Ultrafine Particles in the UK.

An Overview.

Environmental Protection UK Annual Conference,
13 November 2019.

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Vice-Chair Air Quality Committee,
Environmental Protection UK.

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Any remaining errors are mine and mine alone.

“Cinderella” Pollutants? (1).

Ultrafine particles (UfPs) generally.

Black Carbon - a measure of airborne soot-like carbon.

UV Particulate Matter - an indicator of wood and solid fuel emissions (organic compounds).

All currently monitored in the UK but NOT included in regulation.

“Cinderella” Pollutants? (2).

Historic UK Monitoring:

Ultrafines (Particle Size & Numbers).
Marylebone Road (Roadside), 1998 - 2007,
London Bloomsbury (Urban Background) 1999 – 2007,
Harwell (Rural), 1998 - 2007.

Measured by Scanning Mobility Particle Sizer (SMPS).

Size range – 51 “bands” centring from 12.0nm – 437.1nm.

Ultrafines (Particle Numbers).
Glasgow Centre, London North Kensington, Birmingham Centre, Manchester Piccadilly, Belfast Centre (all Urban Background), Port Talbot (Industrial), 2000 - 2009.

Measured by Condensation Particle Counter (CPC).

Total number of particles between ~7nm – 1000nm.

“Cinderella” Pollutants? (3).

Current/Recent UK Monitoring:

Ultrafines (Particle Size & Numbers).
Marylebone Road (Roadside), 2007 - date,
London North Kensington (Urban Background) 2007 – Dec 2018,
London Honor Oak Park (Urban Background) Dec 2018 – date,
Harwell (Rural), 2007 – Dec 2015,
Chilbolton Observatory (Rural), 2016 - date.

Measured by SMPS.

Size range – 51 “bands” centring from 16.55nm – 604.3nm.

Black Carbon/UV Particles.
14 sites across the UK, ranging from Rural to Roadside.

What are ultrafines?

Strictly speaking:

ISO TC 146/SC 2/WG1 N 320 - "A particle sized about 100 nm in diameter or less".

NB. This also applies to nanoparticles.

However the 16.5 - 100 nm range comprises ~80% of the particles as counted by SPMS.

What are their sources? (1)

Two main categories:

Direct emissions, but from multiple source types depending on location.

In urban areas:
Combustion followed by particle nucleation, coagulation and vapour condensation.
(Stone V *et al*, October 2017.)

Regional nucleation/New Particle Formation (NPF).

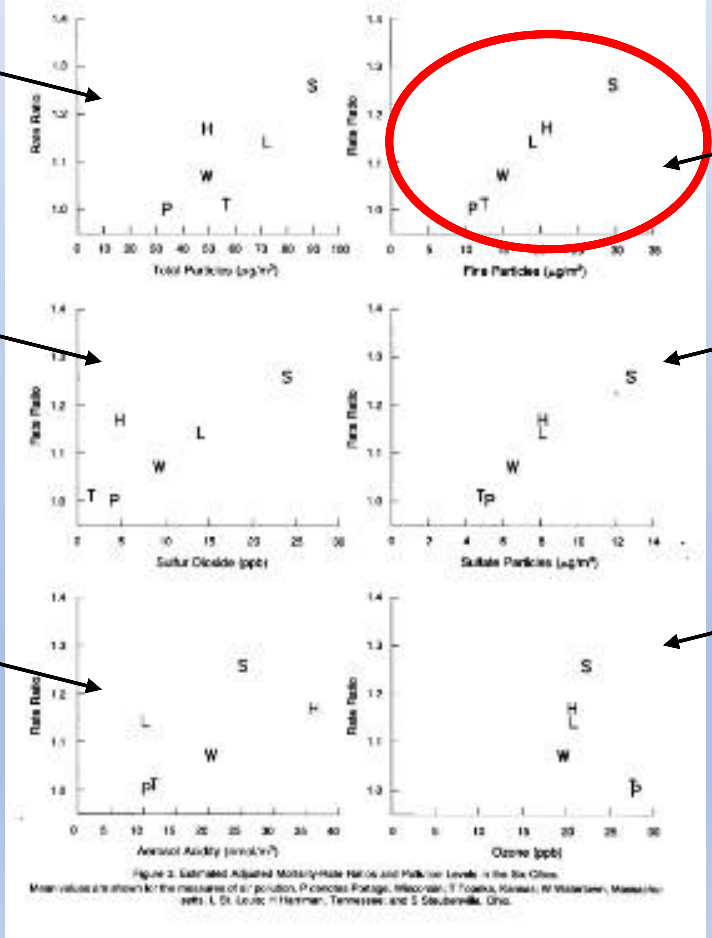
Particles and Health (1).

Six Cities Study showed the importance of particles.

Total Particles

SO_2

Aerosol Acidity



Fine Particles

Sulphate Particles

Ozone

S = Steubenville, Ohio
H = Harriman, Tennessee
L = St. Louis, Missouri
W = Watertown, Massachusetts
T = Topeka, Kansas
P = Portage, Wisconsin

Particles and Health (2).

But what is the critical property of particles?

OR, perhaps more importantly, what are the critical properties of particles?

Particles and Health (3).

Mass?

Surface area?

Number?

Chemical composition?

OR are all important, but in different ways?

AND are we looking at acute effects or chronic effects? Or both?

Particles and Health (4).

Chemical composition.

Gases.

Molecules are essentially chemically identical.

Particles.

Chemical composition varies.

Organic, inorganic, metallic, mineral………

Particles and Health (5).

Physical properties.

Gases.

Molecules are essentially identical, isotopic/isomeric variations excepted.

Particles.

Particles can be considered as a "continuum".

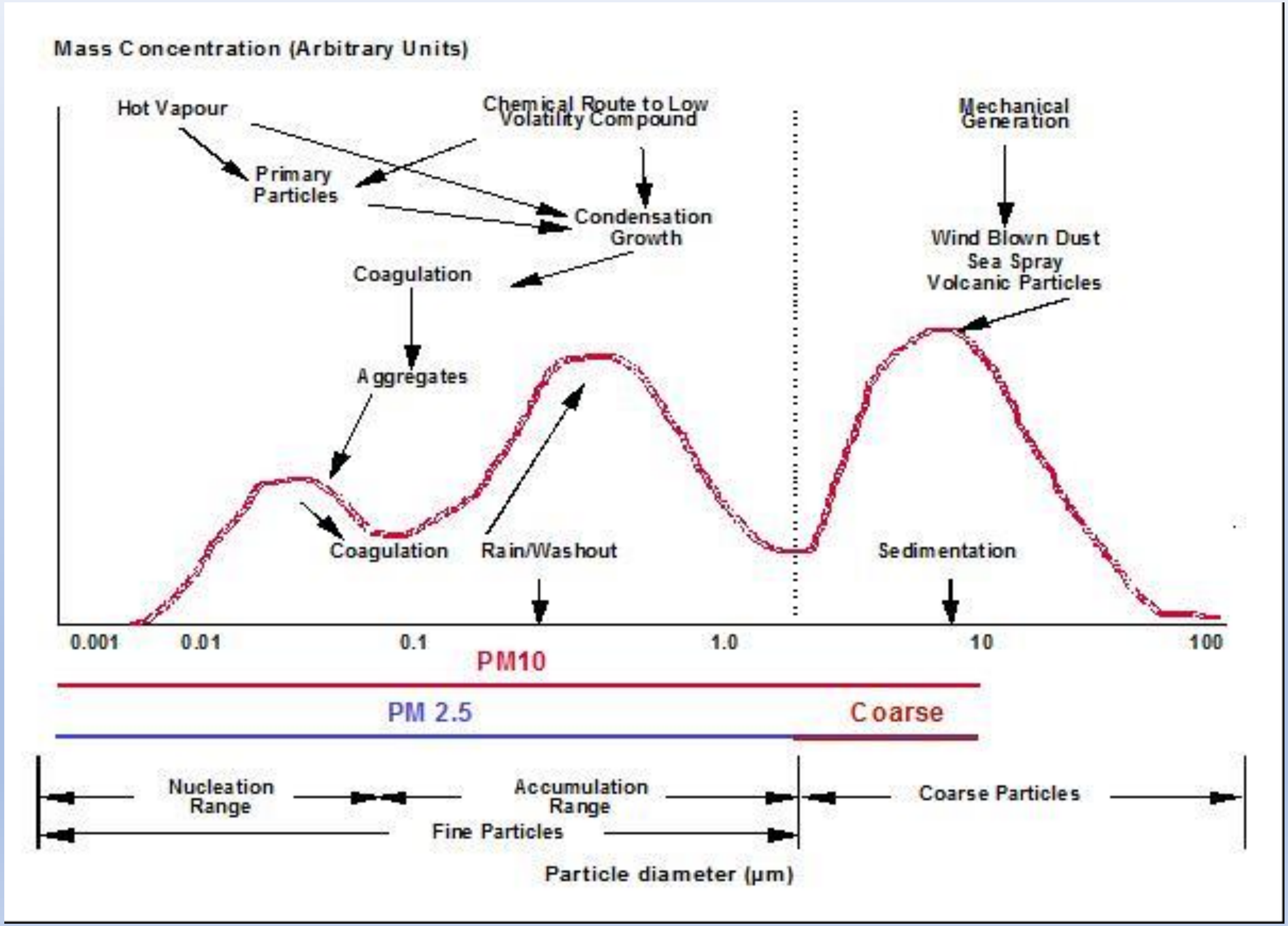
In other words $PM_{2.5}$, PM_{Coarse}, PM_1, Ultrafines etc. are all a "subset" of PM_{10}.

Particles and Health (6).

Physical characteristics.

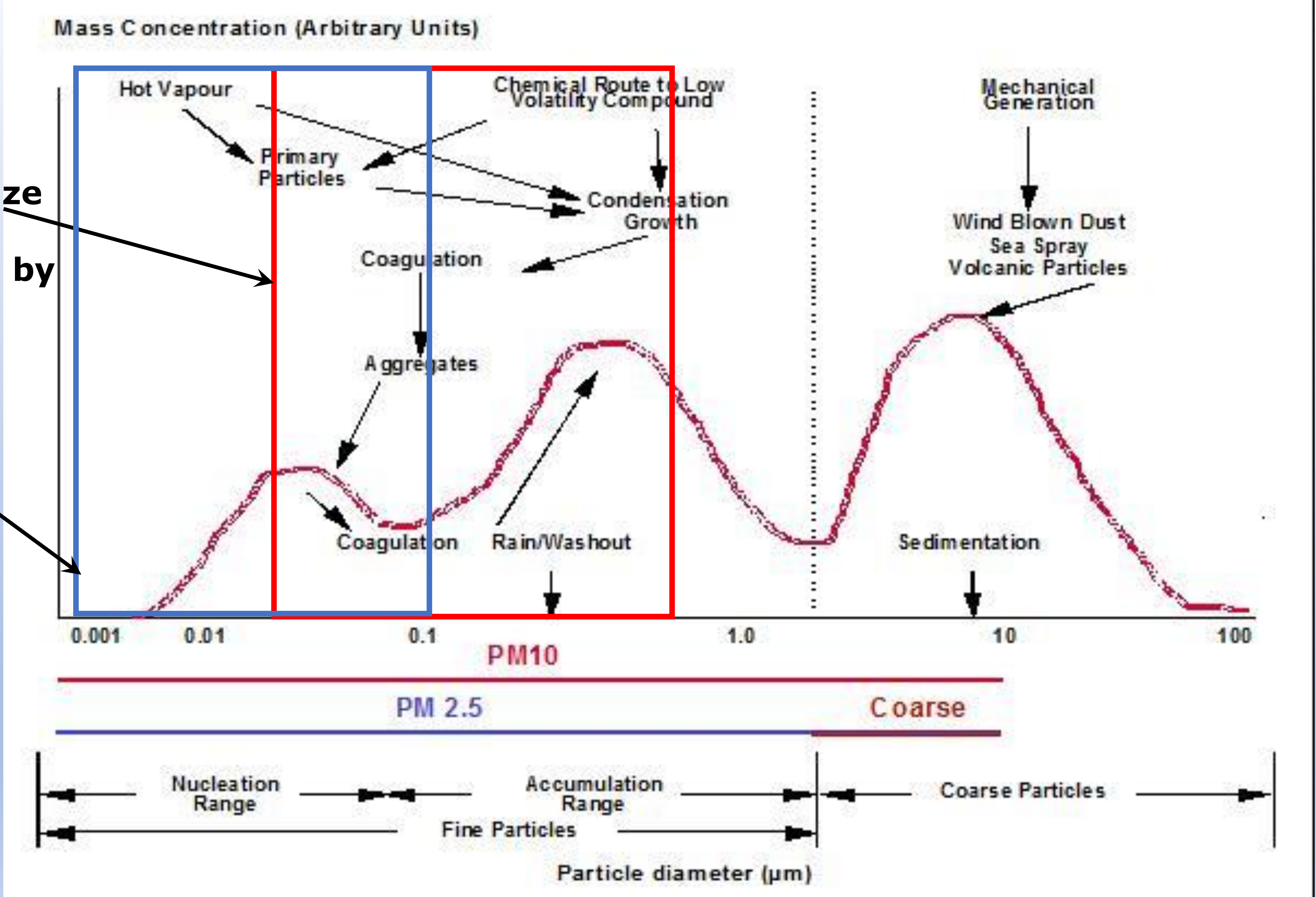
Designation	Diameter (nm)	Number of particles	Total Surface Area (mm^2)	Relative mass per particle
1 mm cube	1000000	1	6	1
PM_{10}	10000	1000000	600	$1x10^{-8}$
$PM_{2.5}$	2500	64000000	2400	$3.91x10^{-11}$
PM_1	1000	1000000000	6000	$1x10^{-12}$
SMPS ultrafines (largest)	604.3	4531502430	9929	$1.3336x10^{-13}$
$PM_{0.1}$	100	1000000000000	60000	$1x10^{-16}$
SMPS ultrafines (smallest)	16.55	220600252736195	362538	$7.5023x10^{-20}$

A trip down "Memory Lane".

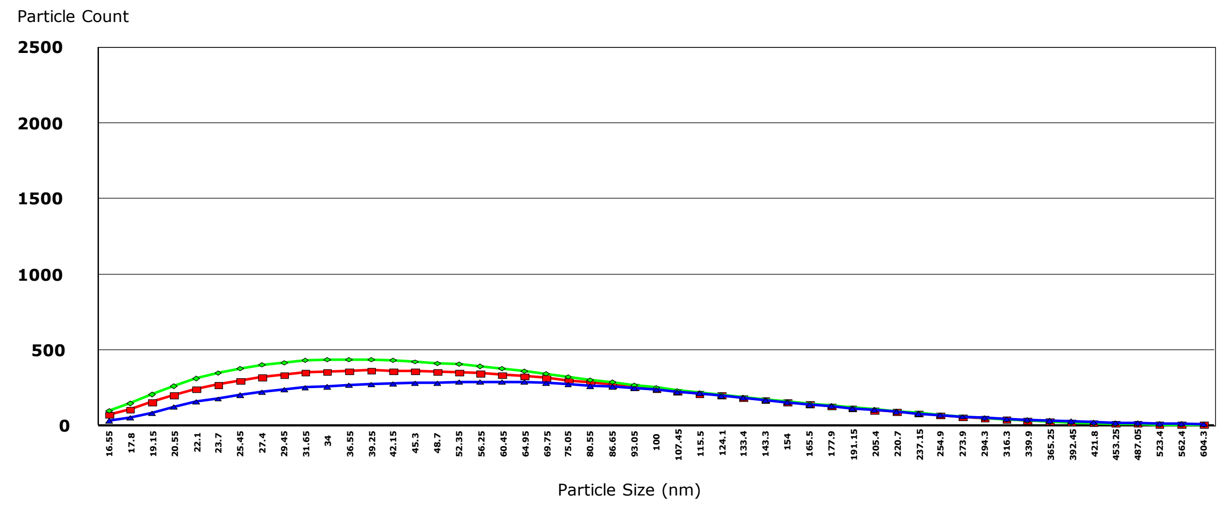


Particle size range measured by SMPS

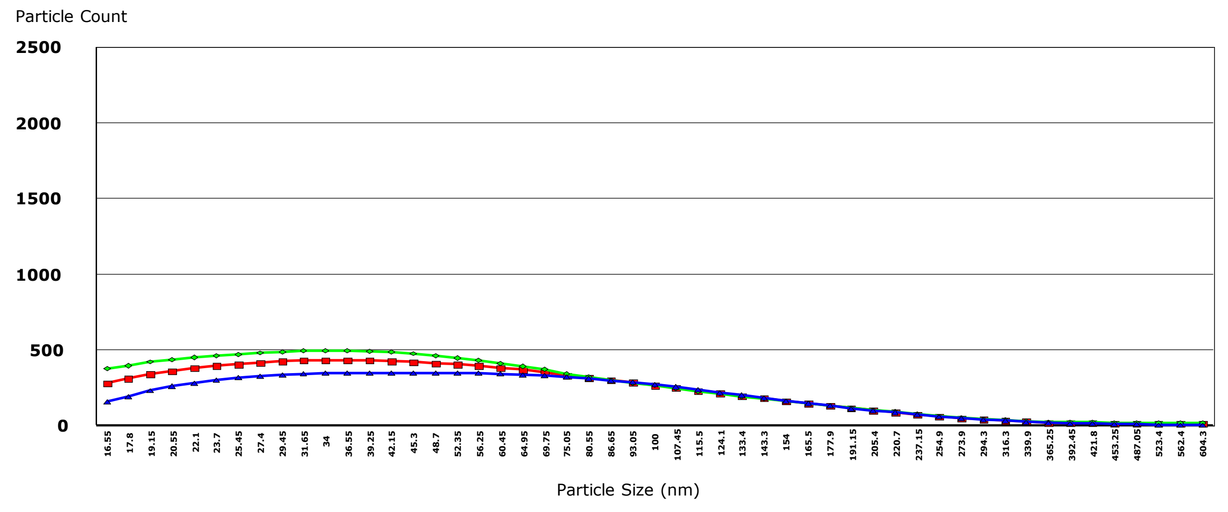
"True" ultrafines



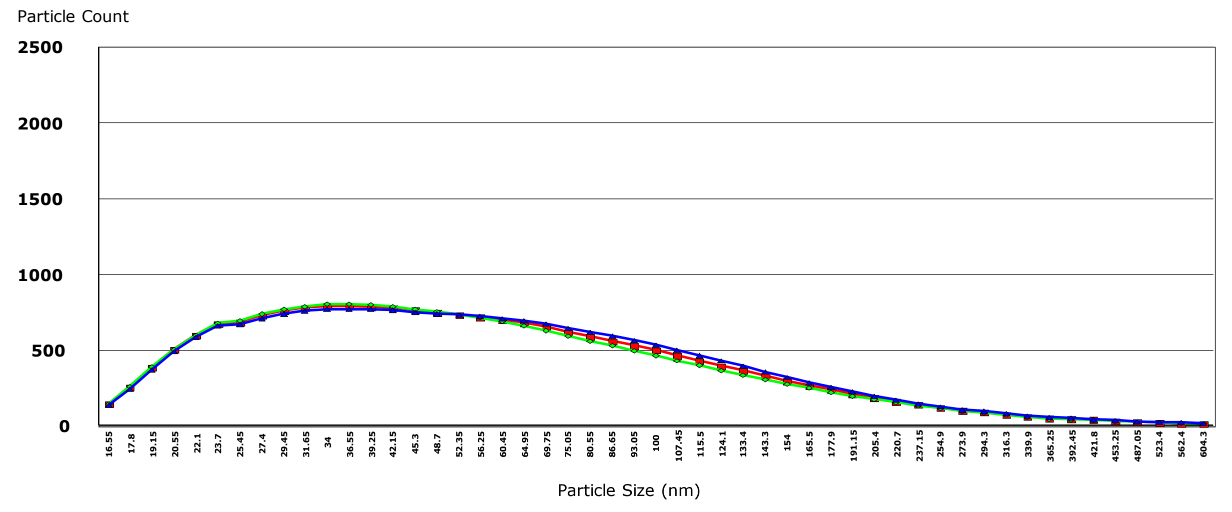
Particle numbers and distribution.



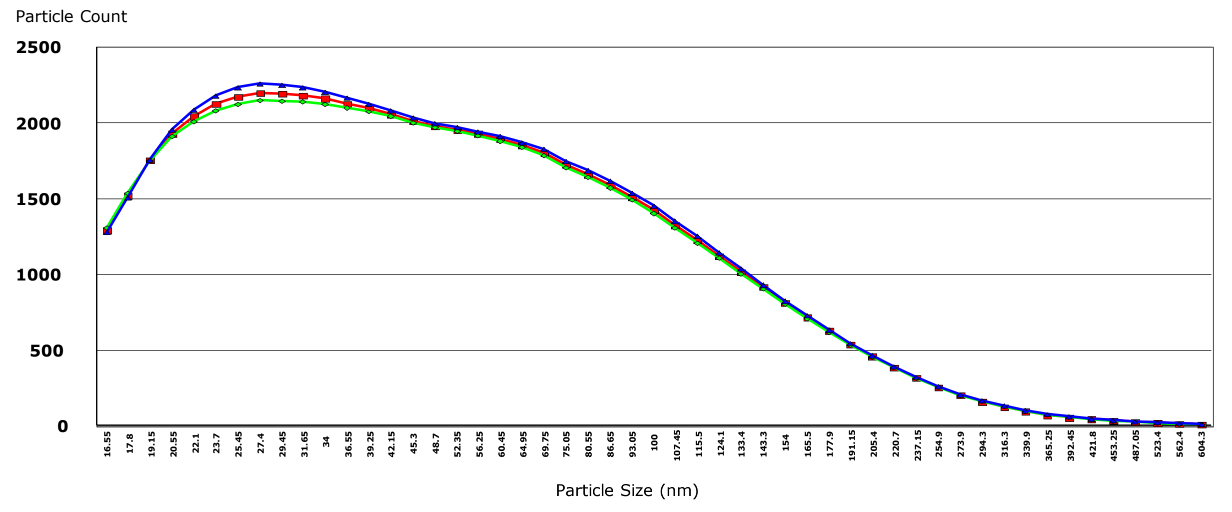
Harwell



Chilbolton Observatory

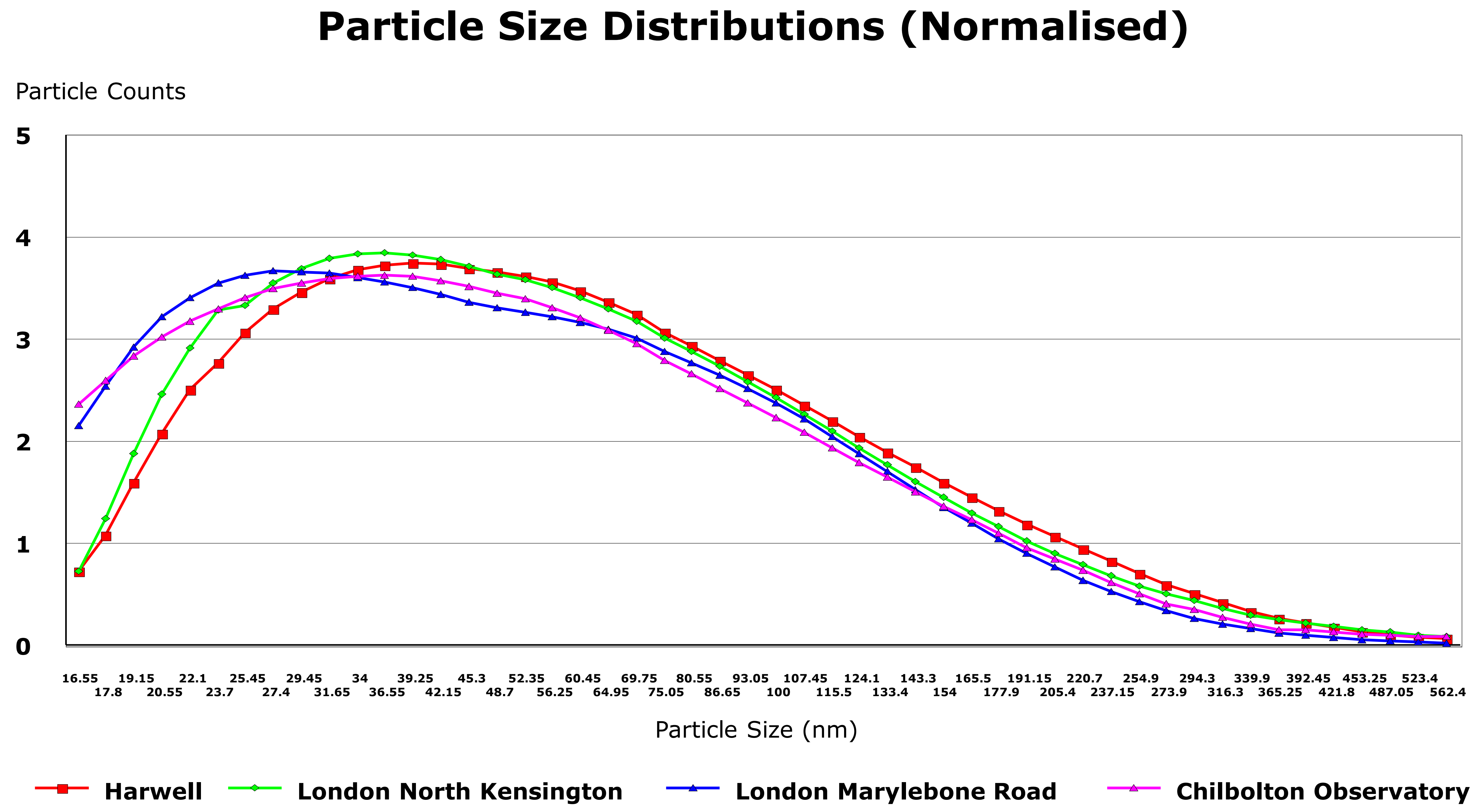


London North Kensington



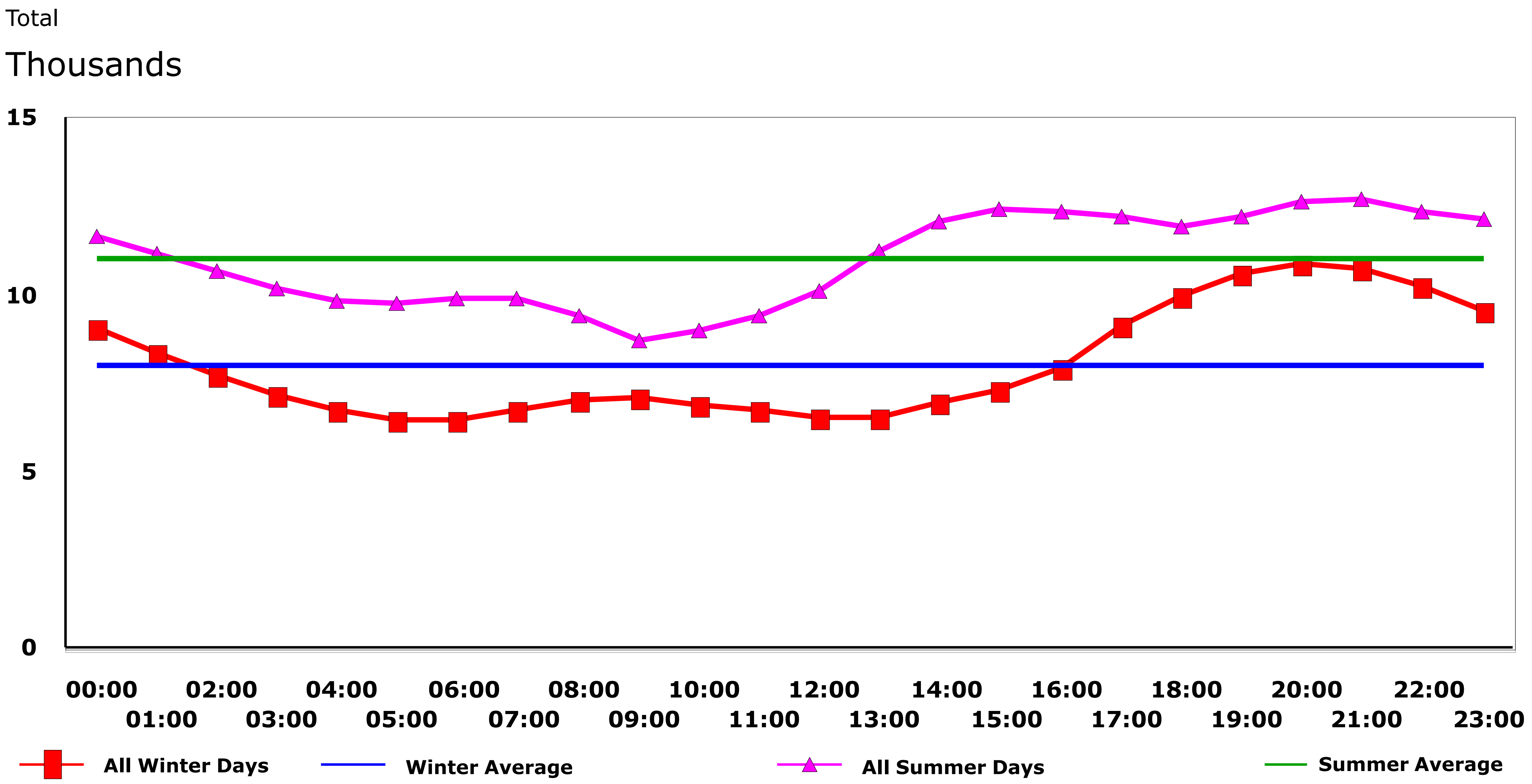
London Marylebone Road

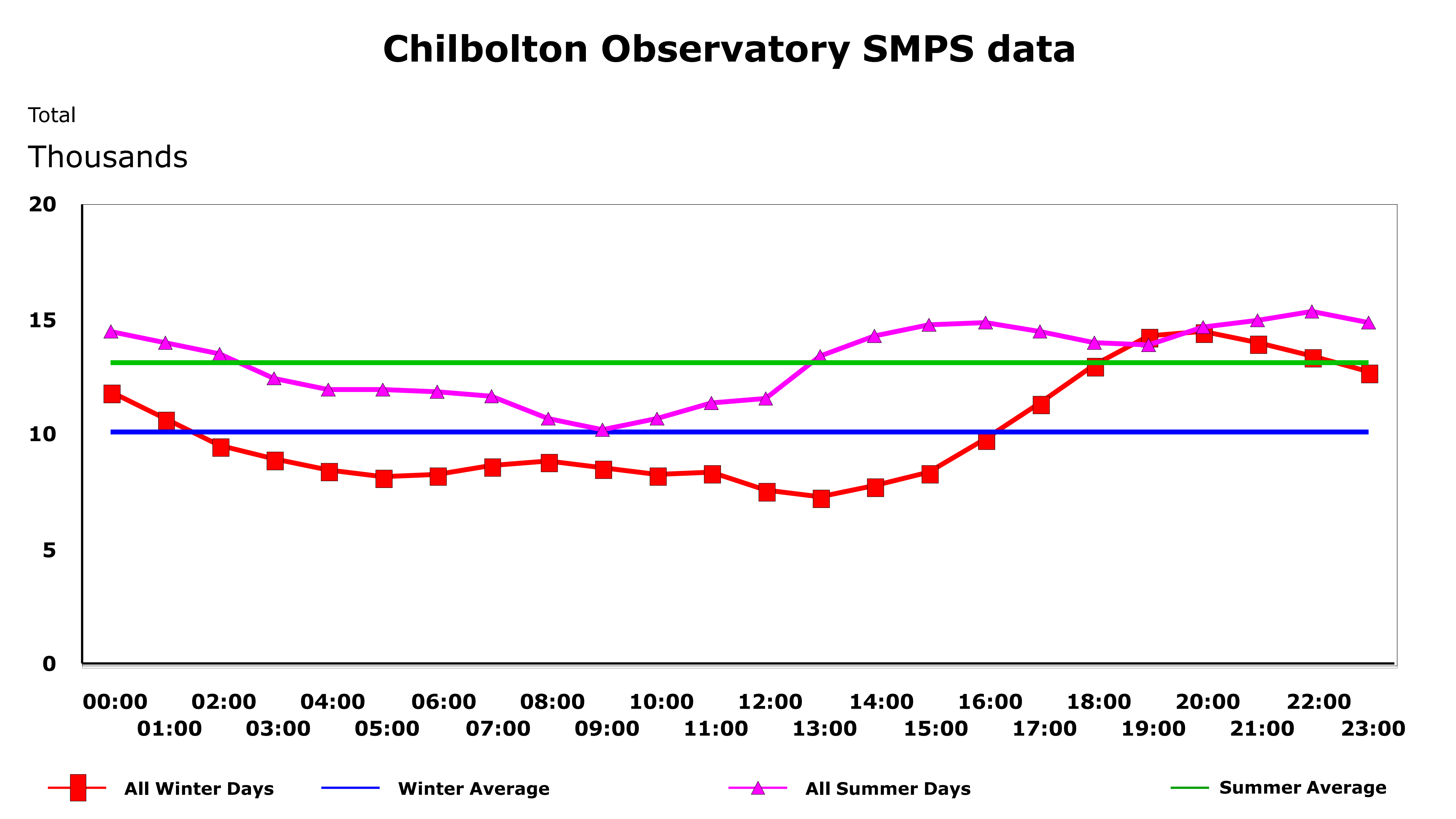
All Years Average — Summer Average — Winter Average



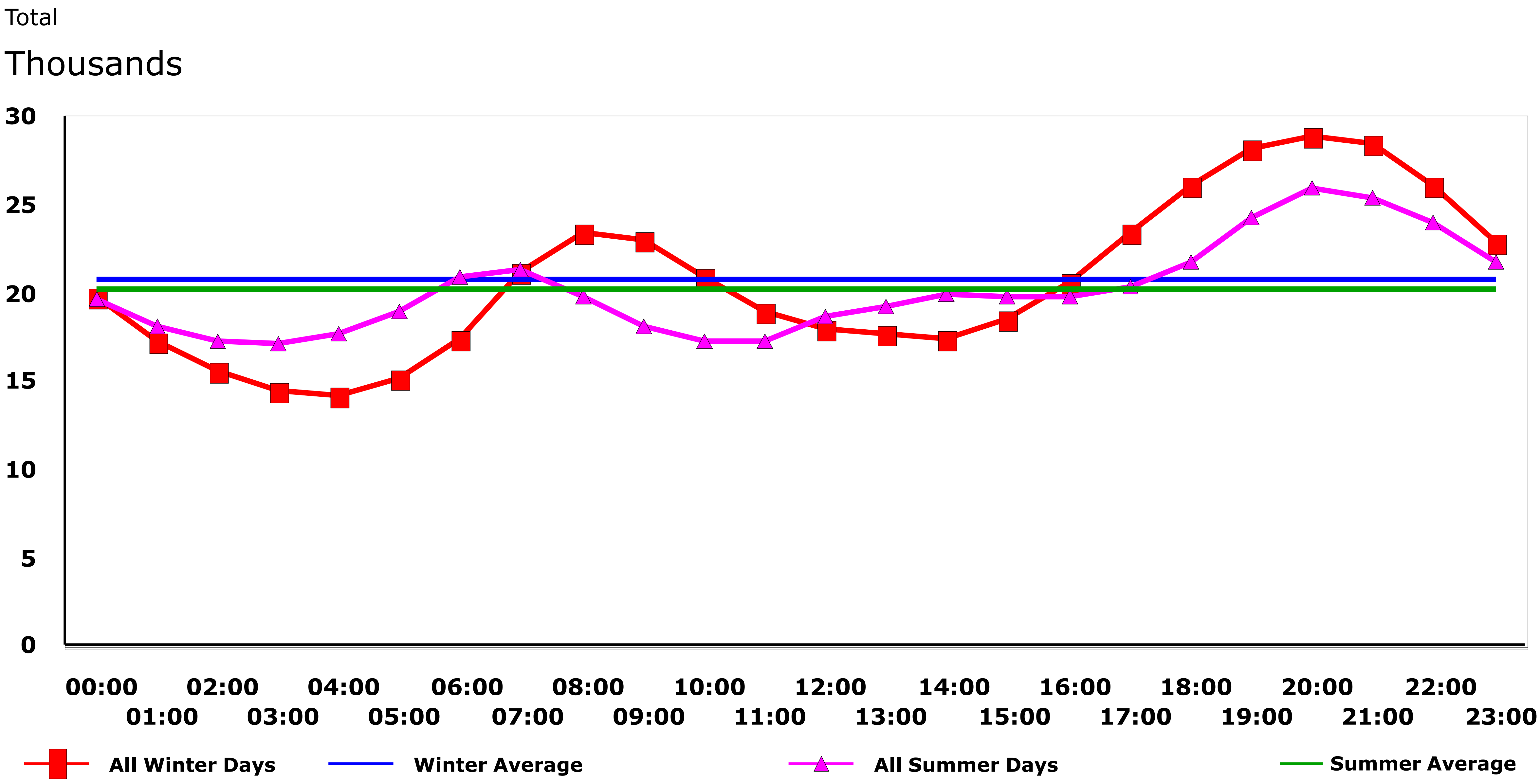
Particle Size Distributions (Normalised)
Particle Counts
5
4
3
2
1
0
16.55 17.8 19.15 20.55 22.1 23.7 25.45 27.4 29.45 31.65 34 36.55 39.25 42.15 45.3 48.7 52.35 56.25 60.45 64.95 69.75 75.05 80.55 86.65 93.05 100 107.45 115.5 124.1 133.4 143.3 154 165.5 177.9 191.15 205.4 220.7 237.15 254.9 273.9 294.3 316.3 339.9 365.25 392.45 421.8 453.25 487.05 523.4 562.4
Particle Size (nm)
Harwell
London North Kensington
London Marylebone Road
Chilbolton Observatory

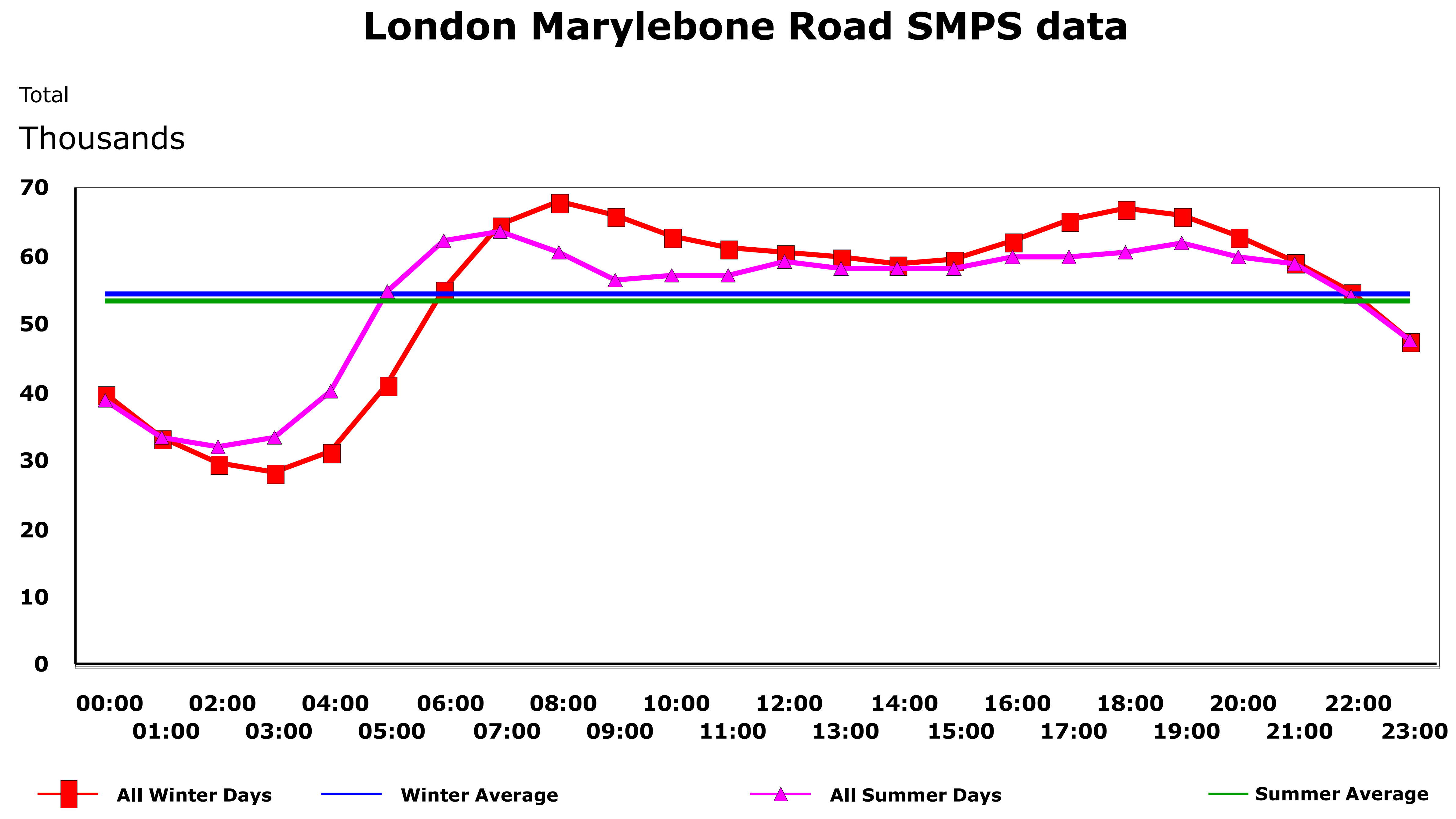
Harwell SMPS data




Chilbolton Observatory SMPS data
Total
Thousands
20
15
10
5
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
All Winter Days
Winter Average
All Summer Days
Summer Average

London North Kensington SMPS data



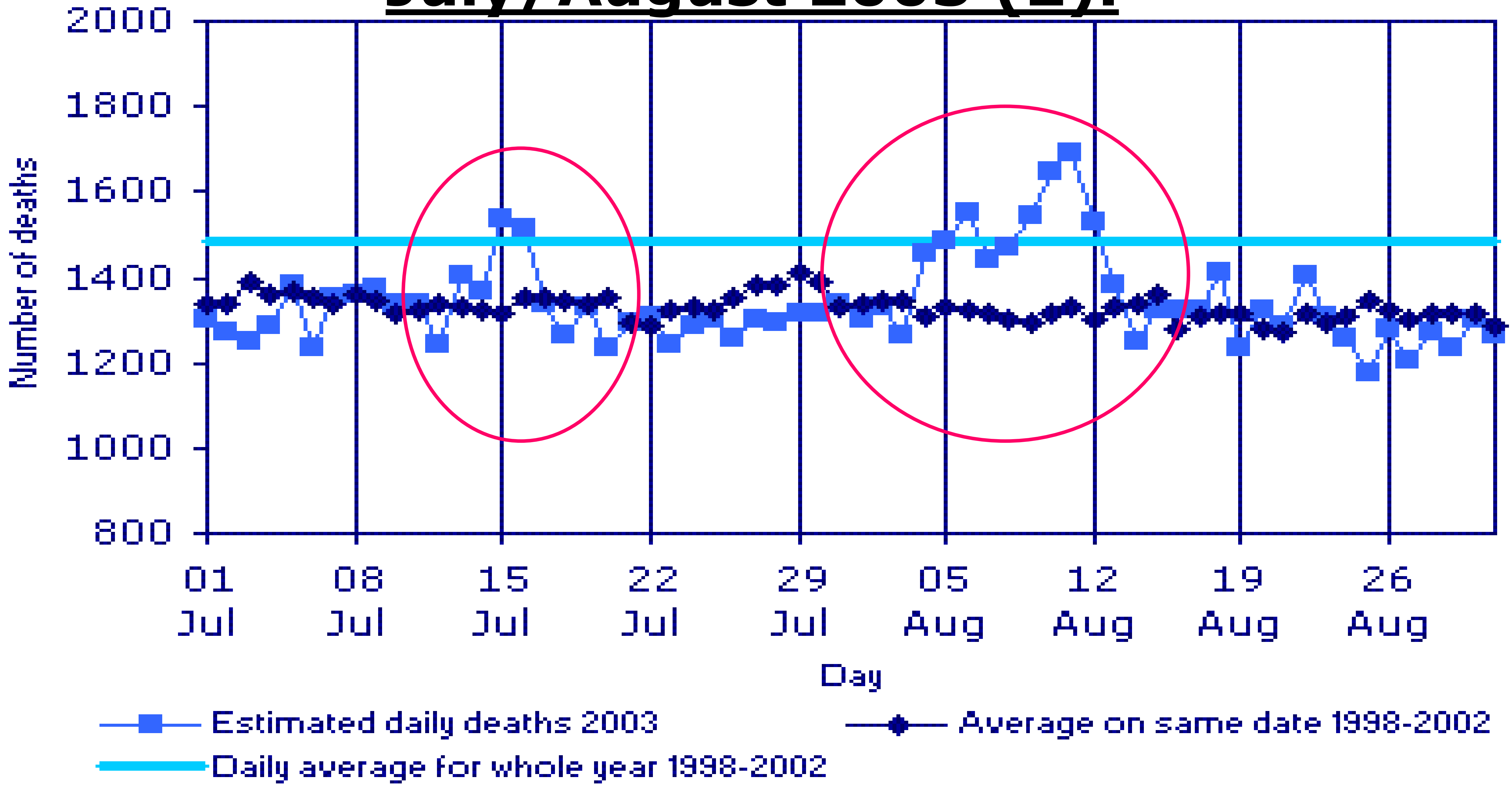

London Marylebone Road SMPS data
Total
Thousands
70
60
50
40
30
20
10
0
00:00
01:00
02:00
03:00
04:00
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
All Winter Days
Winter Average
All Summer Days
Summer Average

July/August 2003 (1).

A summer with two particular instances of unusual mortality in July and August.

Both periods were characterised by high temperatures, high insolation and high concentrations of O_3, PM_{10} and $PM_{2.5}$.

July/August 2003 (2).



July/August 2003 (3).

Between 423 and 769 of the 2045 excess deaths in August have been attributed to elevated concentrations of PM_{10} and ozone.

(Stedman, Atmospheric Environment, Volume 38, Issue 8, March 2004, Pages 1087-1090).

BUT during this period concentrations of ultrafines were very much lower than normal.

July/August 2003 (4).

Normally high levels of insolation encourage NFP.

(Reche C. *et al*, 2011.)

Were the low concentrations of UfPs during this period due to condensation of precursors on the larger particles?

Elevated total particles & other pollutants.

	London Marylebone Road 2007 - 2018		London North Kensington 2007 - 2018		Harwell 2007 - 2015	
	Number of occurrences	Percentage of concurrent data	Number of occurrences	Percentage of concurrent data	Number of occurrences	Percentage of concurrent data
1,3 Butadiene	1614	3.72%	N/A	N/A	23527	50.01%
Benzene	2938	5.96%	N/A	N/A	17807	36.48%
PM_{10}	3173	5.01%	9183	13.76%	24204	51.84%
NO_2	4973	7.57%	11796	14.99%	16342	32.22%
Ozone	182	0.28%	7701	12.57%	29904	53.50%
$PM_{2.5}$	2635	4.29%	9026	14.73%	21451	42.50%
SO_2	4488	7.11%	6444	10.96%	8844	16.03%
UV Particulate Matter	1158	2.09%	7422	12.62%	7525	17.82%
Black carbon	4761	8.60%	10020	13.44%	12276	29.06%

Elevated total particles and <100nm particles.

	Number of occurrences	Percentage of data
London Marylebone Road 2007 - 2018	14402	97.39%
London North Kensington 2007 - 2018	10625	90.69%
Harwell 2007 - 2015	7332	76.54%
Chilbolton Observatory 2016 - 2018	1885	99.32%

Correlation coefficients.

	1,3 Butadiene	Benzene	PM_{10}	NO_2	Ozone	$PM_{2.5}$	SO_2	UV Particulate Matter	Black carbon
London Marylebone Road									
All Days	0.46	0.54	0.45	0.52	-0.34	0.40	0.46	0.19	0.66
Summer	0.47	0.58	0.65	0.65	0.17	0.47	0.41	0.07	0.30
Winter	0.46	0.51	0.49	0.54	-0.36	0.35	0.53	0.18	0.67
London North Kensington									
All Days	N/A	N/A	0.46	0.59	-0.31	0.17	0.27	0.21	0.19
Summer	N/A	N/A	0.35	0.49	-0.23	0.21	0.18	0.13	0.28
Winter	N/A	N/A	0.51	0.68	-0.58	0.49	0.34	0.27	0.13
Harwell									
All Days	0.05	0.27	0.41	0.46	-0.17	0.33	0.18	0.39	0.48
Summer	-0.04	0.28	0.33	0.46	0.04	0.26	0.22	0.13	0.31
Winter	0.30	0.46	0.51	0.60	-0.42	0.44	0.19	0.26	0.65

Some Questions/Complications.

- **Are the sources of ultrafines the same (or similar) at different types of location?**

- **If not, how do they differ?**

- **Insolation encourages formation of UfPs, but particles <15 nm may form during cool evenings by condensation processes involving traffic emissions.**

(Harrison R M et al, 2019.)

- **Is it possible that measures to reduce PM_{10}/$PM_{2.5}$ are actually contributing to ultrafines?**

Some Answers?

- **There are almost certainly some similar sources at most/all locations but also some that differ. The balance between regional nucleation (NPF) and primary emissions needs careful consideration.**

(Reche C *et al*, 2001, Bousiotis D *et al*, 2019)

- **Airports have been identified as important primary UfP sources and emissions can be discriminated by very small size mode.**

(Masiol M *et al*, 2017, Harrison R M *et al*, 2019.)

- **The possibility exists that DPFs reduce emissions of PM_{10}/$PM_{2.5}$ but at the cost of "producing" UfPs.**

- **Higher summer concentrations of UfPs generally and "true" UfPs at Chilbolton are likely to be consequence of NPF.**

Conclusions (1).

- **Particles are probably responsible for a range of adverse health outcomes.**

- **Particles are quite possibly responsible for both chronic and acute health outcomes.**

- **Different components of the particle “mix” are almost certainly responsible for different outcomes.**

Conclusions (2).

- **Ultrafine particles represent a large proportion of the number of particles in any sample of air but only a small proportion of the mass.**

- **Inhaled ultrafine particles have been shown to enter the bloodstream shortly after exposure, with the smallest particles entering most rapidly, and to persist for at least three months.**

(Miller M R *et al*, 2012, Miller M R *et al*, 2017.)

- **There is a great deal of work to be done both in understanding the behaviour of ultrafine particles in the atmosphere and on their health effects.**

Some "light" reading.

Harrison R M *et al*, Atmos. Chem. Phys., 19, 39–55, 2019; https://doi.org/10.5194/acp-19-39-2019.

Bousiotis D *et al*, Atmos. Chem. Phys., 19, 5679–5694, 2019; https://doi.org/10.5194/acp-19-5679-2019.

Reche C *et al*, Atmos. Chem. Phys., 11, 6207–6227, 2011; www.atmos-chem-phys.net/11/6207/2011/ doi:10.5194/acp-11-6207-2011.

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Stone V *et al*, Environmental Health Perspectives, Volume 127, Issue 10, October 2017.

Donaldson K *et al*, Environmental Health Perspectives, Volume 109, SUPPLEMENT 4, August 2001.

Maher B A *et al*, Proc Natl Academy Sci USA September 27, 2016 113 (39) 10797-10801; https://doi.org/10.1073/pnas.1605941113.

Miller M R *et al*, Future Cardiology. (2012) 8(4), 577–602.

Miller M R *et al*, ACS Nano 2017, 11, 4542−4552.

White Paper – Ambient Ultrafine Particles: evidence for policy makers. https://my.syncplicity.com/share/cvlw3fqocyk224u/WHITE%20PAPER-UFP%20evidence%20for%20policy%20makers%20(25%20OCT)

Thank you.

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