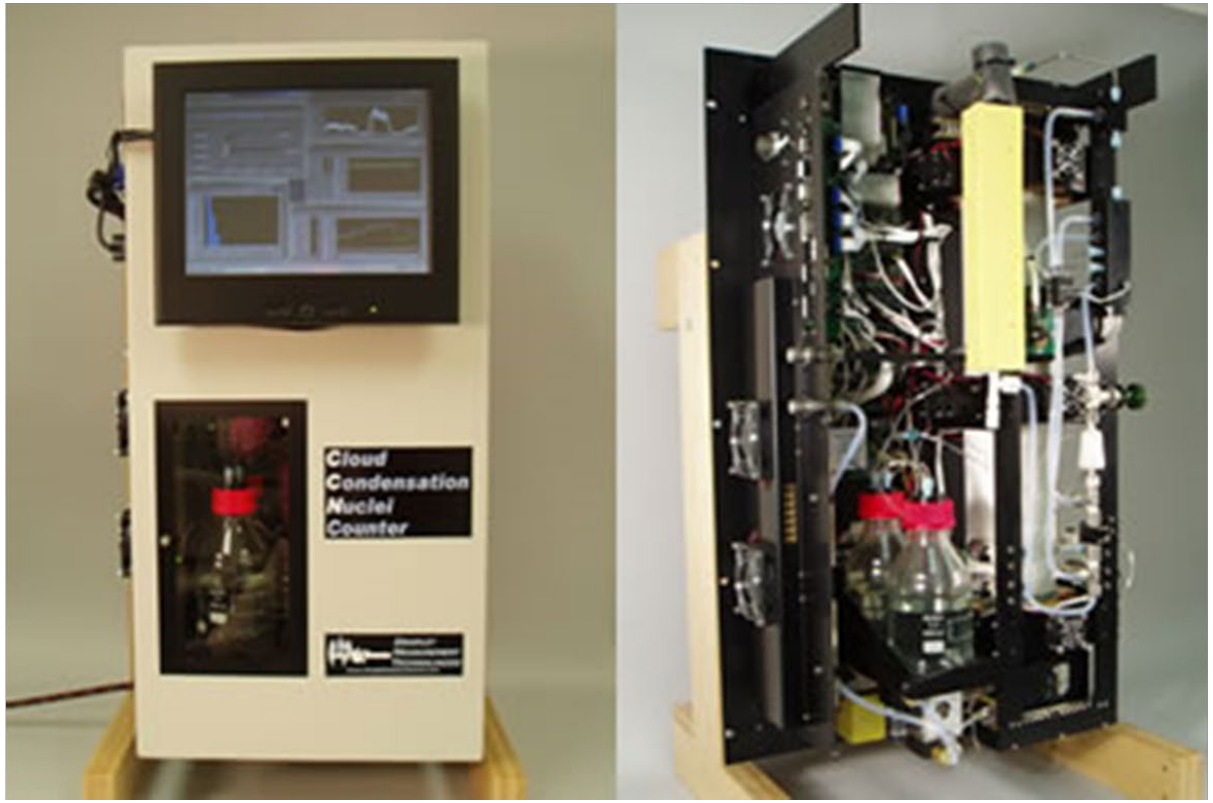
Droplet Measurement Technologies
CCN-100/200 are also cloud chambers

Using the CCN-100/200 to form water droplets, by activating CCN, we can explore the following:

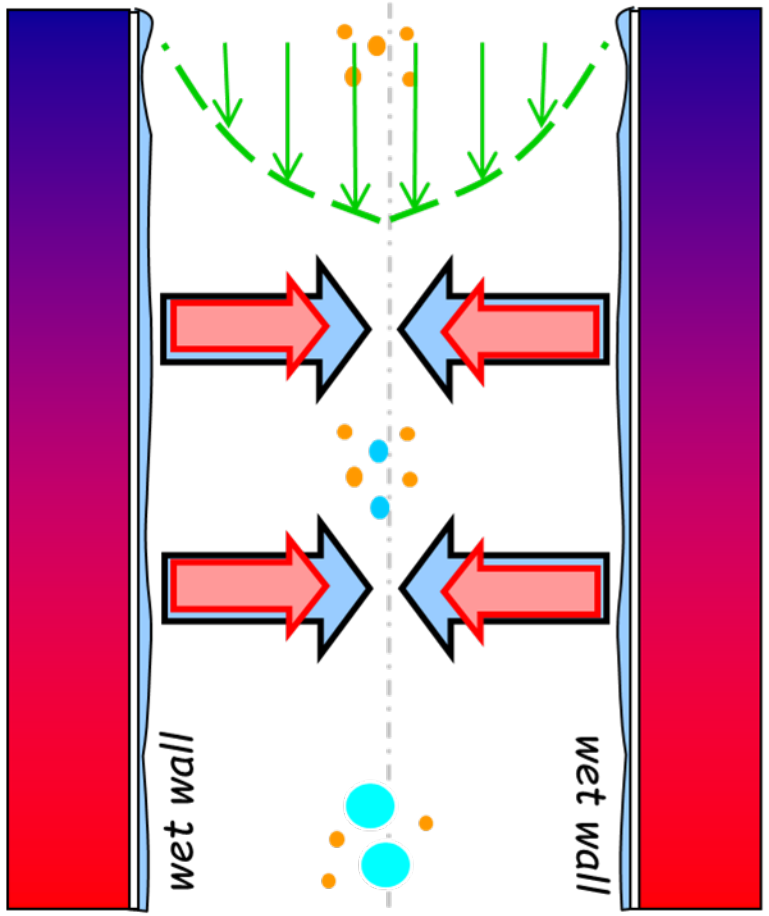
- Cloud processing of aerosols
- CCN activity of black carbon
- CCN activity of primary biological aerosol particles (PBAP)
- Impact of aging on the activity of CCN particles
- CCN as potential INPs
- Optical properties of CCN
- Chemical properties of CCN

Droplet Measurement Technologies Continuous Flow CCN Chamber Developed in 2003, based on design by Roberts and Nenes (2005)

Roberts, G. C. and Nenes, A. (2005), A Continuous-Flow Streamwise Thermal-Gradient CCN Chamber for Atmospheric Measurements, Aerosol Science and Technology, 39:3, 206 – 221



Original paper that described the measurement principles of the DMT CCN-100



Outlet: [Droplets] = [CCN]

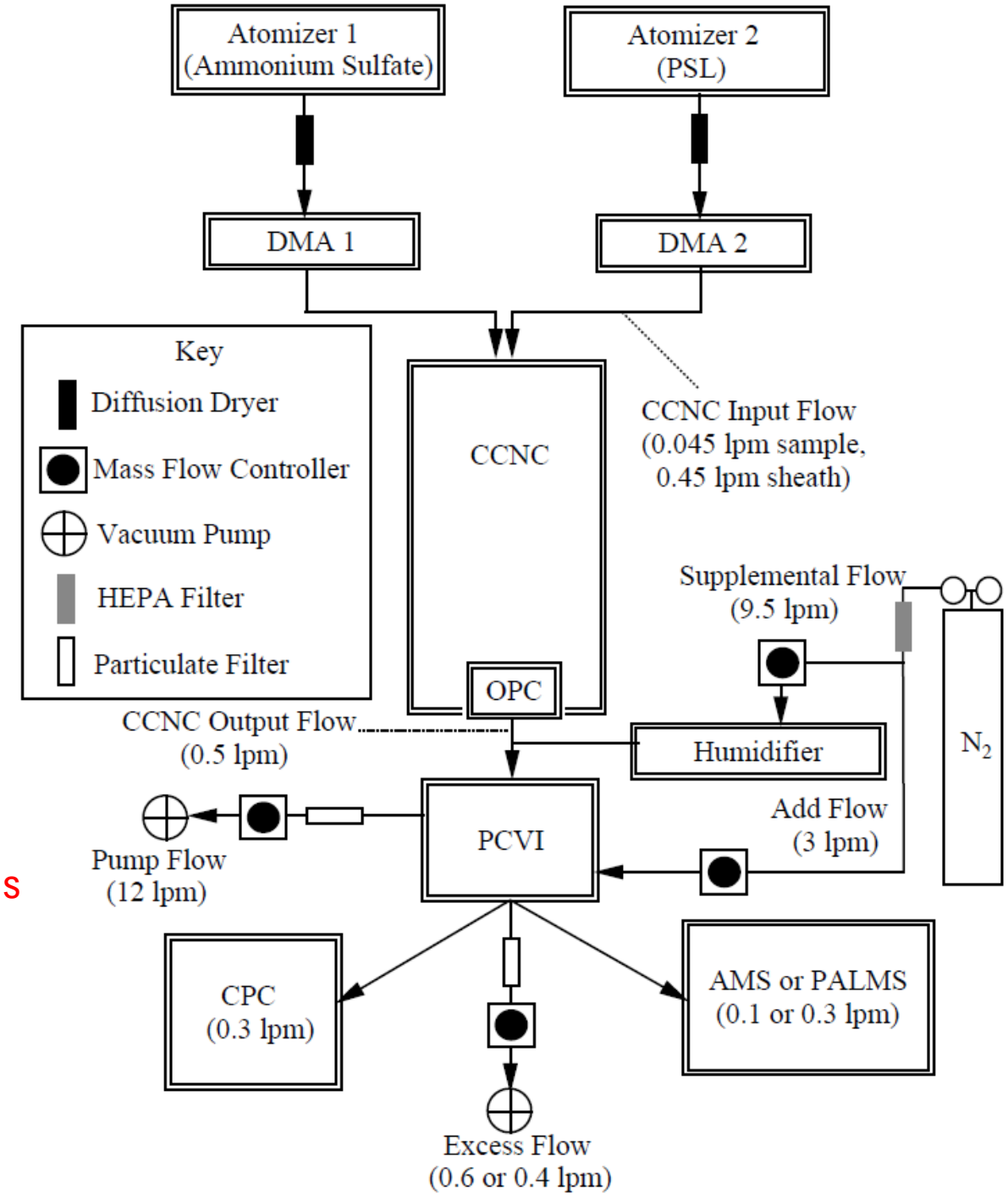
- Metal cylinder with wetted walls
- Streamwise Temperature Gradient
- Water diffuses faster than heat
- Supersaturation, S, generated at the centerline = *f* (Flowrate, Pressure, and Temp. Gradient)

The CCN-100/200 Cloud Incubater

Webster's dictionary definition of to incubate b.) To maintain (something, such as an embryo or a chemically active system) under conditions favorable for hatching, development, or reaction.

Hiranuma, N., Kohn, M., Pekour, M. S., Nelson, D. A., Shilling, J. E., and Cziczo, D. J.: Droplet activation, separation, and compositional analysis: laboratory studies and atmospheric measurements, Atmos. Meas. Tech., 4, 2333–2343, https://doi.org/10.5194/amt-4-2333-2011, 2011.

Successfully demonstrated the methodology to extract activated droplet residuals.



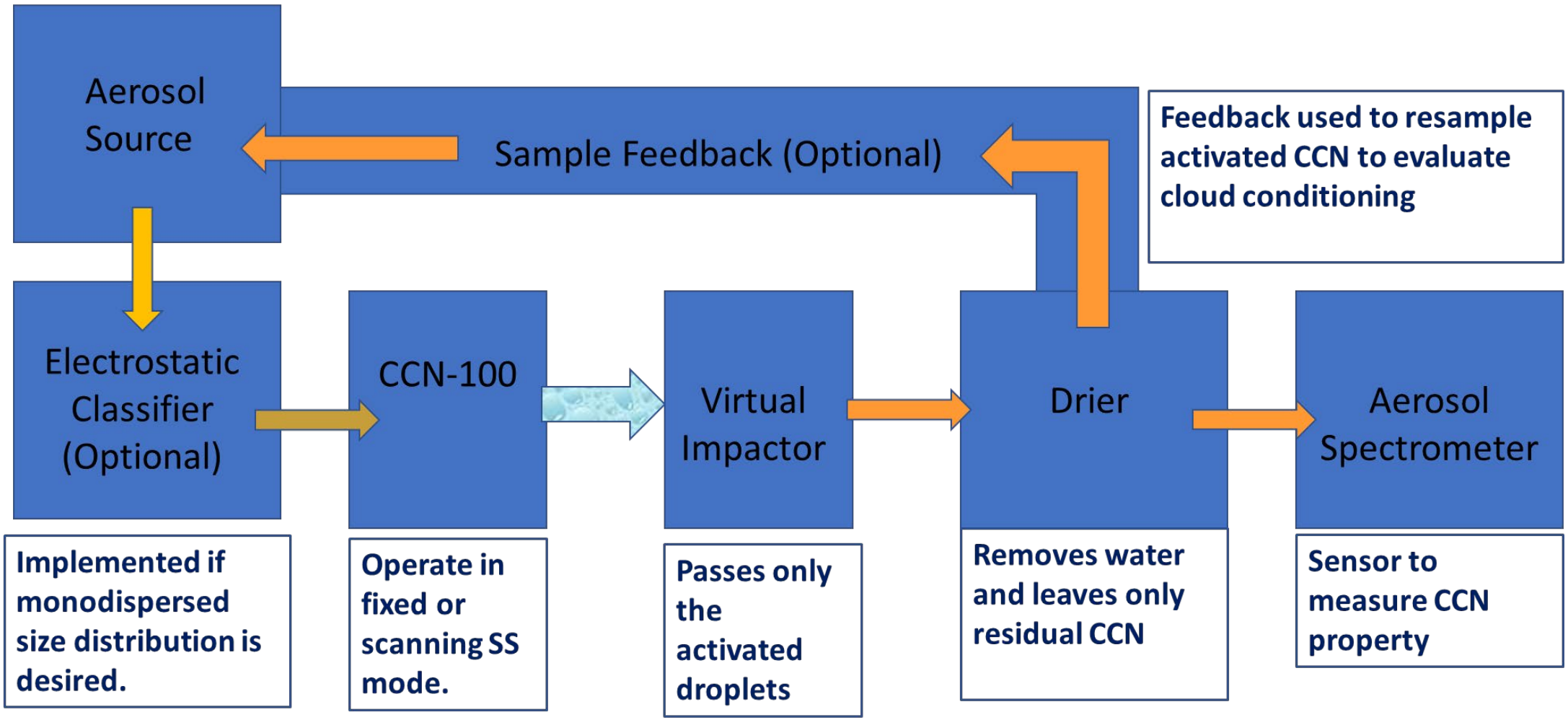
Caveat: The flows shown on this diagram are not the ones that were eventually used to do the measurements.

The CCN-100/200 Cloud Incubater

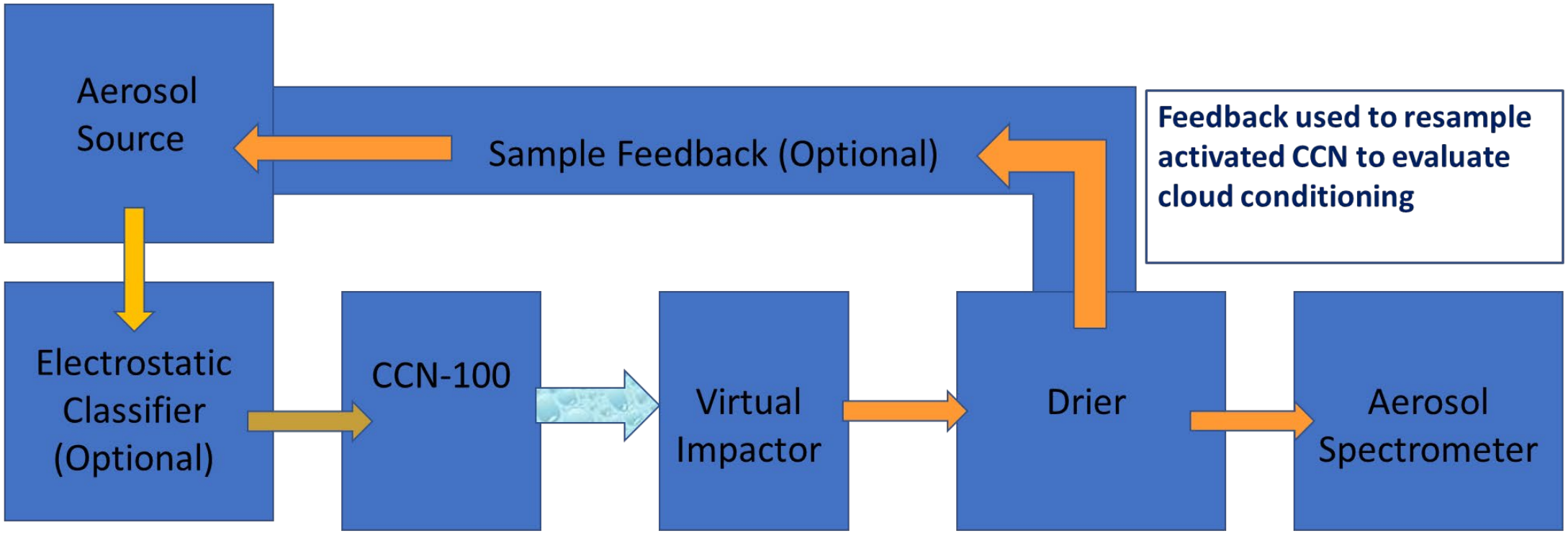
An Innovative Approach for Resolving Unanswered Questions

Related to Cloud and Aerosol Interactions

Primary Set-Up



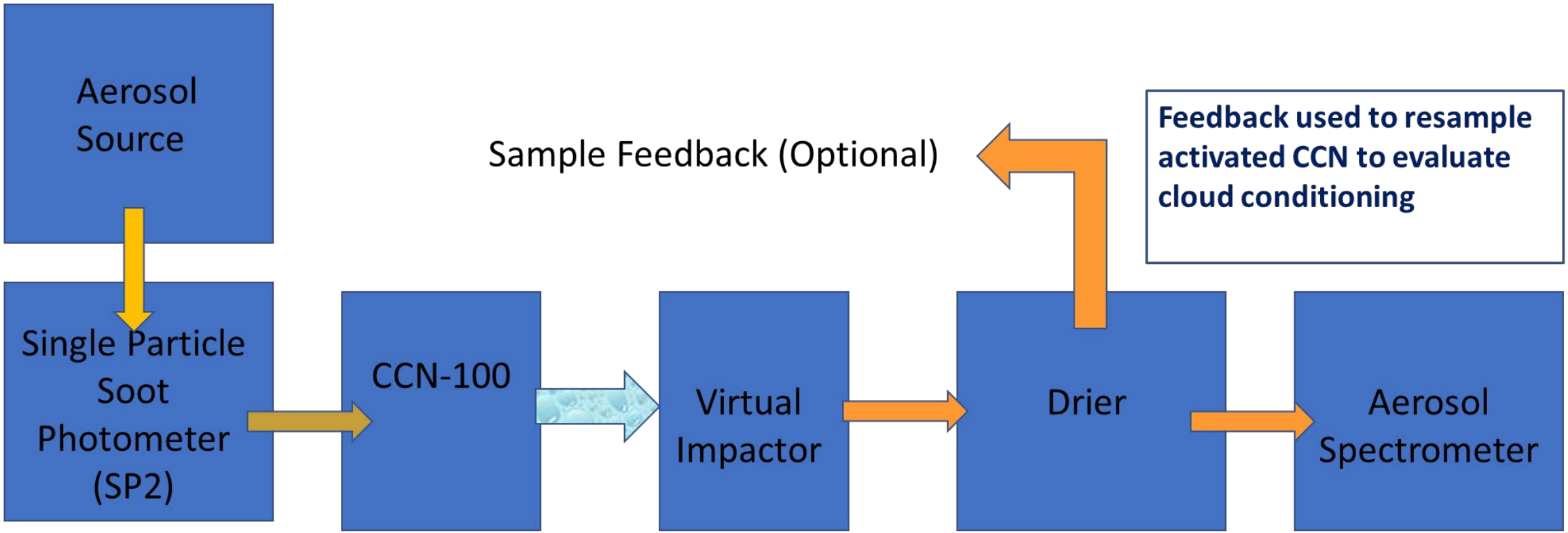
Cloud Processing of Aerosol Experiment



Procedure

- Introduce metered amount of aerosol (ambient or test) into the system (Aerosol Source).
- Remove aerosol source and operate the CCN-100 at a fixed SS.
- Record the change in CCN property with time

Black Carbon Activation Experiment

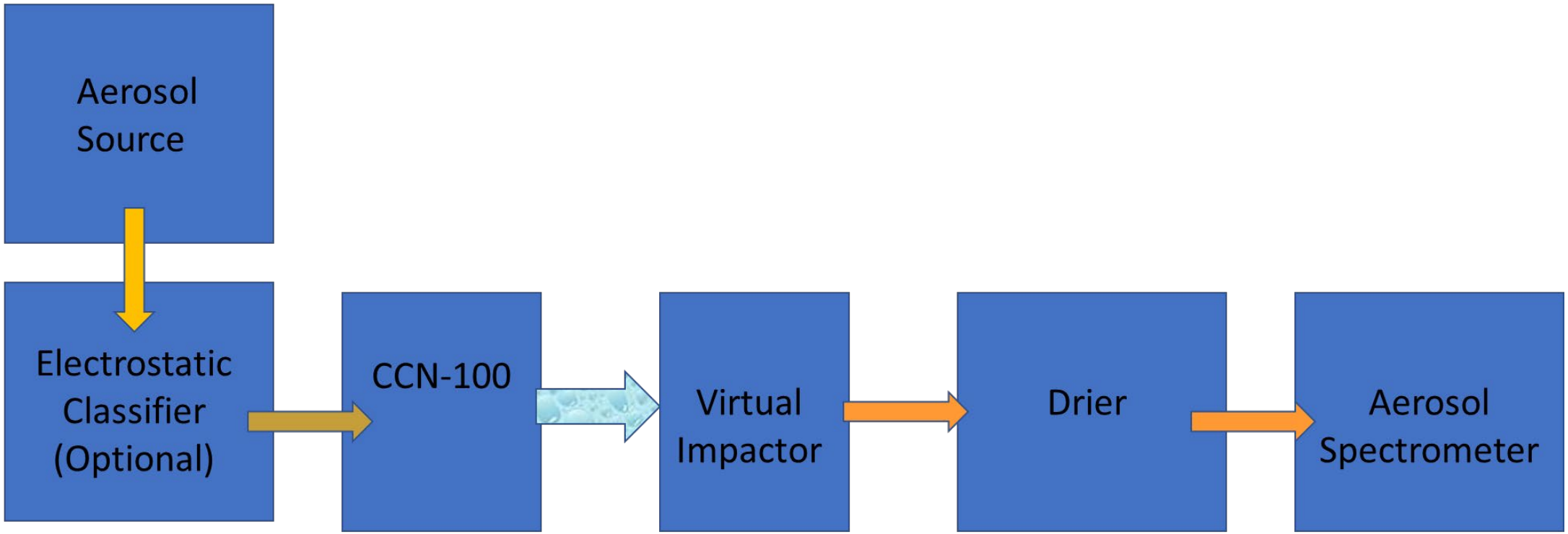


Procedure

- **Introduce aerosol (ambient or test) into the system (Aerosol Source).**
- **Measure CCN properties, i.e. SS spectra, with SP2 turned off**
- **Measure CCN properties, i.e. SS spectra, with SP2 turned on**
- **The SP2 will remove all refractory black carbon**

Aiken, A.C., et al. (2016) Quantification of online removal of refractory black carbon using laser-induced incandescence in the single particle soot photometer, Aerosol Science and Technology, 50:7, 679-692

CCN Activity of Bioaerosols, CCN as INP Chemical and Optical Properties of CCN

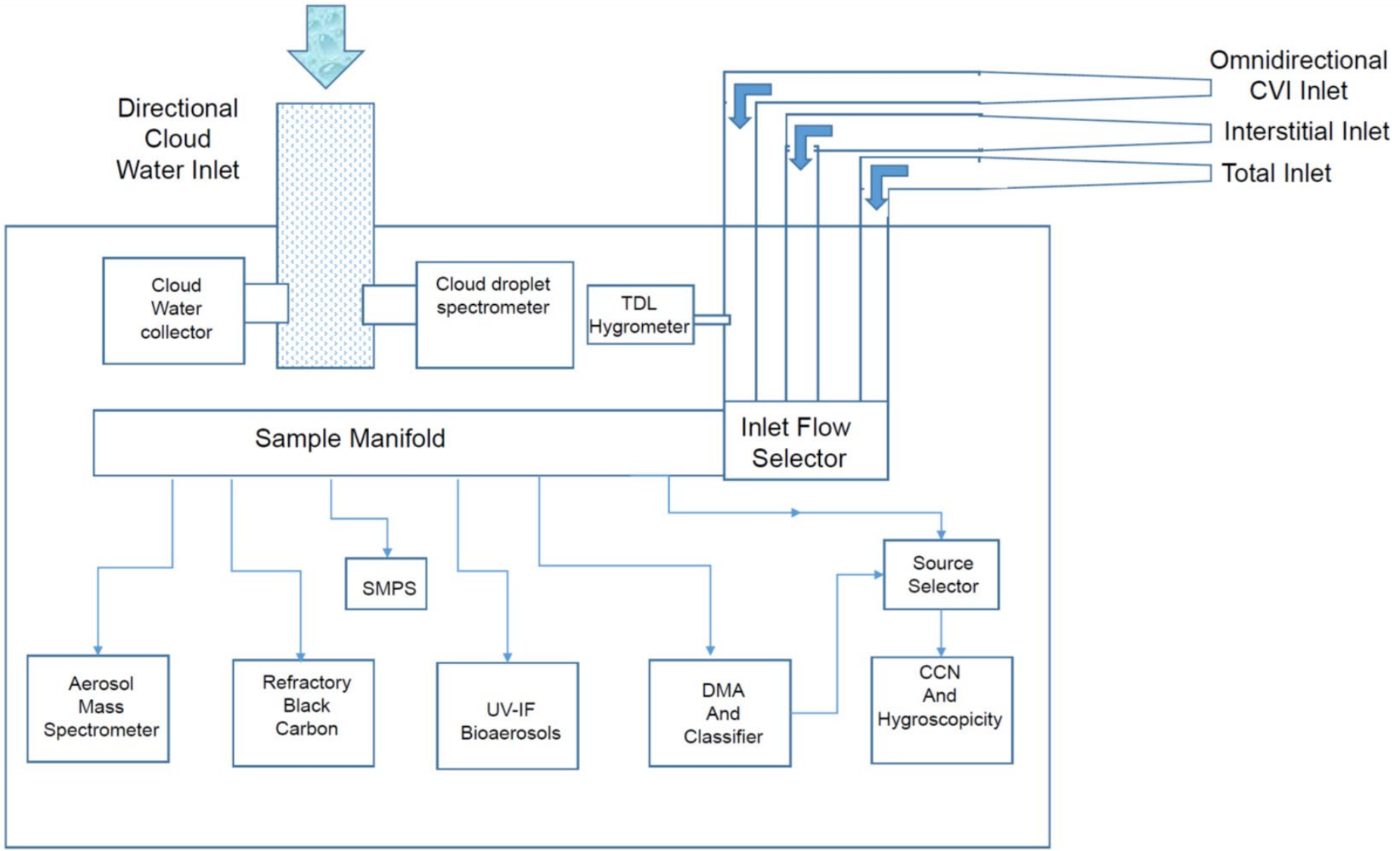


Procedure

- Introduce aerosol (ambient or test) into the system (Aerosol Source).
- Operate the CCN-100 variable SS.
- Record the the CCN property with WIBS (PBAP), SPIN (INP), PAX (optical properties), refractory black carbon (SP2-XR) or with an aerosol mass spectrometer (chemical composition of CCN).

Recent Systems Integrating the CC-100/200 with Other Aerosol Sensors

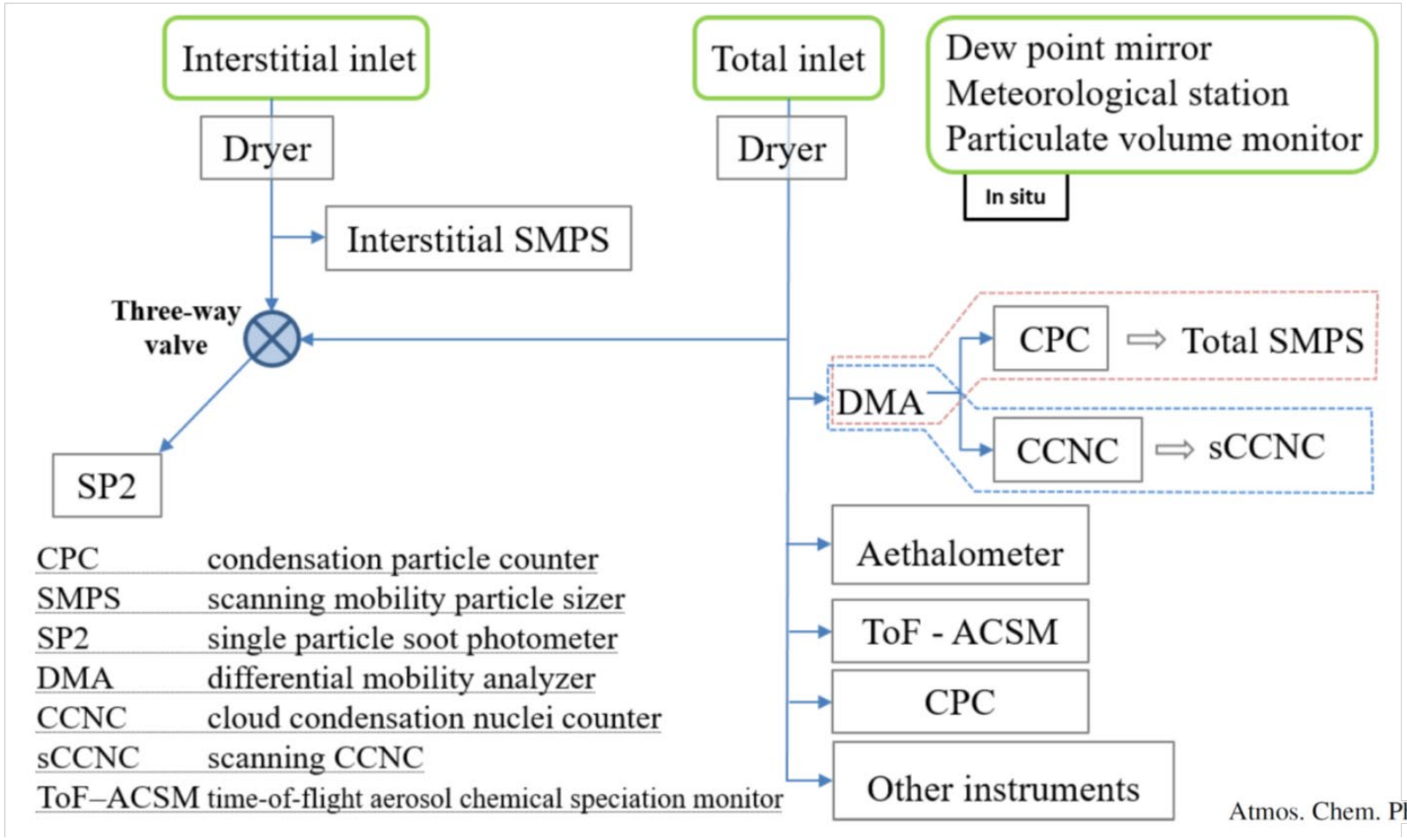
University of Puerto Rico Aerosol and Cloud Analysis System



Paul Sherrer Institute – Laboratory of Atmospheric Chemistry

Droplet activation behaviour of atmospheric black carbon particles in fog as a function of their size and mixing state

Ghislain Motos[1], Julia Schmale[1], Joel C. Corbin[1,a], Marco Zanatta[1,b], Urs Baltensperger[1], and Martin Gysel-Beer[1]



Atmos. Chem. Phys., 19, 2183–2207, 2019

Summary

- Laboratory studies of cloud microphysical processes are essential for addressing unanswered questions about how water droplets and ice crystals activate, grow and interact with one another.
- The Droplet Measurement Technologies CCN-100/200 is a cloud incubation spectrometer that can be implemented to address many of these unanswered questions.
- The CCN-100/200, interfaced with a counterflow virtual impactor allows the extraction of the residual of activated droplets and subsequent analysis with a variety of sensors that measure the physical, chemical and optical properties of those aerosol particles that can form cloud droplets.
- The CCN-100/200 is a cloud incubation spectrometer is an educational, research tool that is as easy to set up in a university graduate lab as in a weather modification aircraft, providing students and researchers an endless number of possible experiments that help us better understand clouds and their impact on our environment.

Thank you for you attention!

For more information:

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