Measurements of Airborne Particles
Particle Counters

Prof. Zoran Ristovski

ILAQH

School of Earth and Atmospheric Sciences,
QUT

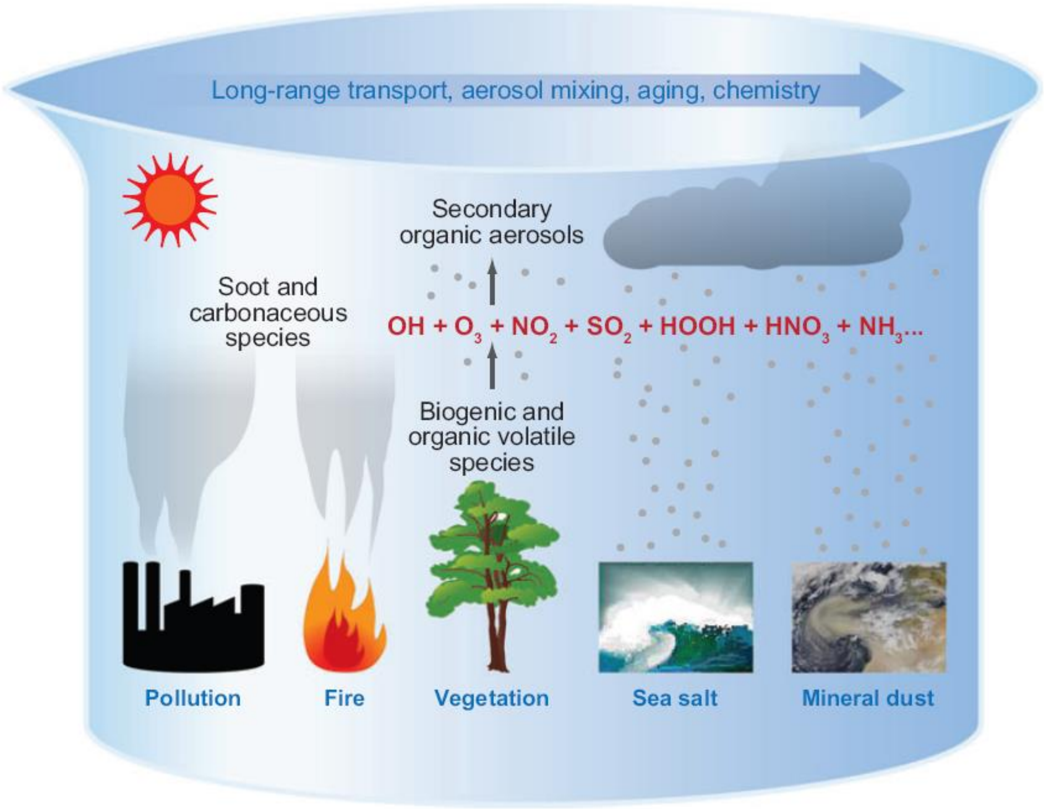
What is air pollution?

- Gasses:
  - CO_2
  - CO
  - NOx (NO + NO2)
  - Unburned hydrocarbons
- Smoke (Particles suspended in the air– Aerosols)

Particles / Aerosols

- NOMENCLATURE:
- Particle refers to a solid or liquid, larger than a molecule, diameter > 3 nm, but small enough to remain in the atmosphere for a reasonable time, diameter < 100 µm.

- **<u>Aerosol</u>** is a suspension of particles in a gas.



Long-range transport, aerosol mixing, aging, chemistry
Secondary organic aerosols
Soot and carbonaceous species
$OH + O_3 + NO_2 + SO_2 + HOOH + HNO_3 + NH_3$...
Biogenic and organic volatile species
Pollution
Fire
Vegetation
Sea salt
Mineral dust

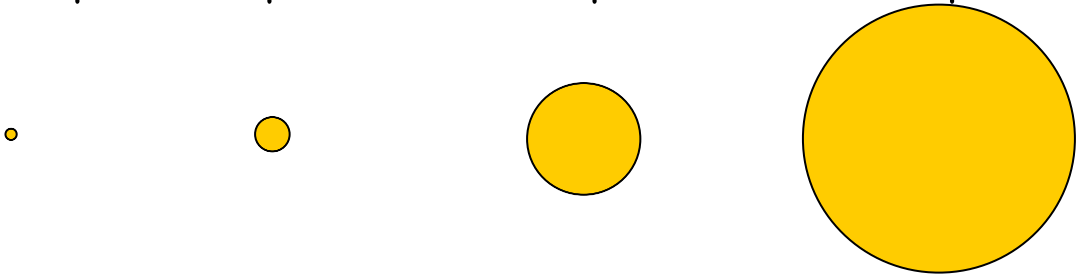
Size does matter

- Particles, like gases, are characterized by chemical composition, usually expressed in mg m^{-3}, but unlike gases, particles also have a characteristic size.
- Why is size important?
  - Atmospheric transport
  - Lung deposition

Particle Settling in Still Air

Time to settle 1cm by unit density spheres (1 g/cm^3)

0.5μm	1μm	10μm	100μm



1000s	300s.	3.2s	0.03s

If the density is larger i.e. 2 g/cm^3:

500s	150s	1.6s

Particles of higher density settle quicker.

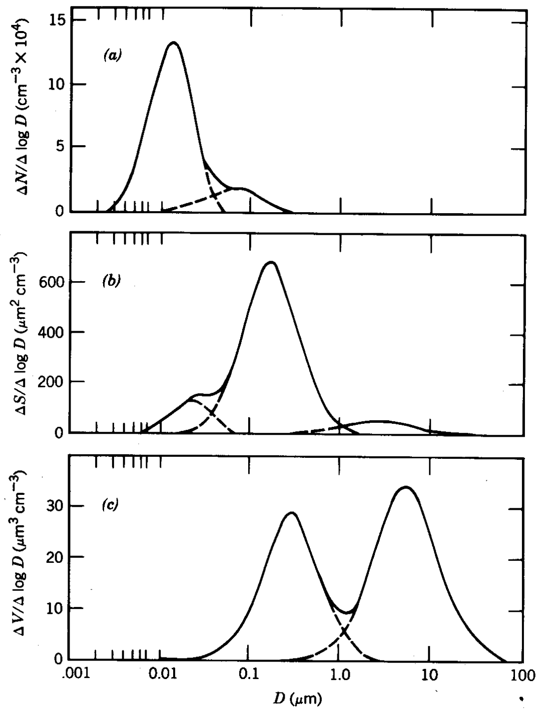
H2020 VIDIS, No. 952433

Which particle characteristic to measure?

- Particle mass/volume concentration
  - Expressed as total particle mass/volume in a unit of volume ~ mg/m^3 or $\mu m^3/m^3$
- Particle number concentration
  - Expressed as total particle number in a unit of volume ~ $\#/m^3$
- Particle surface area concentration
  - Expressed as total particle surface area in a unit of volume ~ $\mu m^2/m^3$

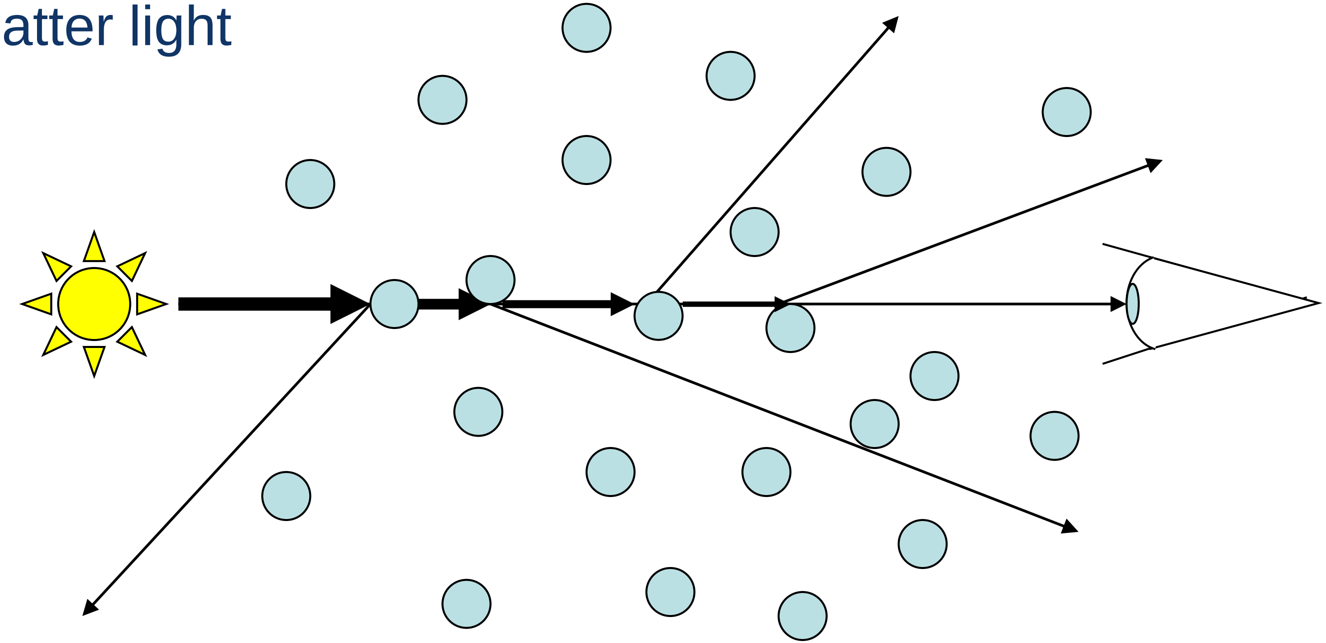
Particle Size distributions

- Number
- Surface
- Volume
  - mass



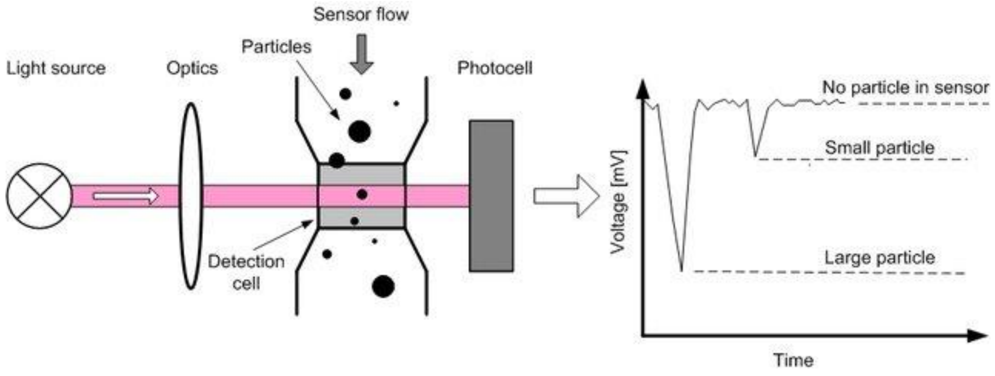
How to measure particle number concentration?

- Particles scatter light



Optical Particle Counters

- Collimate the particles in a narrow flow path so only one by one particle passes through the detection cell
- Illuminate the detection cell with a narrow collimated beam of light (laser)
- Place a detector behind the cell
- Once the particle passes in front of the laser beam it will scatter the light beam and the detector measures a negative pulse (less light coming to the detector)

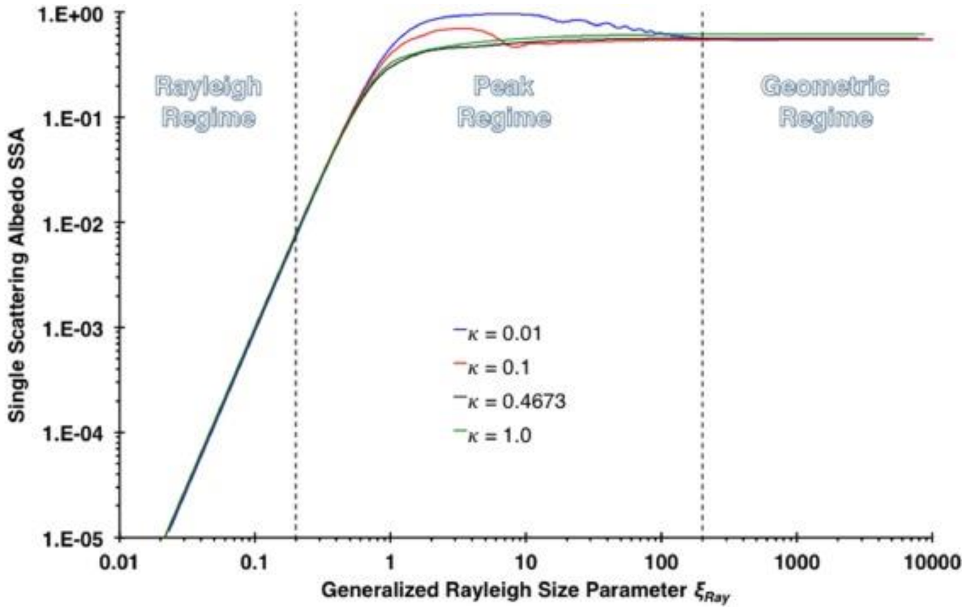


Particle Concentration = Number of pulses per second / flow rate [#/m^3]

Optical Particle Counters

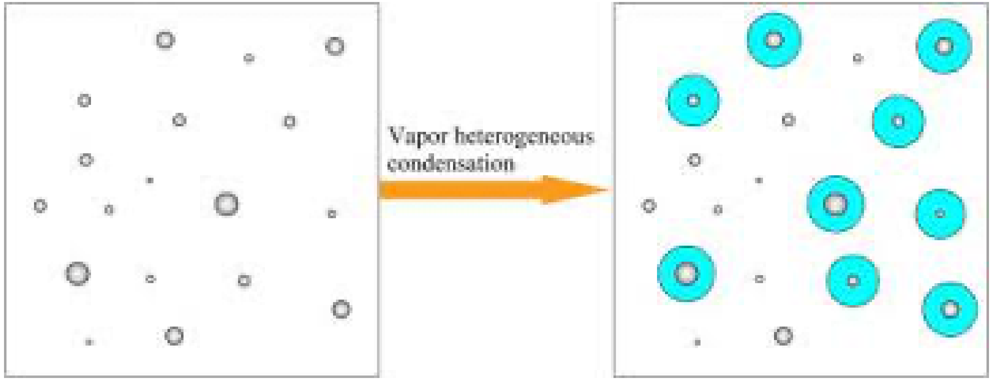
Limitations of optical particle counters

- The amount of scattered light depends on the particle size.
- The single scattering albedo (how much light a particle blocks per cross section area) significantly drops with the particle size.
- Particle bellow ~100nm hardly scatter any light and cant be detected using the OPC's.



How to detect particles as small as several nm?

- Expose the particle to a supersaturated vapor such as water or alcohol.
- The vapor starts to condense on the particle and the particle grow.
- This is a fairly fast process if there is an excess of condensing vapors <<1s.



When does the vapor start to condense?

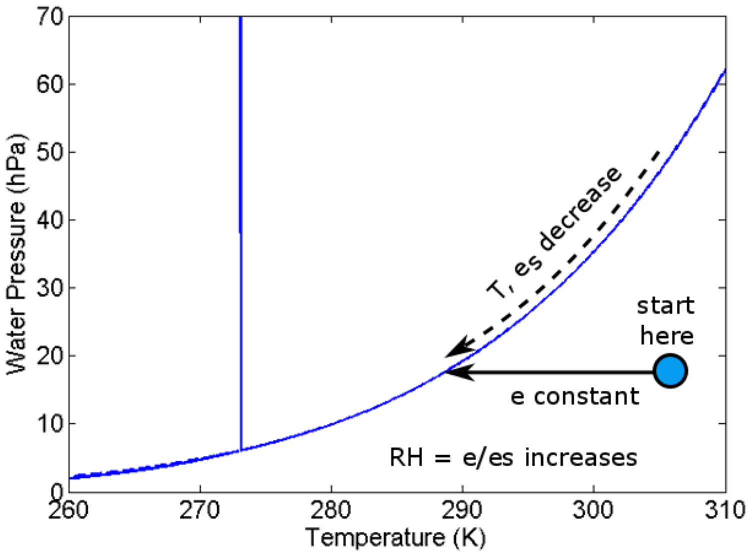
- Vapors will condense on existing particles and the particles will grow once supersaturated conditions are achieved.
- When the **saturation ratio**

  $$S = e/e_s > 1$$

- **supersaturation**:

  $$s = S-1 = e/e_s - 1$$

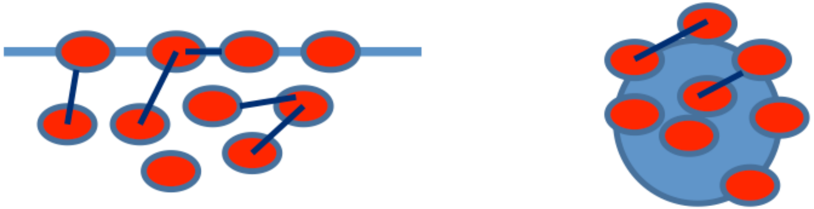
How to achieve supersaturation:



Cool the air down.

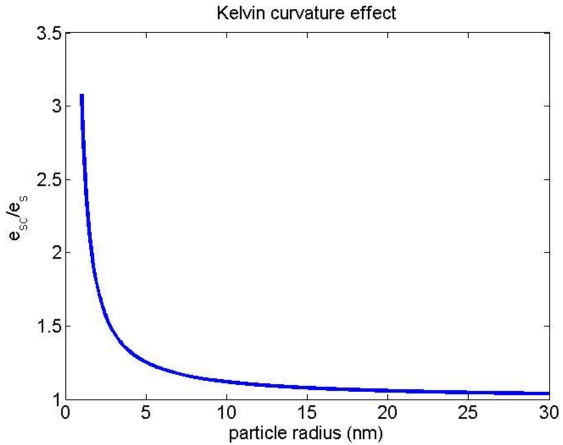
Do both small and large particles grow at the same *s*? Kelvin Effect

- The Kelvin equation describes **the change in vapour pressure due to a curved liquid vapour interface**, such as the surface of a droplet.



$$e_{sc}(T) = e_s(T) \cdot \exp\left(\frac{2\sigma}{n_L \cdot R^* \cdot T \cdot r_d}\right)$$

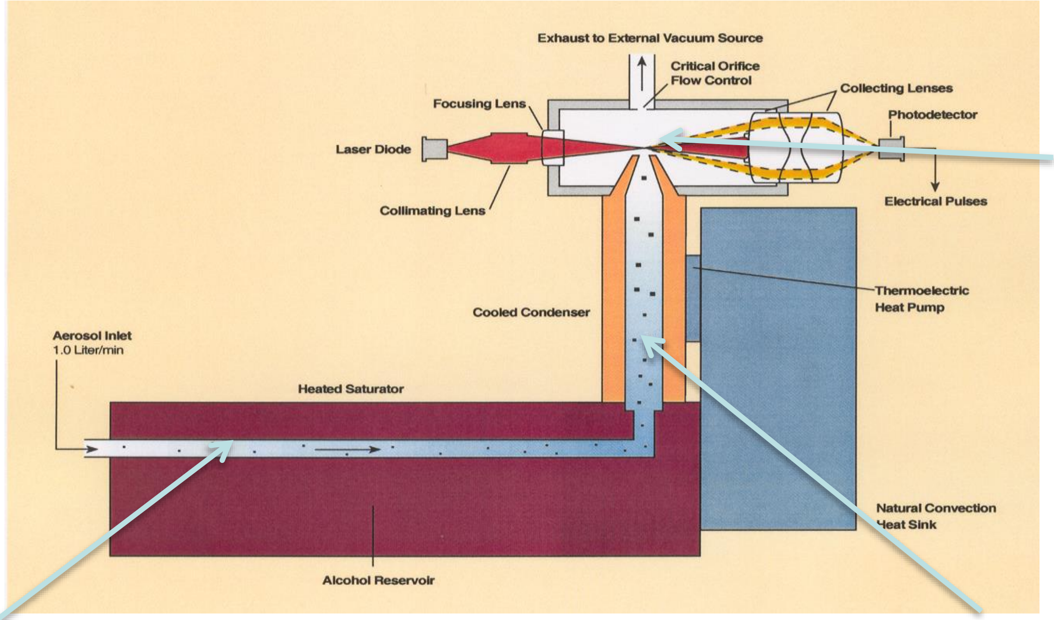
Water



Condensation Particle Counters

- Important instruments in aerosol technology are Condensation Particle Counters (CPC).
- They are used to measure the particle number concentration down to the nanometer size range (~3nm).
- The particles are enlarged due to supersaturation and a subsequent condensation of a condensable gas.
- The condensing liquid is usually
  - Butanol,
  - ethyl alcohol
  - glycol
  - water.
- The particles reach a size at which they can be optically detected.
- The number concentration is measured for all particle larger than the lower detection diameter.

Schematic sketch of butanol based CPC

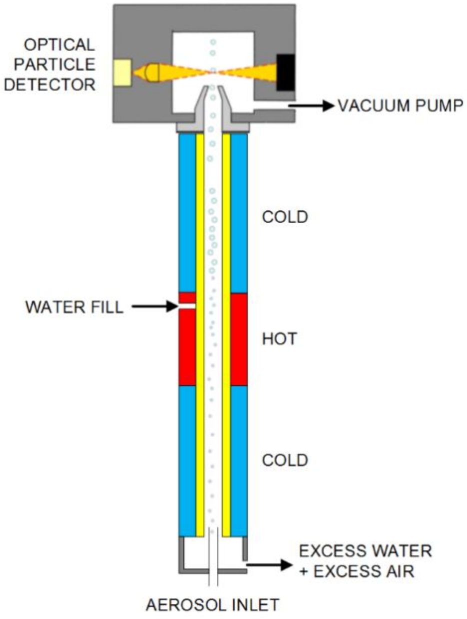


3. Particles grow very quickly to >1μm in size and can be detected with a simple OPC.

1. The aerosol flow is saturated with butanol in a slightly heated saturator ~40°C.

2. The temperature of the butanol-aerosol mixture is decreased by 17-27°C in the condenser of the CPC. When the temperature is reduced the vapor becomes supersaturated

Water based CPC



- Use water as a condensing liquid
- The sample flow first passes through a cool, wetted saturator and becomes temperature equilibrated and saturated with water vapor as water diffuses into the sample stream.
- The sample flow and water vapor pass into a growth tube that has heated wet walls that produce an elevated vapor pressure.
- Water vapor diffuses to the center of the aerosol stream at a faster rate than the heat is transferred from the walls to the aerosol because the mass diffusivity of water vapor is higher than the thermal diffusivity of air.
- Aerosol flow thus reaches a critical degree of supersaturation, and water vapor condenses heterogeneously onto virtually all particles larger than a minimum nucleation diameter.

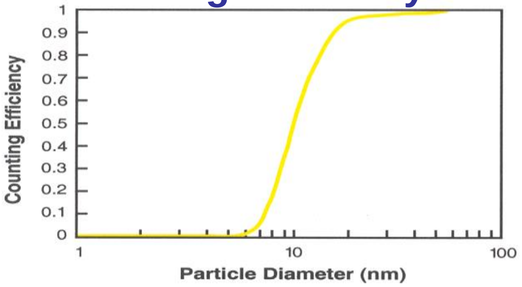
Limitations

<u>The lower detection diameter is determined by:</u>

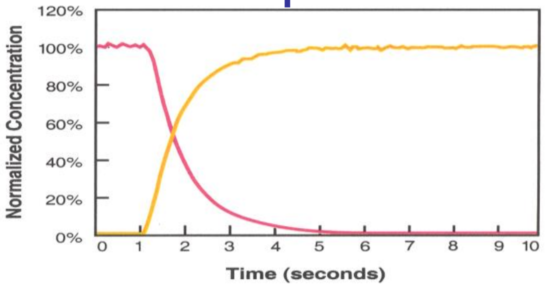
1. the Kelvin diameter (supersaturation)
2. diffusion coefficient of the condensable gas
3. the particle material

The upper and lower detection limits are specific for each CPC type.

Counting efficiency curve



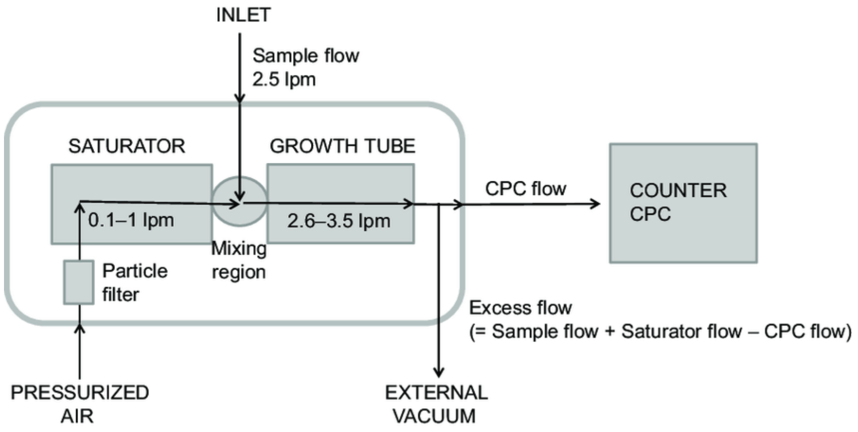
Response time



How to increase the lower cut-off point

Particle Size Magnifier

- Uses Diethylene Glycol (>99%)
- Measures down to 1nm



Conclusion

- Condensation Particle Counters are versatile instruments covering particle size ranges from 1nm up to several micrometers and response time as short as 0.25s .
- Depending on the application they can use a range of condensation liquids from water to alcohols.
- They can be handheld-portable, drone flying versions to full laboratory units.

Acknowledgement

The author acknowledges H2020 VIDIS project “Virtual Centre for Distributed Atmospheric Sensing for Reduction of Pollution Pressures”, Grant Agreement 952433