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"Developing parameters for local multimode ambient aerosol models including nanometer mode"

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Outline

- Background
- Ventilation System
- Definition of PM_1 , $PM_{2.5}$ and PM_{10} modes
- Definition of Ultrafine modes (Nucleation and Aitken)
- Equations needed to calculate PM_x
- Parameters for log-normal modes from literature
- How PM_1 values relate to $PM_{2.5}$ values
- Conclusions

Background

- Particulate Matter (PM) in occupied environments raises concerns because of heavy pollution in many cities and the time spent by people indoors
- Air conditioning systems with mechanical ventilation and air cleaning capabilities can be effective tools to control PM concentration indoors
- To predict indoor PM concentration simplifications (time averages) and data needed (size distributions, mode parameters, indoor generation)
- Air filter PM impact can be calculated by new EN ISO 16890 standard
- ISO 16890 filter efficiency data stops at 300 nm, neglecting the nanoparticle size range (calculation steps applicable to any size range)
- New EN ISO 21083 will address filter media efficiency down to 3 nm

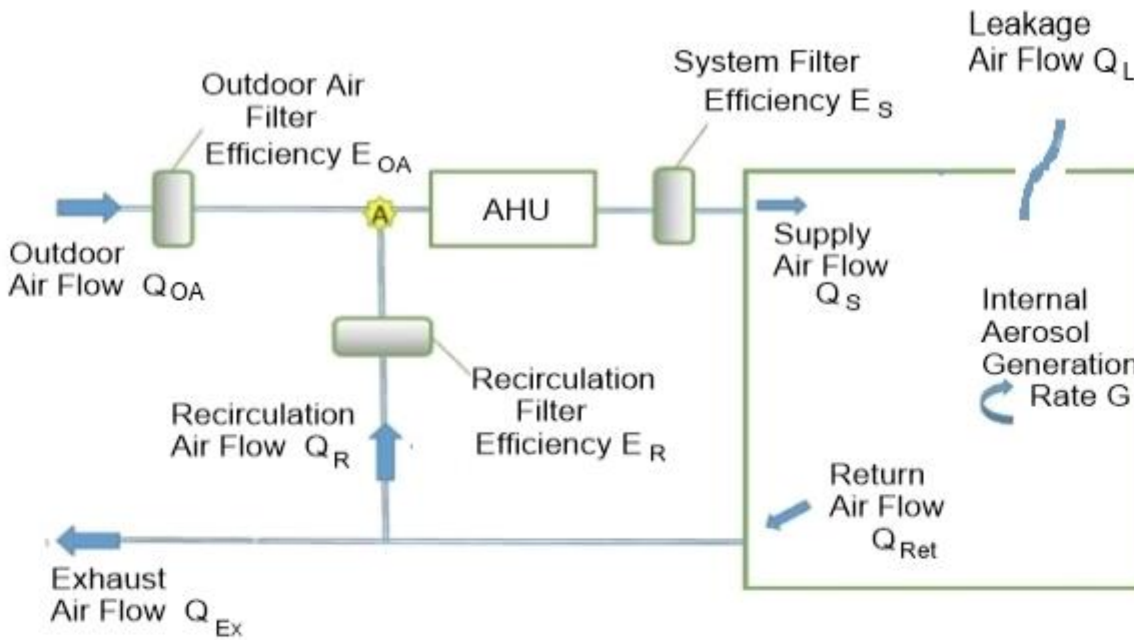
Background

- Filter media efficiency not enough
- Calculations also need mode parameters (geometric mean diameter (d_{50}), standard deviation (σ_g) and peak height (number, mass/m^3) for all modes
- PM_1 data usually not available but it provides no information about ultrafine particles (cut size = 1000 nm)
- $PM_{2.5}$ data (available and/or measurable) can be used to get PM_1 data
- Two more modes observed:

    nucleation: d_{50} = 15 to 80 nm; $\rho \approx 1000$ kg/m^3

    Aitken: d_{50} = 70 to 200 nm; $\rho \approx 1500$ kg/m^3

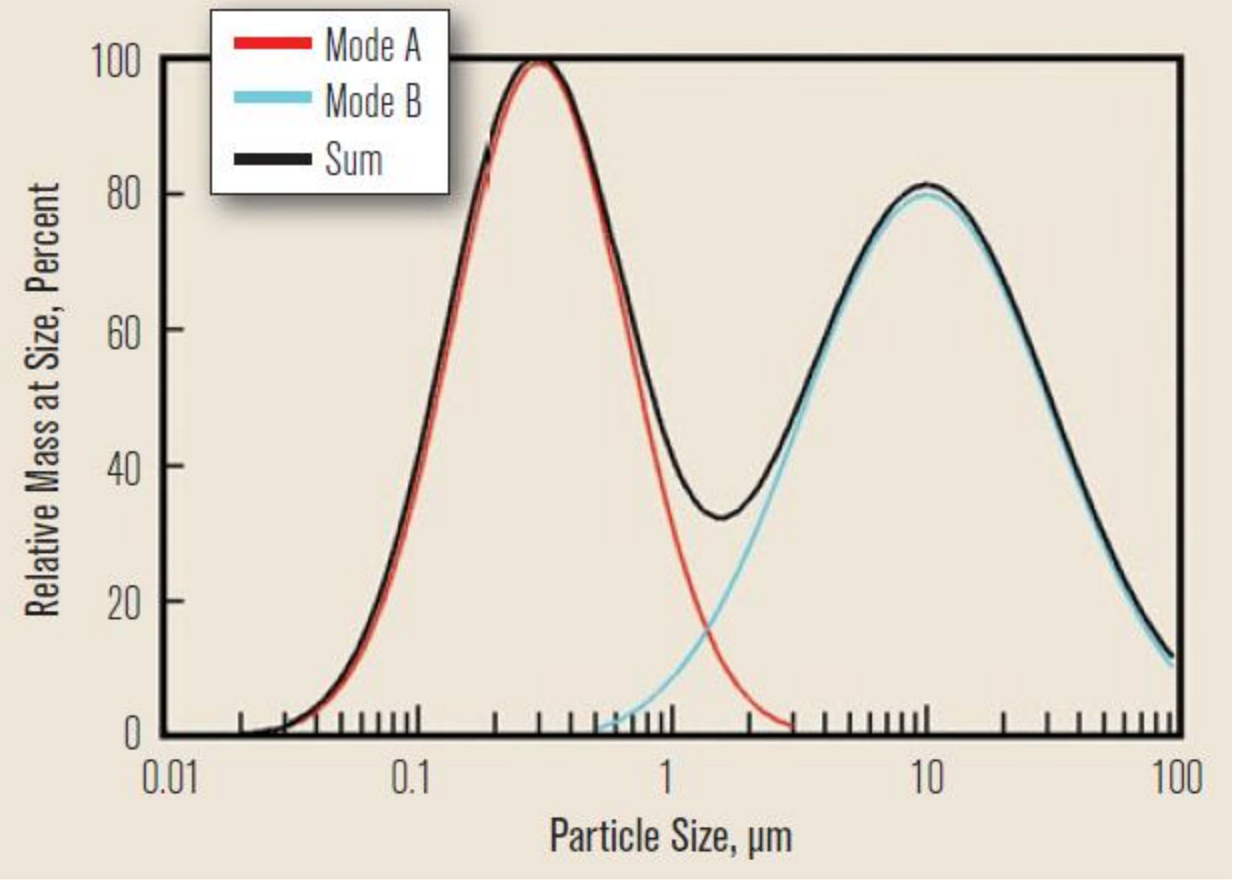
Basic ventilation system with recirculation



- $Q_{OA} + Q_R = Q_S$ $Q_{Ret} = Q_S \pm Q_L$ $Q_{Ex} = Q_{Ret} - Q_R$
- 3 equations , 6 unknowns, more information needed
- Qs is determined by thermal requirements, or occupant comfort, or carbon dioxide level.

Urban particle-size distribution

Standard urban particle-size distribution specified by ISO 16890-1



Core PM_x concentration calculations

(1) $f\left(d,\ \sigma_g, d_{50}\right) = \frac{1}{\ln\sigma_g} \cdot exp\left[-\frac{(\ln d - \ln d_{50})^2}{2\left(\ln\sigma_g\right)^2}\right]$

(2) $P(\mathrm{d}) = \sum y_{\mathrm{i}} \cdot f\,(d, \sigma_{\mathrm{gi}}\,, d_{\mathrm{50i}})$ (3) $d = (d_2 + d_1)^{0.5}$

(4) $N = P(d) \cdot (\ln d_2 - \ln d_1)$

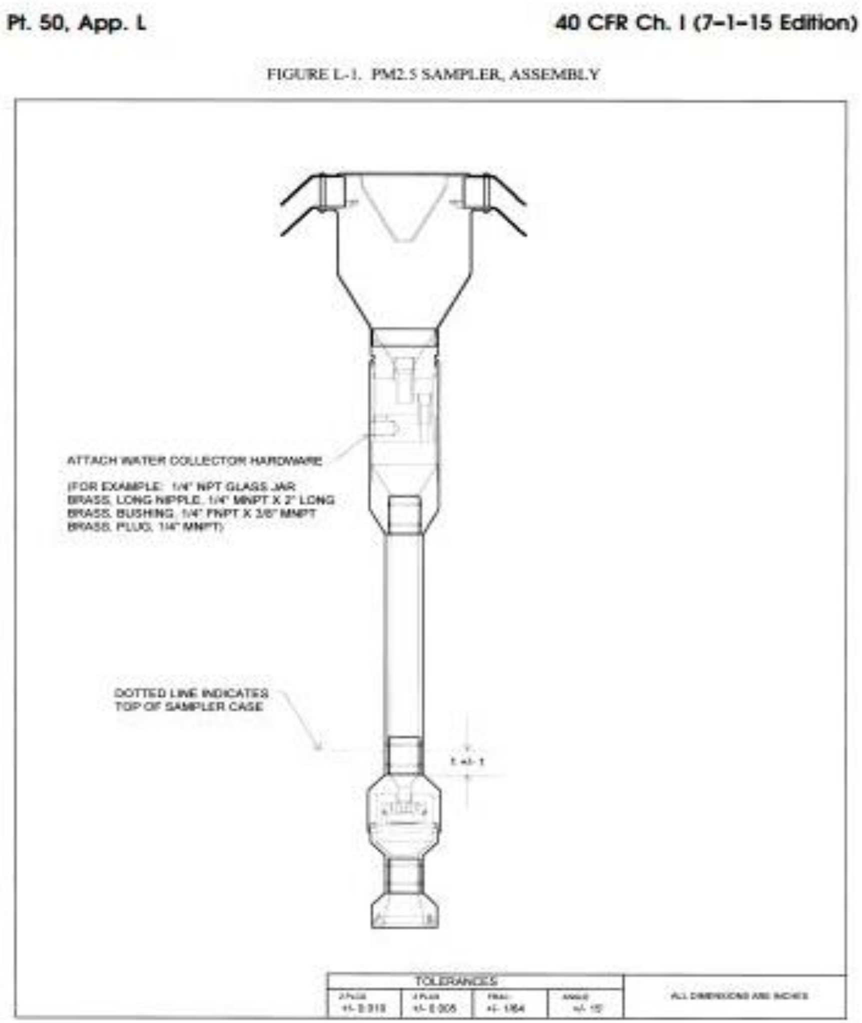
(5) $\Delta m(d) = \rho_{\mathrm{m}} \cdot \pi\, d^3/6 \cdot P(d) \cdot (\ln d_2 - \ln d_1) \cdot (1 - E(d))$

(6) $PM_X = \sum \rho_{\mathrm{m}} \cdot \pi\, d^3/6 \cdot P(d)(\ln d_2 - \ln d_1)(1 - E(d)) \cdot Pin(d)$

ISO PM_X efficiencies using ISO 16890-1 standard distribution

AEROSOL COUNTER CHANNEL i	MEAN DIAMETER d_{gi}, µm	CHANNEL WIDTH $\Delta ln(d_i)$	DISTRIBUTION FRACTION IN CHANNEL $q_3(d_{gi})$	VOLUME IN CHANNEL $q_3(d_{gi}) \cdot \Delta ln(d_i)$	VOLUME X AVERAGE EFFICIENCY $E(d_i) \cdot q_3(d_{gi}) \cdot \Delta ln(d_i)$	VOLUME X POST-CONDITIONING EFFICIENCY $E_D(d_i) \cdot q_3(d_{gi}) \cdot \Delta ln(d_i)$	PM_X EFFICIENCY EPM_X	PM_X MINIMUM EFFICIENCY $E_{MIN} PM_X$
1	0.39	0.51	0.17050	0.086955	0.059129	0.057390	–	–
2	0.59	0.34	0.14302	0.048627	0.039145	0.038415	–	–
3	0.84	0.36	0.11898	0.042833	0.037907	0.038121	ePM_1	$e_{min}PM_1$
			Sums for Channels 1 to 3	0.178415	0.136181	0.133926	76%	75%
4	1.14	0.26	0.11080	0.028808	0.026993	0.026791	–	–
5	1.44	0.21	0.11799	0.024778	0.023886	0.023787	–	–
6	1.88	0.32	0.14035	0.044912	0.044059	0.044014	–	–
7	2.57	0.31	0.18137	0.056225	0.055494	0.055381	$ePM_{2.5}$	$e_{min}PM_{2.5}$
			Sums for Channels 1 to 7	0.333138	0.286613	0.283899	86%	85%
8	3.46	0.29	0.22320	0.064728	0.063951	0.063887	–	–
9	4.69	0.32	0.25390	0.081248	0.080517	0.080436	–	–
10	6.20	0.24	0.26179	0.062830	0.062264	0.062578	–	–
11	8.37	0.36	0.24483	0.088139	0.088139	0.088139	ePM_{10}	$e_{min}PM_{10}$
			Sums for Channels 1 to 11	0.630083	0.581484	0.578939	92%	92%

Definition of the $PM_{2.5}$/PM_{10} monitors (1/2)



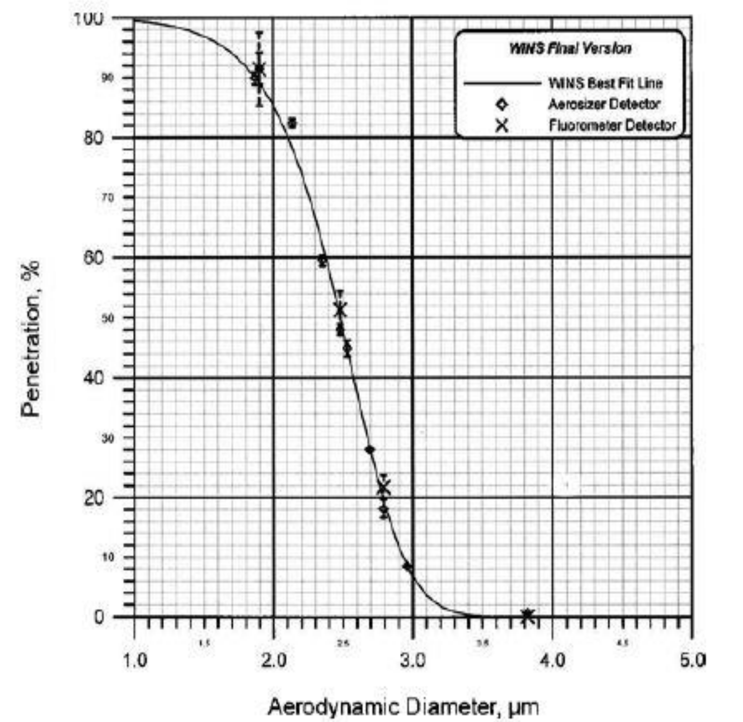
CFR – the Code of Federal Regulations – is a daily publication from Washington giving official forms of US Federal regulations

This drawing of the combined PM_{10} and $PM_{2.5}$ monitors is part of the US official definition of those two samplers

Penetration curve for a real size-selective inlet for a $PM_{2.5}$ sampler

Source: Peters et al, *Aerosol Science & Technology,* **34**: 389-397, 2001)

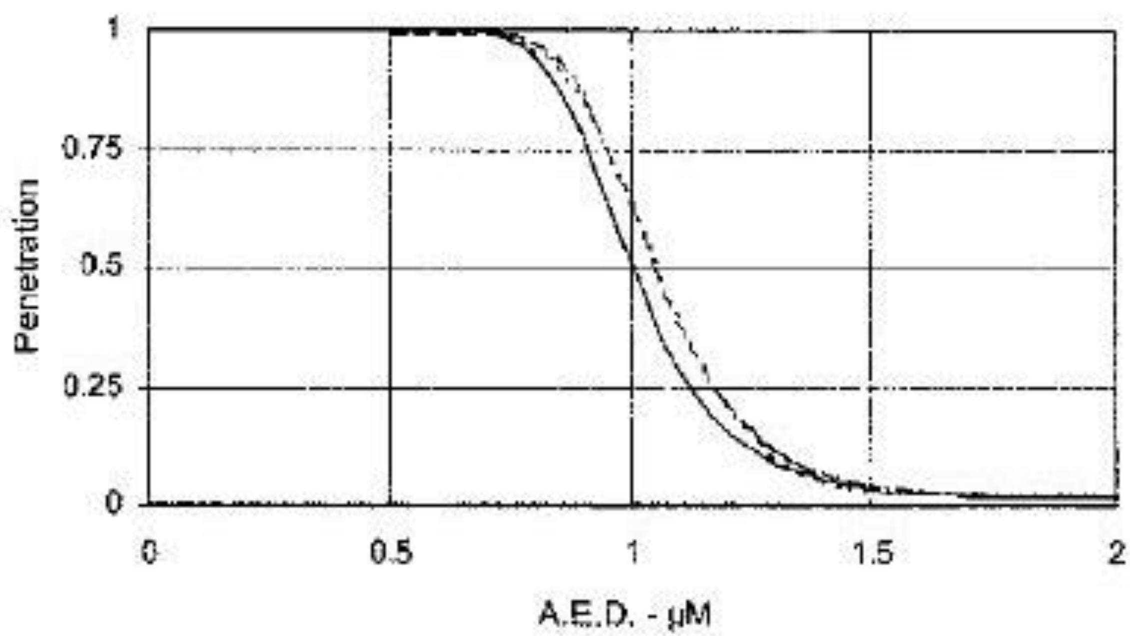
Diameter range: 0 – 3.254 µm



Mathematical expression proposed to simulate its behavior

$$\% Pin = 100 - 52.453(1 + \tanh(2.08(0.991d - 2.5)))$$

For PM_1 inlet (a cyclone)



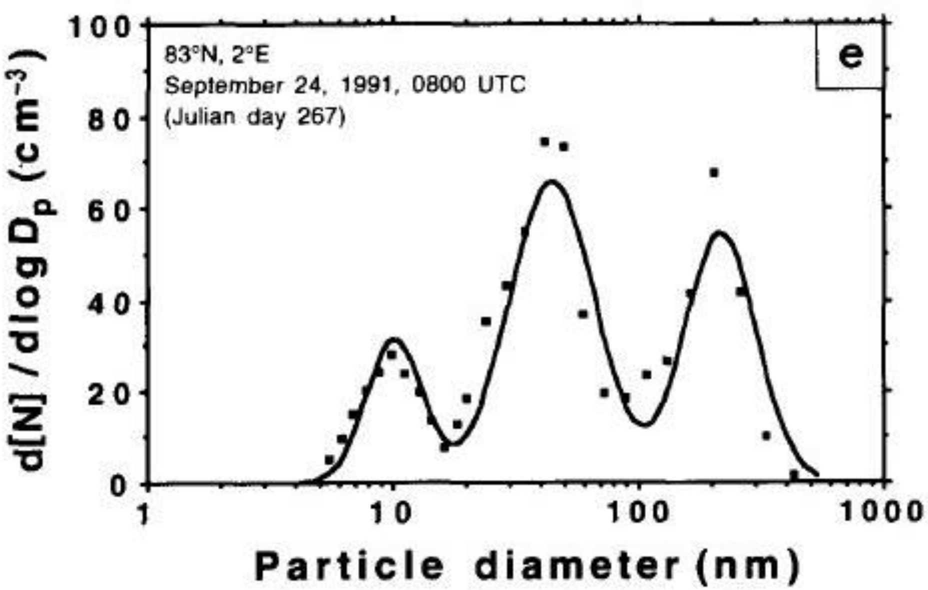
- % *Pin* = 100 - 50.0(1.0 + tanh(*d* – 1.0))
- Range for diameter *d* is 0 – 1.7 µm

PM concentrations and $PM_1/PM_{2.5}$ ratios

Ref.	Locale	Sampling Season, Days	Mean PM Values, µg/m³ PM_1	$PM_{2.5}$	PM_{10}	Ratio, $PM_1/PM_{2.5}$
P1	urban, Vienna Austria	year 365	14.9	18.9	26.5	0.873
P1	urban, Vienna Austria	year 365	14.7	18.8	29.1	0.782
P1	suburban, Vienna Austria	year 365	17.5	21.1	31.0	0.829
P2	urban, Athens Greece	year 365	18.5	23.7	51.3	0.781
P2	urban, Athens Greece	year 365	20.1	29.3	52.2	0.686
P2	university in hills near sea, Crete	year 365	10.3	17.9	32.5	0.575
P4	urban, Taipei, Taiwan China	spring 91	14.0	20.2	35.1	0.693
P4	urban, Taipei, Taiwan China	winter 90	9.7	12.7	26.4	0.764
P4	urban, Taipei, Taiwan China	spring 91	19.2	29.9	51.3	0.642
P4	urban, Taipei, Taiwan China	autumn 92	29.5	34.4	46.0	0.858
P5	urban, Xi'an China	year 365	127.3	182.2*	-	0.699
P6	urban, arid, Phoenix Arizona USA	spring 91	4.4	18.4	25.8	0.239
P6	urban, arid, Phoenix Arizona USA	summer 92	5.9	8.4	81.6	0.702
P6	urban, arid, Phoenix Arizona USA	autumn 92	9.9	14.2	57.8	0.697
P7	urban rooftop, Chengdu China	spring 91	49	56	76	0.875
P7	urban rooftop, Chengdu China	summer 92	40	43	49	0.930
P7	urban rooftop, Chengdu China	autumn 92	54	56	60	0.964
P7	urban rooftop, Chengdu China	winter 90	76	83	92	0.916
P8	urban rooftop, normal year, Delhi	winter 90	204	236	338	0.864
P8	urban rooftop, normal year, Delhi	summer 90	43	69	178	0.623
P8	urban, monsoon season, Delhi	Aug./Sept 61	37	54	132	0.685
P8	urban rooftop, post-monsoon, Delhi	Oct./Nov 61	337	389	548	0.866
P9	urban, highway traffic, Barcelona	July/Nov 150	17	25	38	0.680

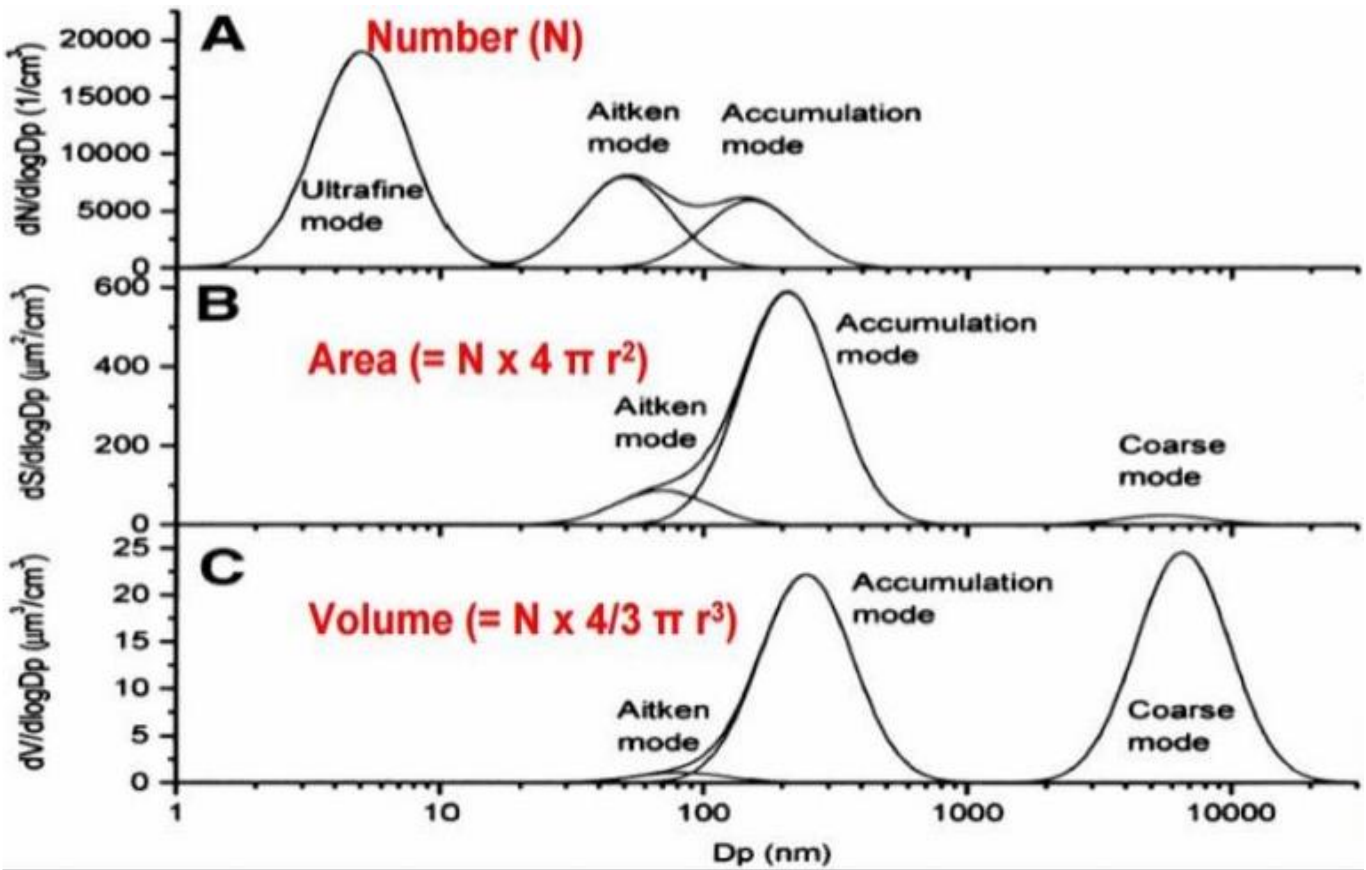
Ultrafine particle modes

- PM_1 sampler can't separate these peaks
- It sees particles below 650 nm as one pile



- Data gathered in the Arctic shows distinct modes with d_{50} below 100 nm

Particle mass, surface, or numbers … what a tremendous difference



The ultrafine mode vanishes from the volume plot

Parameters for "nanometer" modes found in aerosol literature

		Nucleation mode ρ ~ 900 kg/m3			Aitken mode ρ ~ 1500 kg/m3		
Ref.	Location	d_{50}	σ	Y	d_{50}	σ	Y
1	Mid Pacific Ocean	22.0	1.15	0.50	36.8	1.19	0.50
1	S. Pacific Ocean	23.7	1.12	0.25	45.8	1.15	0.75
1	Pacific Tropics	23.0	1.12	0.60	50.0	1.14	0.40
2	European cities	--	--	--	50.8	1.98	--
3	Arctic Canada	--	--	--	40.0	2.00	--
4	City, SE Germany	15.8	1.33	0.65	67.4	1.68	0.35
	Averages:	21.1	1.18	0.50	48.5	1.52	0.50

1) Ueda et al 2016 *Atmos. Envir* 142: 324-339
2) Asmi et al 2011 *Atmos. Chem. Phys.* 11: 5505-5538
3) Covert et al 1996 Tellus 48B: 197-212
4) Birmili et al *J. Geophys. Res. Atmosphere* 106: 32005-328818

Particle Distribution Parameters: Accumulation and Coarse Modes

Zone:	Urban		Rural	
Mode:	Accumulation	Coarse	Accumulation	Coarse
d_{50} µm	0.3	10	0.25	11
σ_g	2.2	3.1	2.2	4.0
γ	0.45	0.55	0.18	0.82

Conclusions

- Reasonable models of outdoor particle concentrations and particle-size distributions can be constructed by the use of multiple log-normal particle modes
- Academic papers and government agencies provide the parameters to quantify these modes for many locales around the world
- Test data for the efficiency of filters for low nanometer sizes will be available soon
- Weak or missing items in these calculation procedures are the realistic simulation of filter loading with dust; the characteristics of dust generated indoors; convenient applications to do the calculations
- To make good use of parameters describing the nanometer mode, cognizant authorities should provide PM concentration limits as number concentration, not as mass concentration

Thank you for your attention!