Cambustion

An Aerosol Flame Photometer to Study Indoor Aerosol Dispersion

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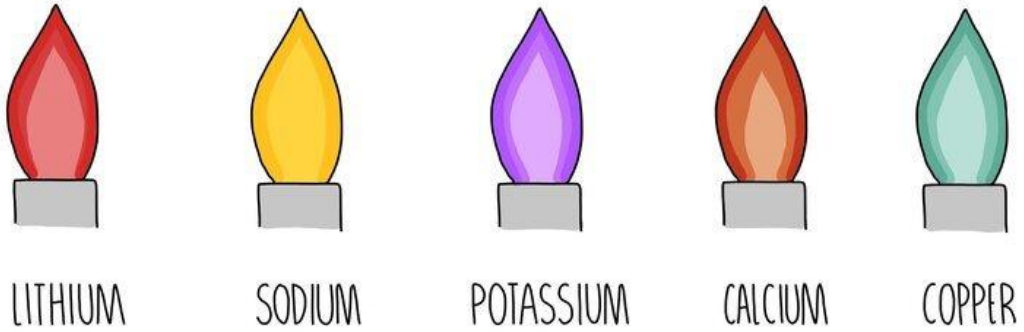
Indoor air quality

- Outdoor air quality has been the subject of regulation for a long time
  - Focus on emissions from combustion and industrial sources
  - Numerous studies have shown negative effects of pollution on human health and the environment
- Indoor air quality (IAQ) has attracted increasing attention lately
  - Majority of our time is spent indoors
  - Covid-19 pandemic has stressed the issue
- Ventilation is essential to improve indoor air quality
  - Trade-off between ventilation and energy efficiency: ventilation needs to be studied & optimised
- CO_2 sensors are commonly used as a low-cost monitoring solution
  - Can only inform about poor IAQ associated with CO_2-generating activities
  - **Gas and particle dynamics can be quite different – gas tracing not necessarily representative of aerosol dispersion**

What is flame photometry?



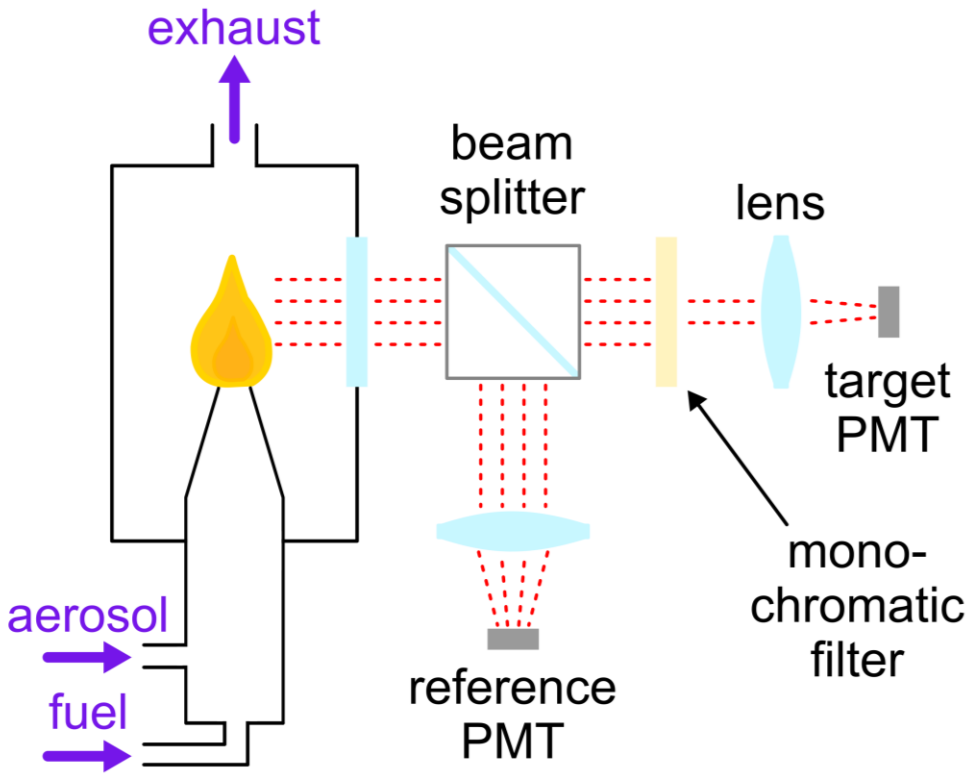
- Flame photometry is a type of atomic emission spectroscopy
- Measures the concentration of metal ions in a sample by analyzing the light emitted from a flame
- Each species gives a characteristic spectral output (e.g. sodium = “yellow”)
- Signal proportional to mass concentration of species present
- Commonly used in analytical chemistry to analyze liquid samples for metal salt concentrations, by aerosolizing the solution and passing through a flame
- Also used in filter testing with sodium chloride aerosols to test filtration efficiency

Flame photometry: advantages for dispersion studies

- **Specificity**: not sensitive to spurious particles
  - Will only respond to the specific source, which in most circumstances is not naturally abundant
  - Aerosols such as NaCl can be generated easily and are considered safe
- **Sensitivity**: possible to detect down to a few ng/m^3
- **Trusted**: specified in some international standards
  - ISO EN149:2001+A1:2009 for testing of respiratory protective devices
- **Online**: real-time measurement
  - Capture the evolution of time-varying aerosols/phenomena
  - Space-resolved data is possible by moving the sampling point

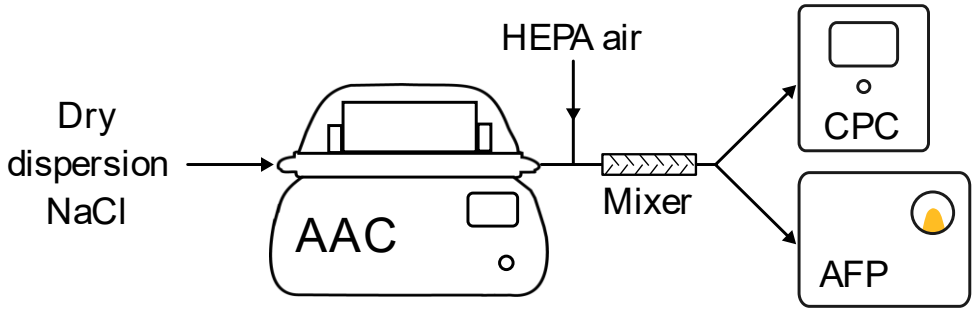
Aerosol Flame Photometer: working principle

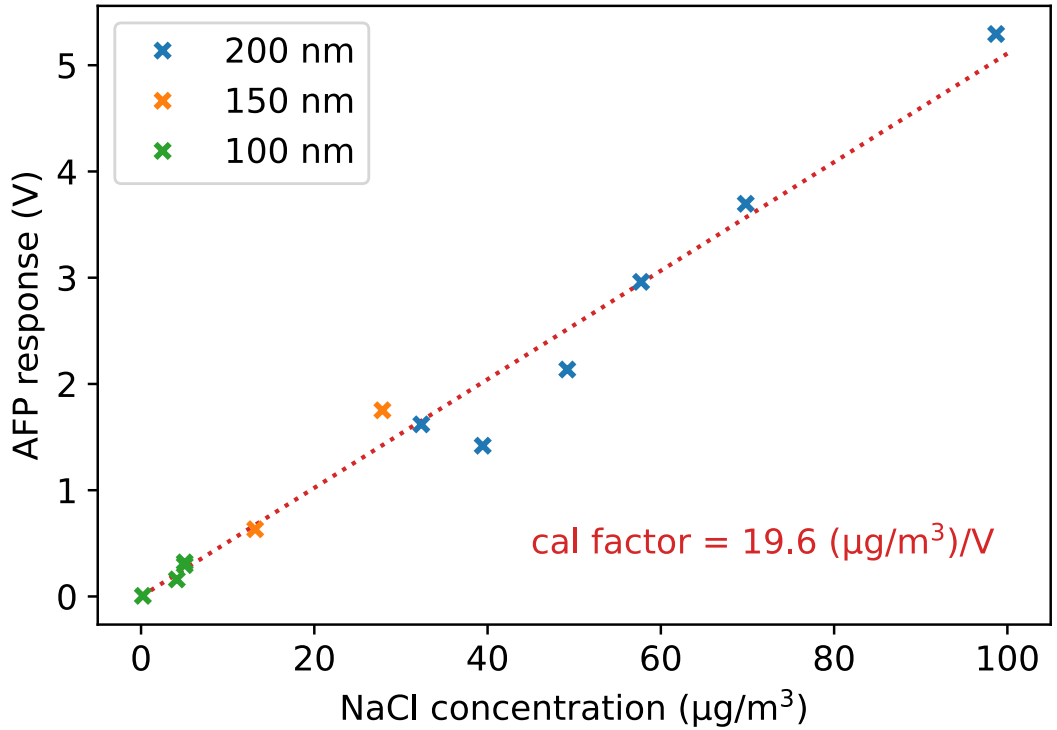
- Propane-air (aerosol) premixed flame
- Flame excites ions in the aerosol
- Ions emit light at an element-specific wavelength
- Light is passed through a monochromatic filter and detected by a PMT
- PMT signal is thus proportional to the mass concentration of the ion in the aerosol
- A reference PMT (looking at the total flame emission) is present to monitor correct operation and allow correction for any cross-sensitivities



AFP calibration

- NaCl aerosol generated by dry dispersion
- Size-selected with Aerodynamic Aerosol Classifier (AAC) for true monodispersity
- Mass concentration obtained from CPC concentration and AAC setpoint (& known NaCl density)
- Checked linearity
  - At different mass concentrations (0.2 – 100 µg/m^3)
  - For different particle sizes
- Sensitivity of ~15 ng/m^3 of NaCl

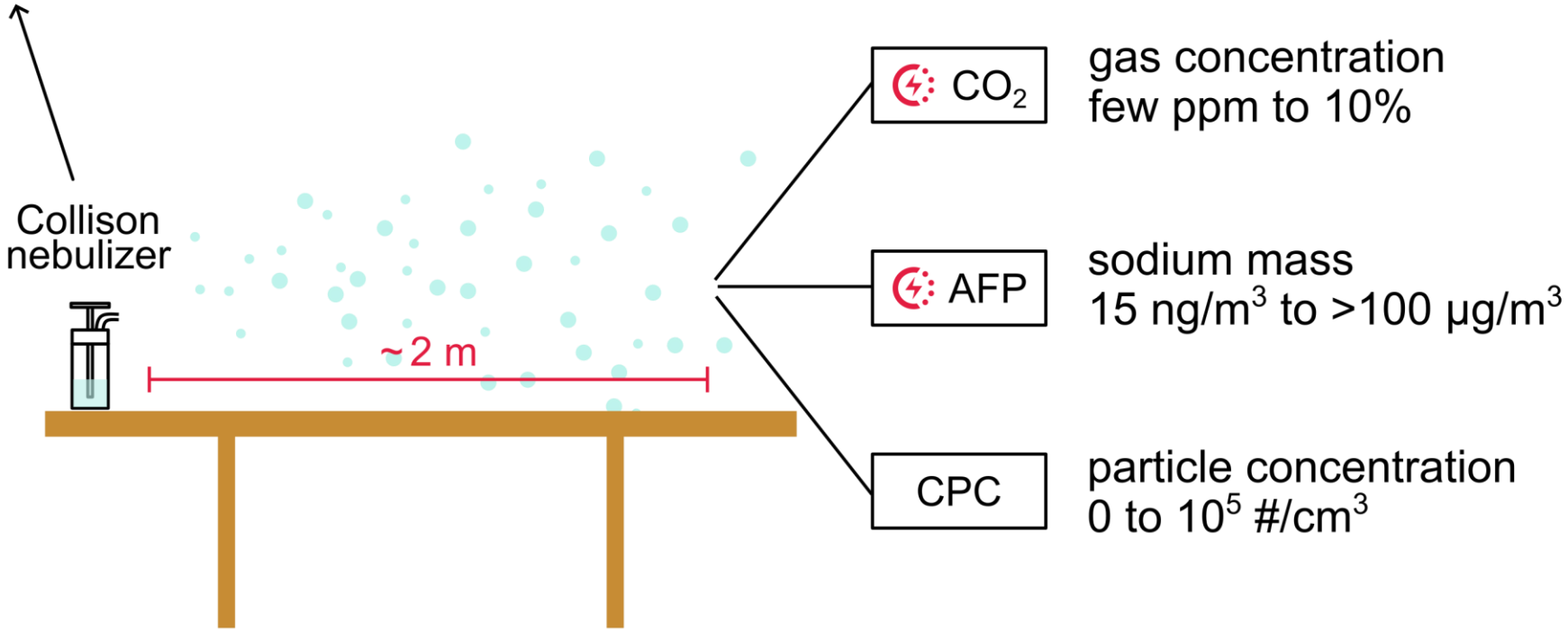




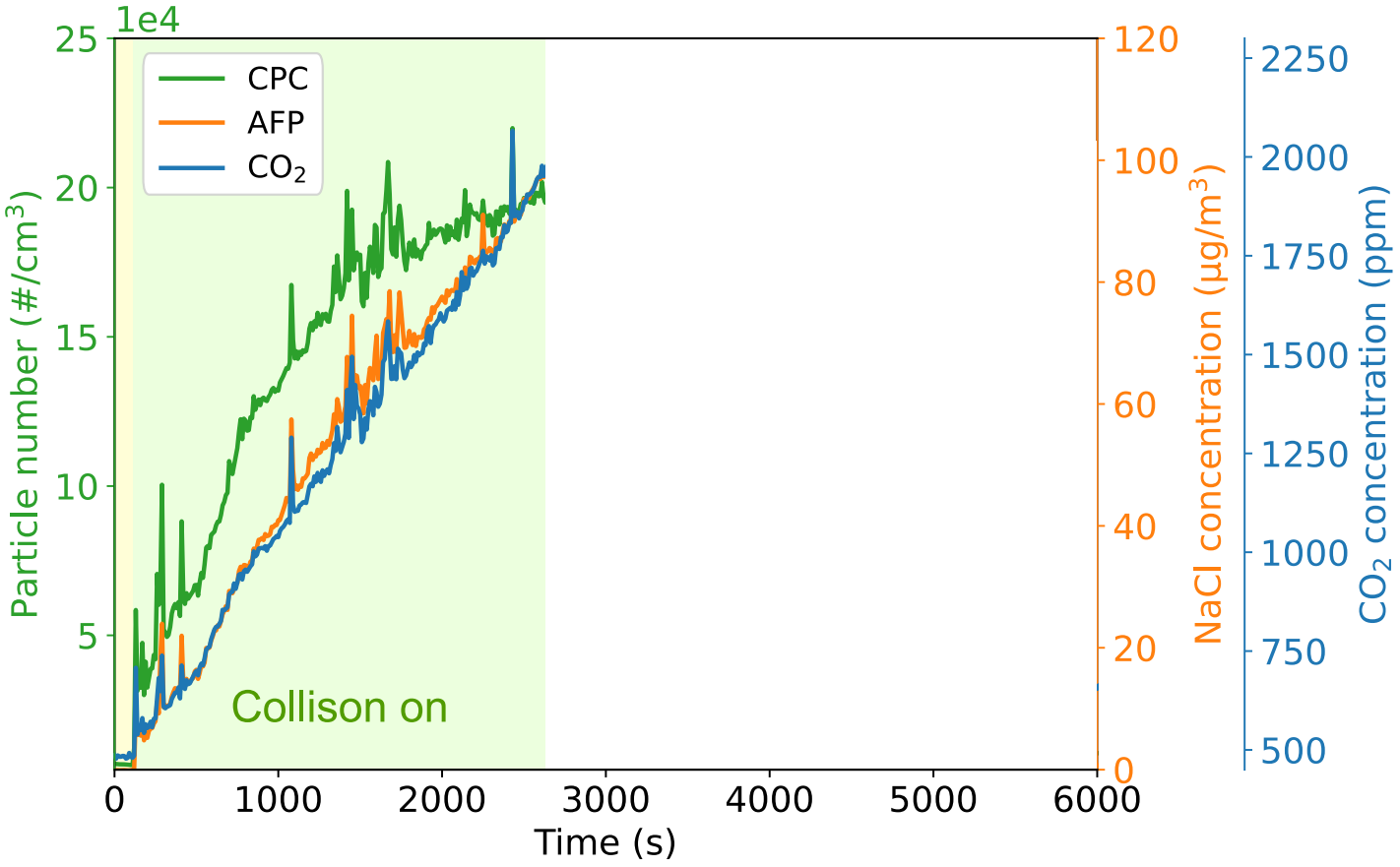
Experimental setup

Meeting room (~ 24 m^3)

0.9% NaCl solution
3 lpm of 20% CO_2 in N_2



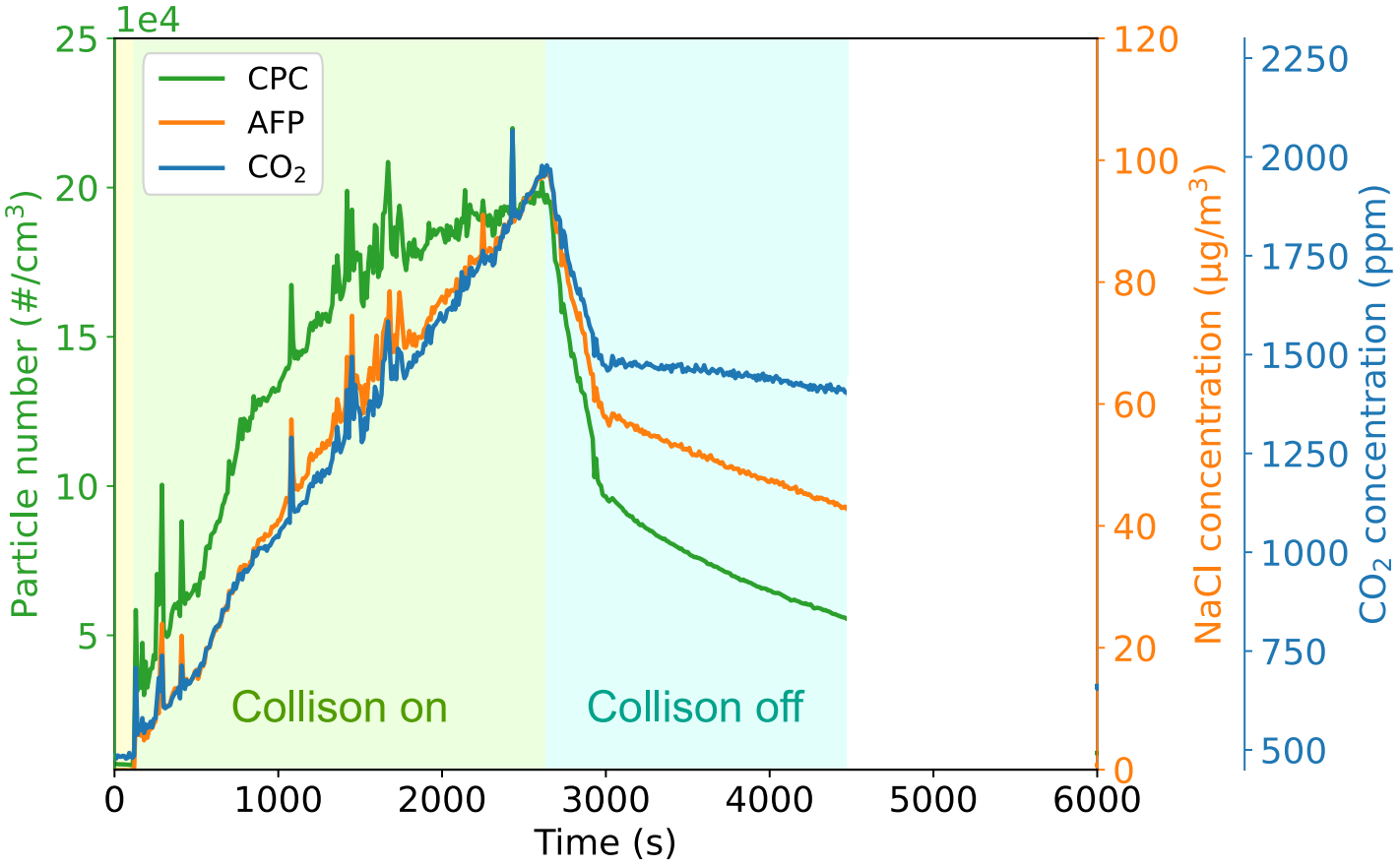
Results (1)



When the nebulizer is running:

- Strong correlation between Na and CO_2 signals
  - Near-linear increase with short-term variations
- Rate of increase of CPC signal drops with time

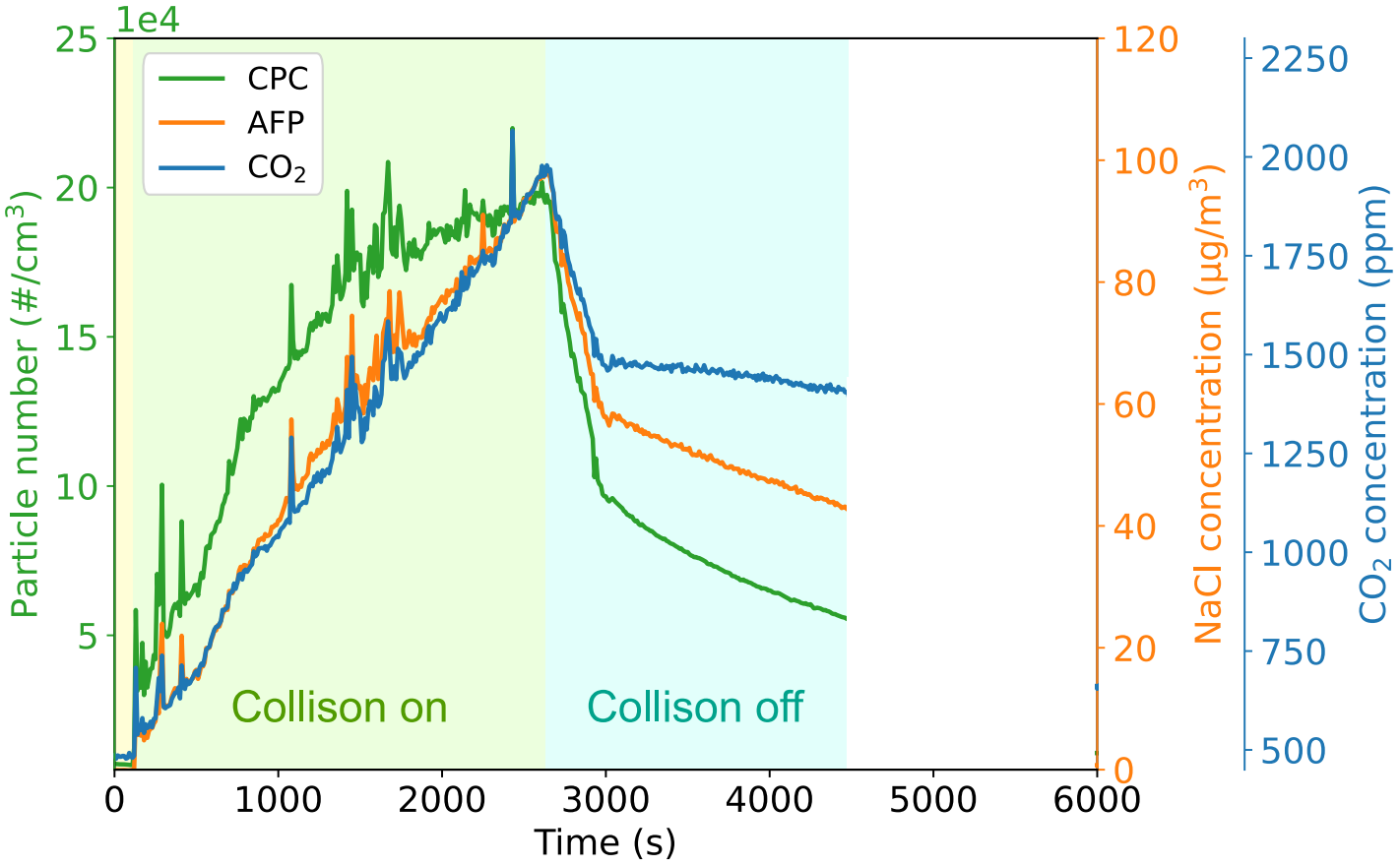
Results (2)



As soon as the nebulizer is turned off:

- All concentrations fall sharply
- Short-term fluctuations reduce
- Due to homogenisation of flow within the room

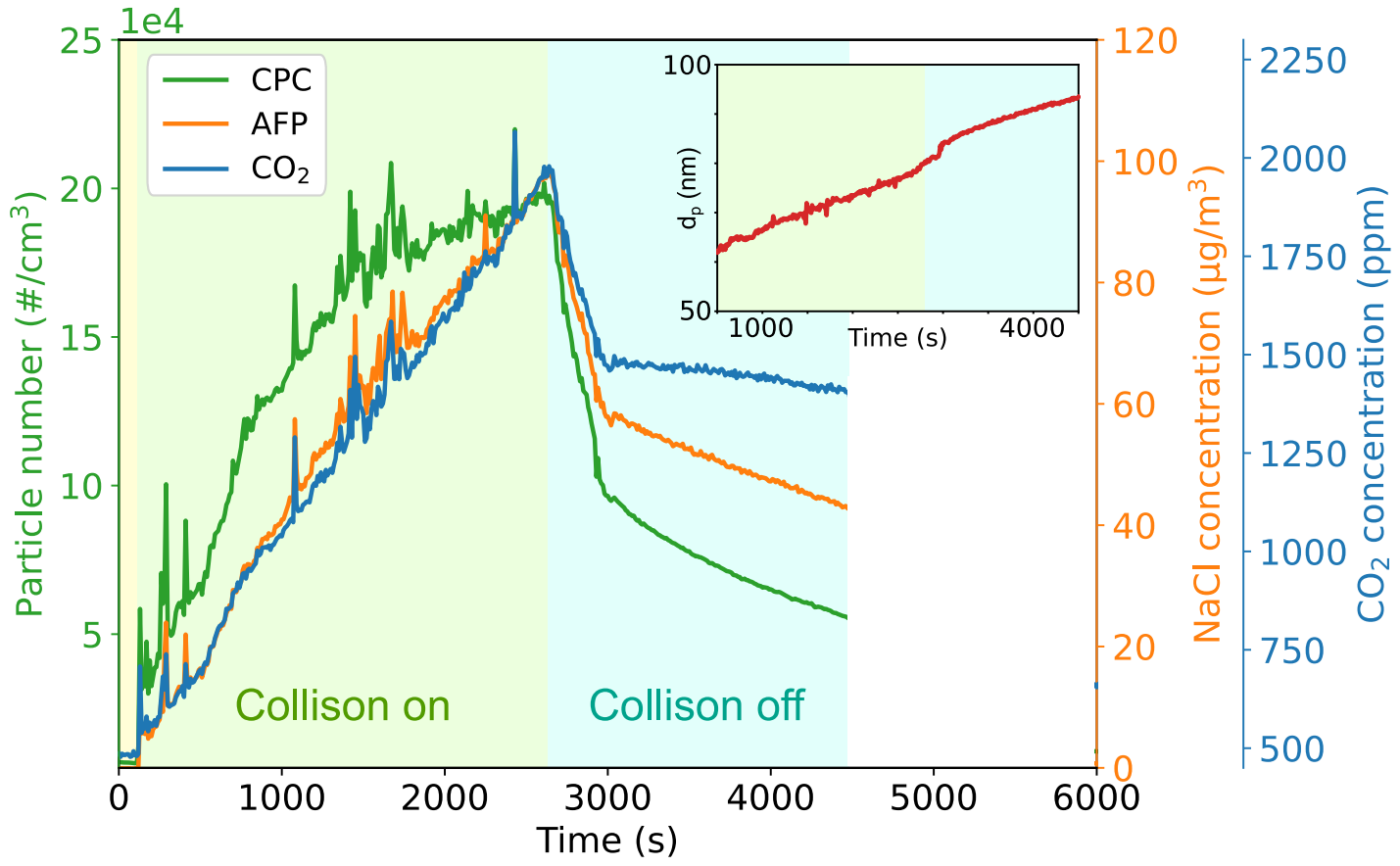
Results (3)



Once equilibrium is reached:

- CO_2 signal stabilizes due to absence of ventilation
- Na and CPC signals keep decreasing due to deposition (and agglomeration)

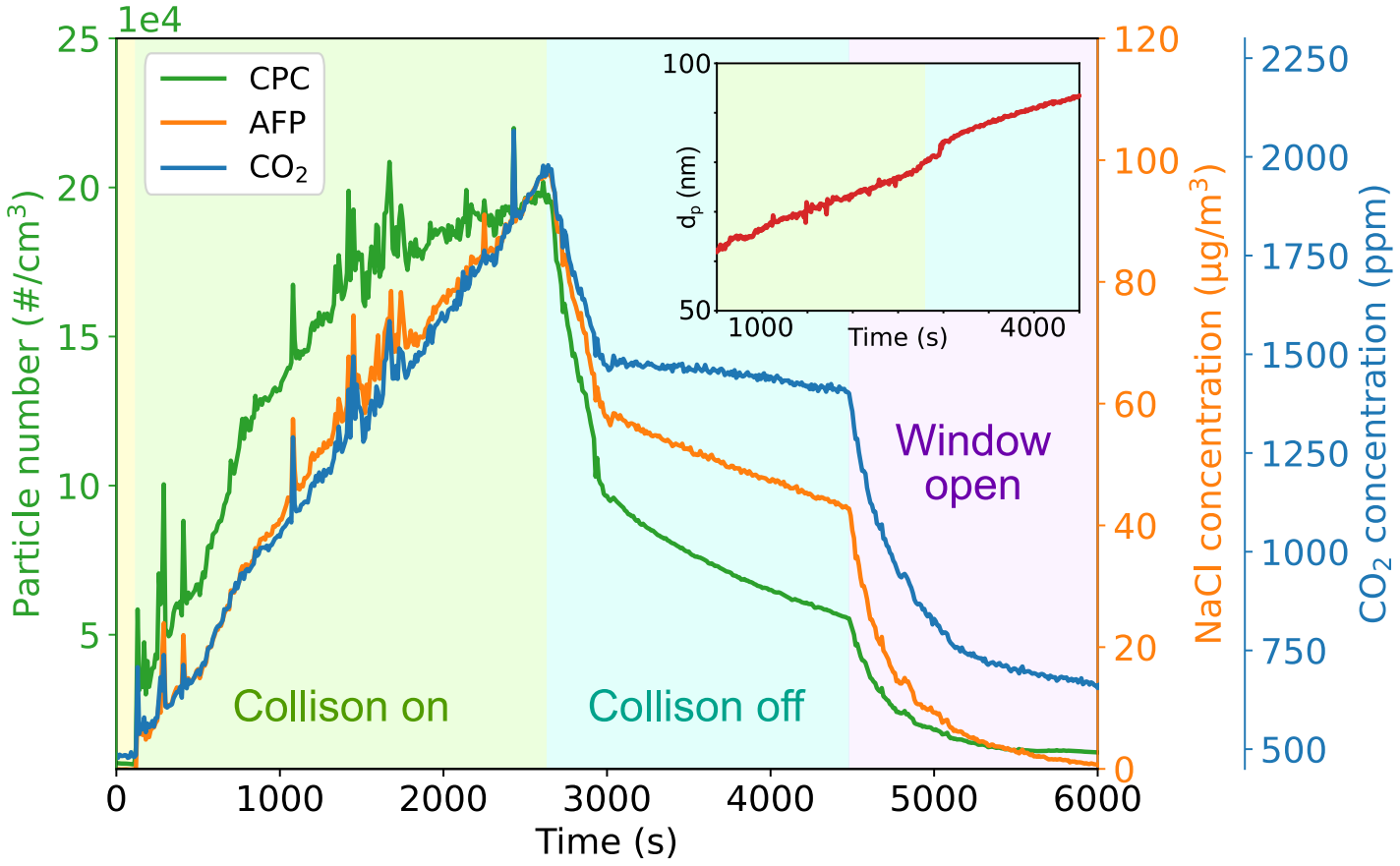
Results (4)



The effect of agglomeration:

- Non-linear rise of CPC concentration and subsequent faster fall
- Increase in the mean particle diameter as calculated from the Na and CPC signals

Results (5)



Once the windows are opened:

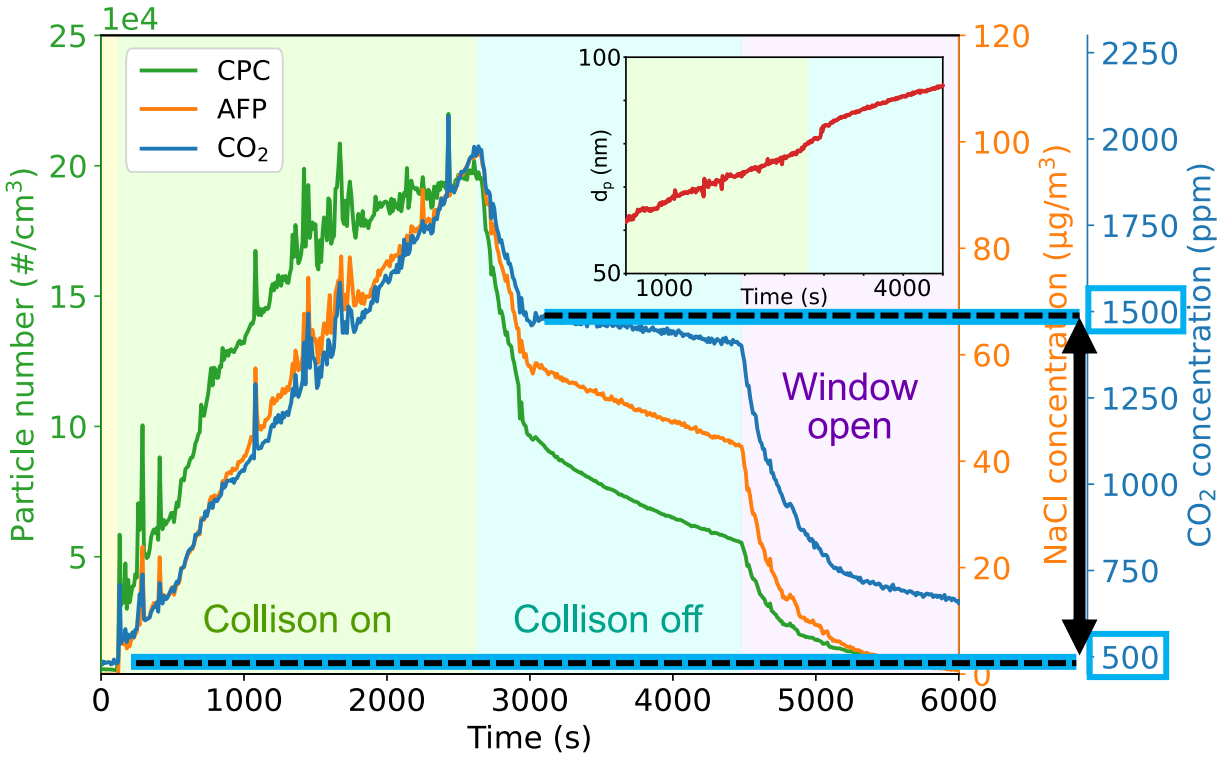
- All concentrations decay exponentially due to the air exchange
- Half-life after opening the windows

CPC	190 s
NaCl	206 s
CO_2	232 s

Results (6)

- Comparison with integrated output from Collison nebulizer

Gas volume	0.12 m^3 (0.5% of the room)
CO_2 output	1000 ppm
Solution volume	10 – 15 ml
NaCl output	~5 mg/m^3



Results (7)

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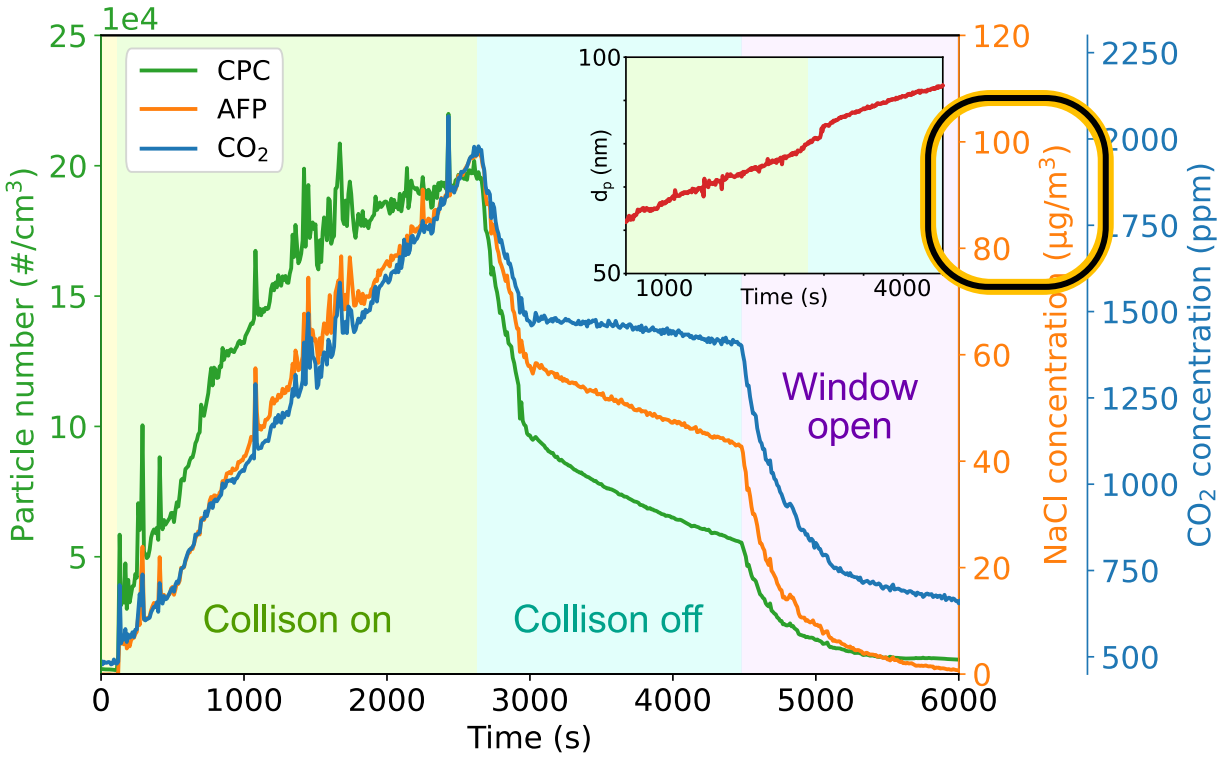


Conclusions to indoor study

- Choosing appropriate metrics is important to investigate air quality:
  - Particles and gases behave very differently
  - Mass and number concentration give different information

- The technique is particularly relevant to studies on viral load and on the transmission of respiratory diseases:
  - The mass of sodium in each droplet remains constant during the evaporation
  - The response only depends on the initial droplet diameter and is not affected by the state of the particles (liquid or solid) upon detection

What about outdoors? Application scenario

- Agricultural overspray can be a concern for local communities and environment
- Classification of sprays according to their size (volume mean diameter, VMD) is given in ASABE Standard S572.1

Spray Quality*	Size of Droplets	VMD Range (Microns**)	Color Code	Retention on Difficult to Wet Leaves	Used for	Drift Potential
Extremely Fine	Small	<60	Purple	Excellent	Exceptions	High
Very Fine		61-105	Red	Excellent	Exceptions	
Fine		106-235	Orange	Very Good	Good Cover	
Medium		236-340	Yellow	Good	Most Products	
Coarse		341-403	Blue	Moderate	Systemic Herbicides	
Very Coarse		404-502	Green	Poor	Soil Herbicides	
Extremely Coarse		503-665	White	Very Poor	Liquid Fertilizer	
Ultra Coarse	Large	>665	Black	Very Poor	Liquid Fertilizer	Low

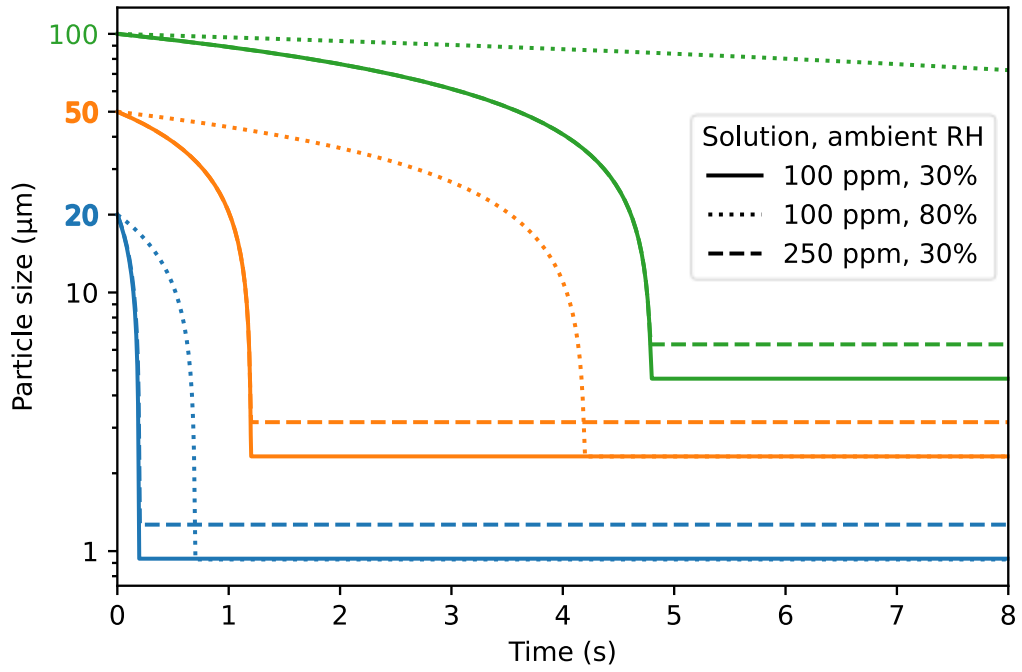
*Always read the pesticide label to determine which spray quality is required.

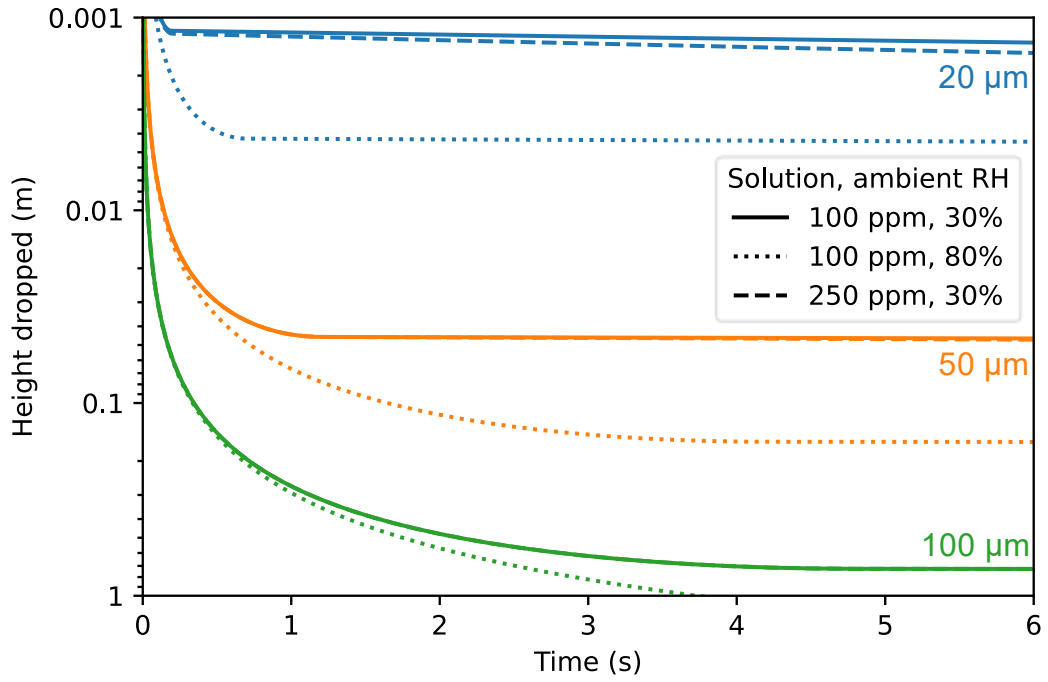
**Estimated from sample reference graph in ASABE/ANSI/ASAE Standard S572.1

- Can we use flame photometry to characterize drift of proxy particles of these sizes?

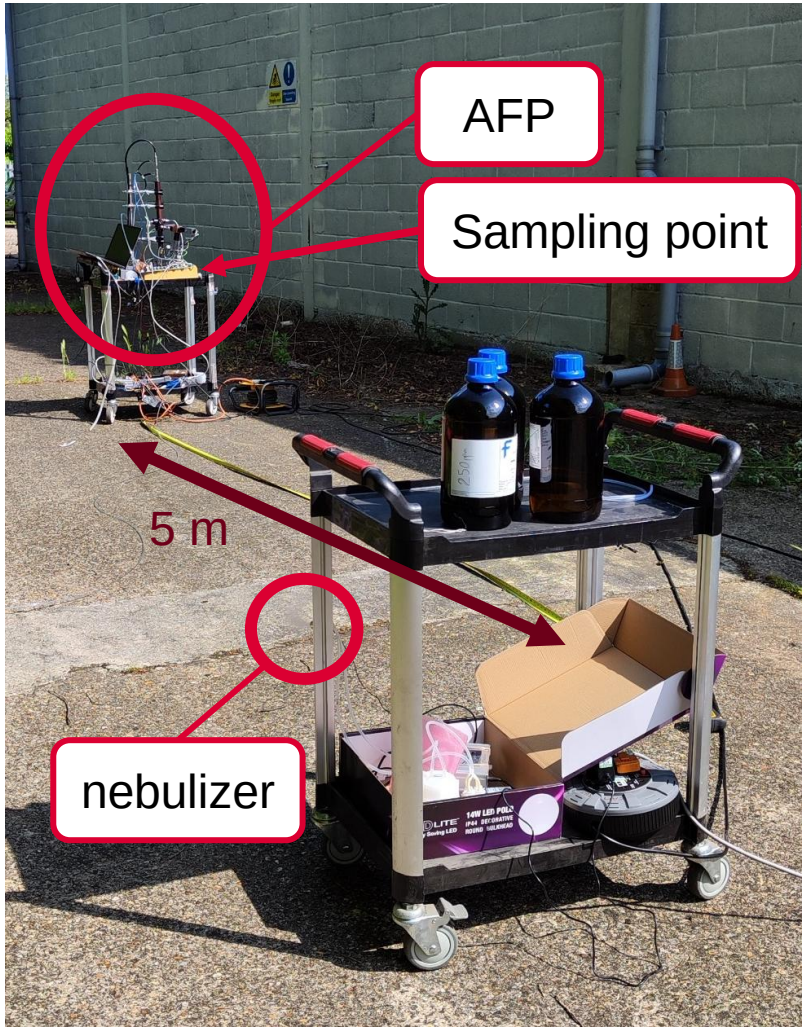
What about outdoors? Considerations

- Investigate droplet evolution with simple model
  - Final size of particles of the order of a few microns
  - Ambient RH has a large influence on evaporation and hence settling



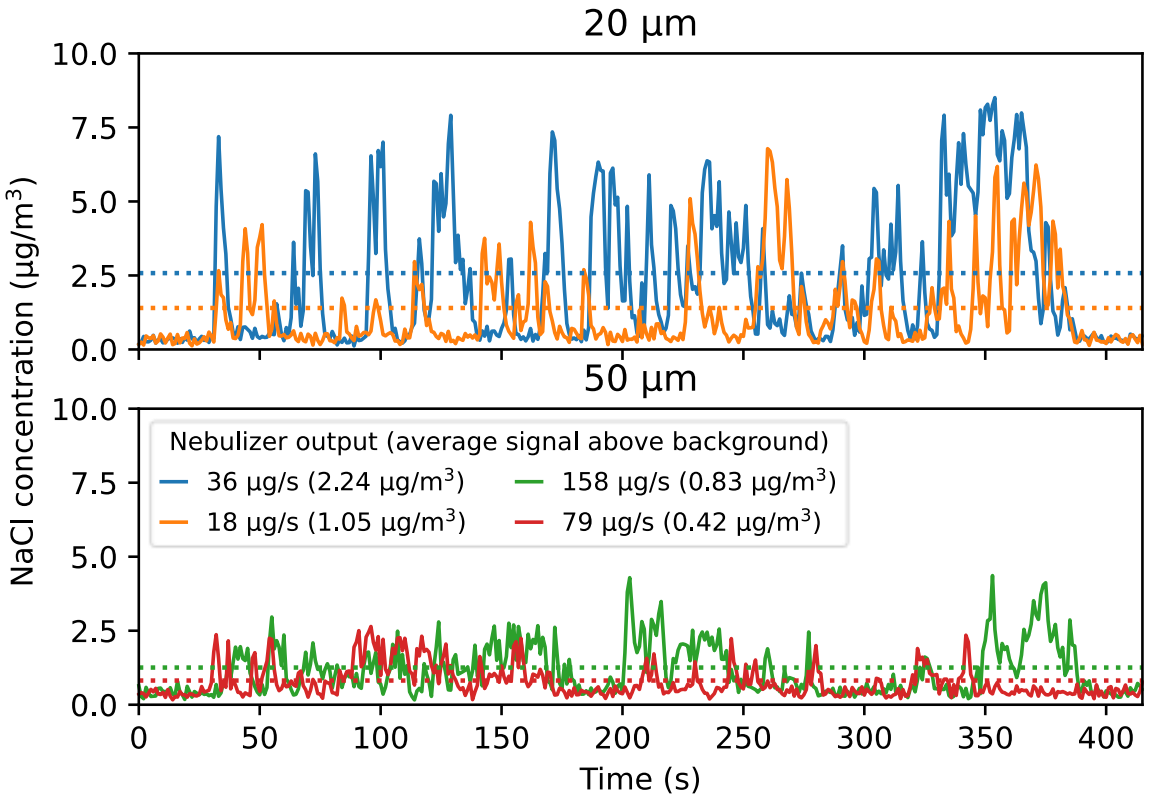


What about outdoors? Experimental setup



- Oriented along prevailing wind direction
- Estimated wind speed 0.5 – 4 m/s
- Flow visibly turbulent at the nebulizer
- Varying meteorological conditions:
  - 17ºC, 50-70% RH
  - Sunny spells
- Output from piezoelectric nebulizer: 15 – 300 µg/s NaCl
  - Two droplet sizes
  - Two solution concentrations
  - Variable percentage output
- Increased PMT gain for increased sensitivity
  - Adjusted calibration curve: 0.86 (µg/m^3)/V

What about outdoors? Initial results



- Results are strongly affected by slight changes in weather – but the combination of technique and application is promising

- Measured background concentration: 0.3 – 0.4 µg/m³
- Noisy signal, but averages provide insights
- Reduced transport of 50 µm particles compared to 20 µm

Conclusions

- Aerosol flame photometry is a well understood technique that can be applied to measure ambient aerosols in indoor and outdoor environments
- The specificity of the technique to selected tracers allows discrimination, which is essential when ambient particles not of interest are uncontrolled
- The response of the instrument to mass of tracer makes it attractive for studying droplet dispersion
- The real-time measurement capability is well suited to time varying processes such as environmental mixing
- Particles have very different transport propertied to gases – to understand particle dispersion a particle-based technique should ideally be used

Acknowledgements

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Thank you for listening!

Questions?

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