Atmospheric Pollution

Lecture 6

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INTRODUCTION

Particles are one of the most important and certainly the most visible aspects of air pollution.

The effects span the areas of health (1% increase in mortality per 10 μg m^{-3}); acid rain, visibility degradation, radiation and photochemistry and cloud microphysics changes (and thus climate changes), and the Antarctic ozone hole.

NOMENCLATURE

Particle refers to a solid or liquid, larger than a molecule, diameter > 0.01 μm, but small enough to remain in the atmosphere for a reasonable time, diameter < 100 μm.

Aerosol is a suspension of particles in a gas

AEROSOLS IN THE ATMOSPHERE

Aerosols are tiny solid or liquid particles suspended in the atmosphere.

Aerosols are generated both naturally and as a result of human activities.

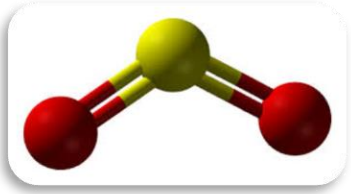
Atmospheric Aerosol

75% of total mass from natural or anthropogenic sources (primary)

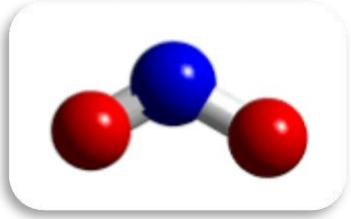
Sea spray (40%)

Combustion and other industry (5%)

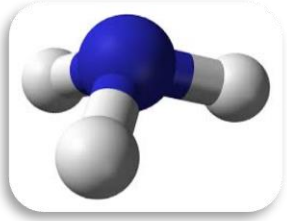
25% of total mass from conversion of gaseous constituents to small particles by photochemical and other chemical processes.



SO_2



NO_2



NH_3

Aerosols such as salt, dust and black carbon come in numerous shades depending on their chemical composition.

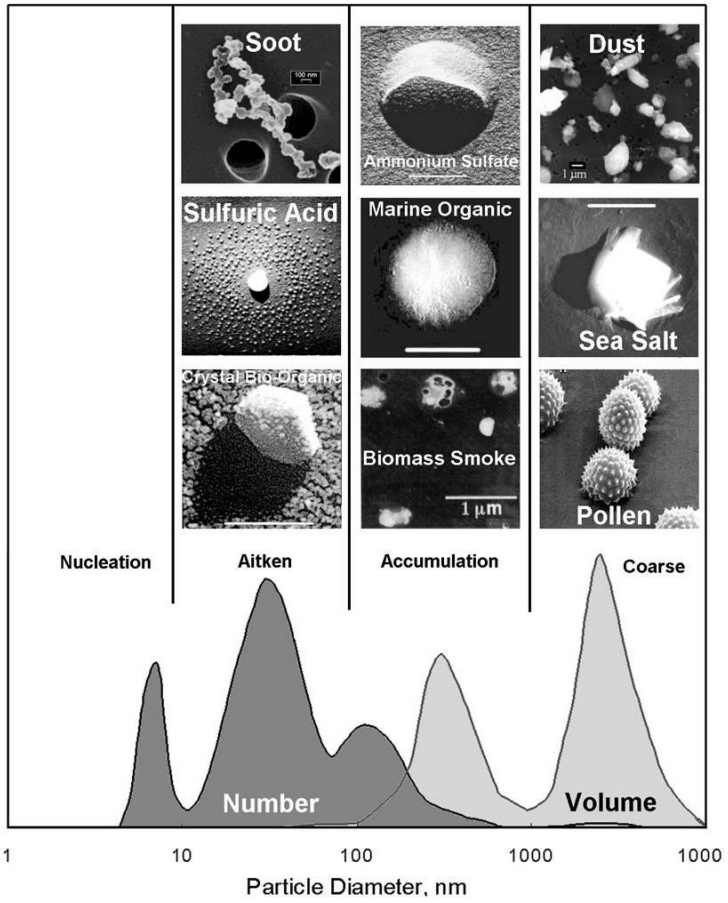
The Aerosol Modes

Aitken mode – 0.01-0.1 μm

Accumulation mode (Large Nuclei) – 0.1-1 μm

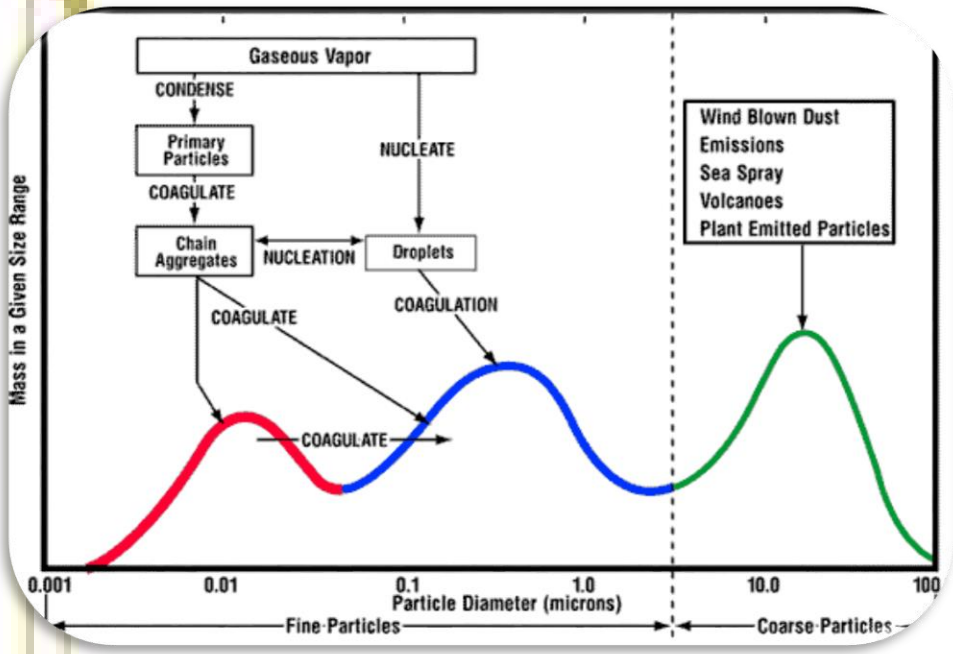
Coarse mode - >1 μm

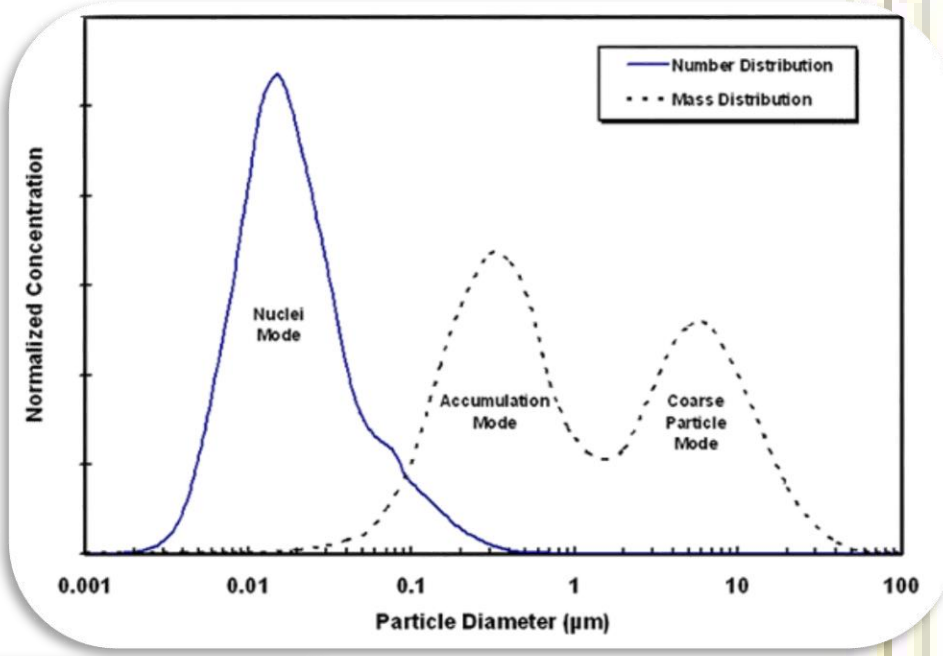
and sometimes, the elusive nucleation mode <0.01 μm

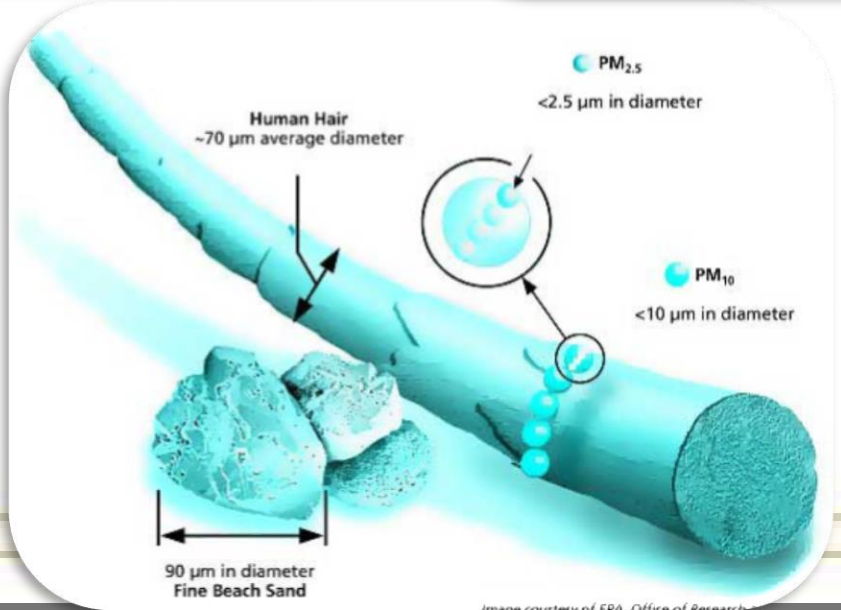


Thought accumulation mode to be most important in natural cloud formation

These particles range in size from less than 0.01µm to greater then 10µm



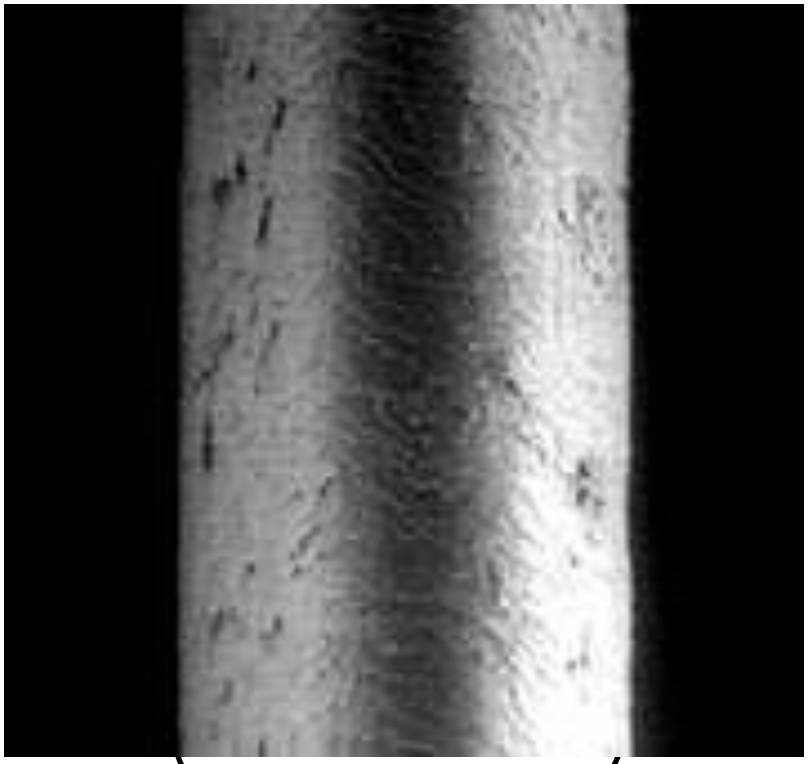




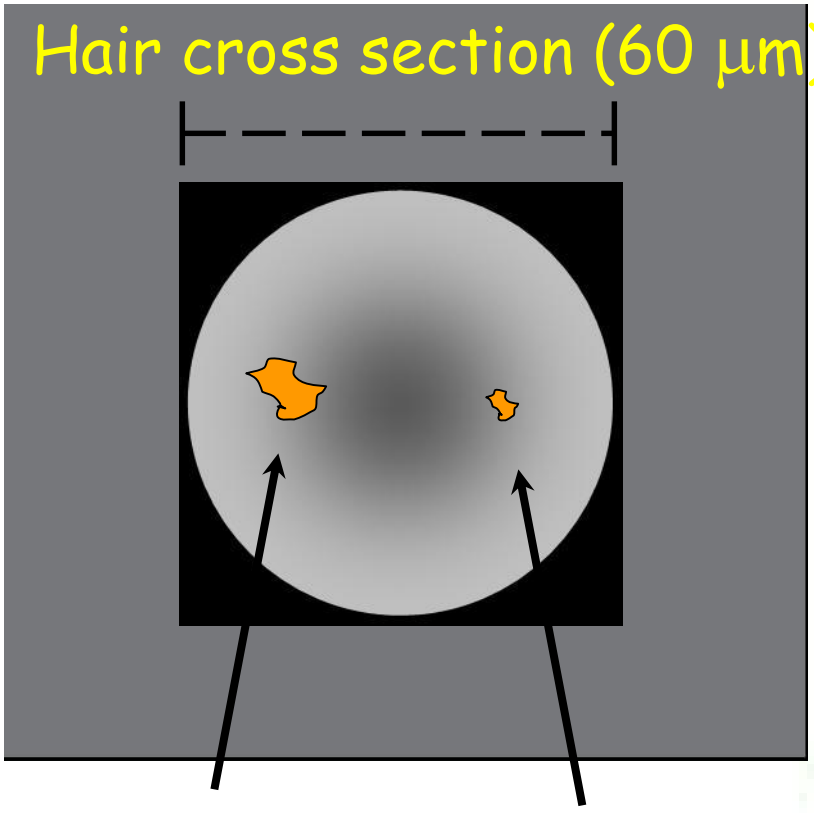
Atmospheric Aerosol Sizes

Aerosol can be as small as 0.001 μm to as large as 10 μm. They vary spatially due to the local conditions.

Air Quality Monitoring



Human Hair
(60 μm diameter)



PM_{10}
(10 μm)

$PM_{2.5}$
(2.5 μm)

Total suspended particles (TSP)

PM_{10} – thoracic particles

$PM_{2.5}$ – respirable particles

There are two PM_{10} standards,

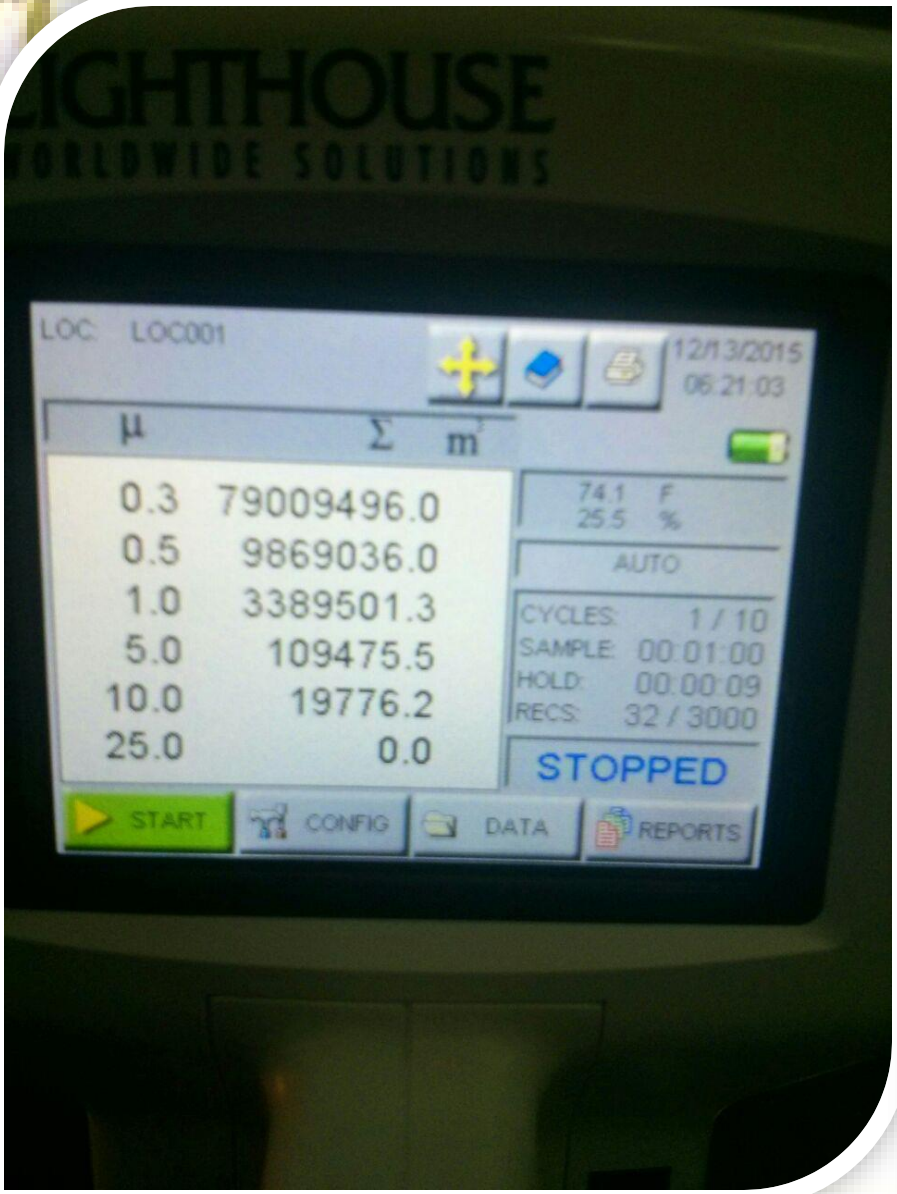
a 24-hour standard and an annual standard.

These standards are:

150 micrograms per cubic meter ($\mu g/m^3$) for the 24 hour standard

50 micrograms per cubic meter ($\mu g/m^3$) for the annual standard

Primary/ Secondary	Indicator	Averaging Time	Level [1]
Primary	TSP [2]	24-hour	260 μg/m^3
		Annual	75 μg/m^3
Secondary	TSP	24-hour	150 μg/m^3
		Annual	60 μg/m^3
Primary	$PM_{2.5}$	Annual	12.0 μg/m^3
Secondary		Annual	15.0 μg/m^3
Primary and Secondary		24-hour	35 μg/m^3
Primary and Secondary	PM_{10}	24-hour [2]	150 μg/m^3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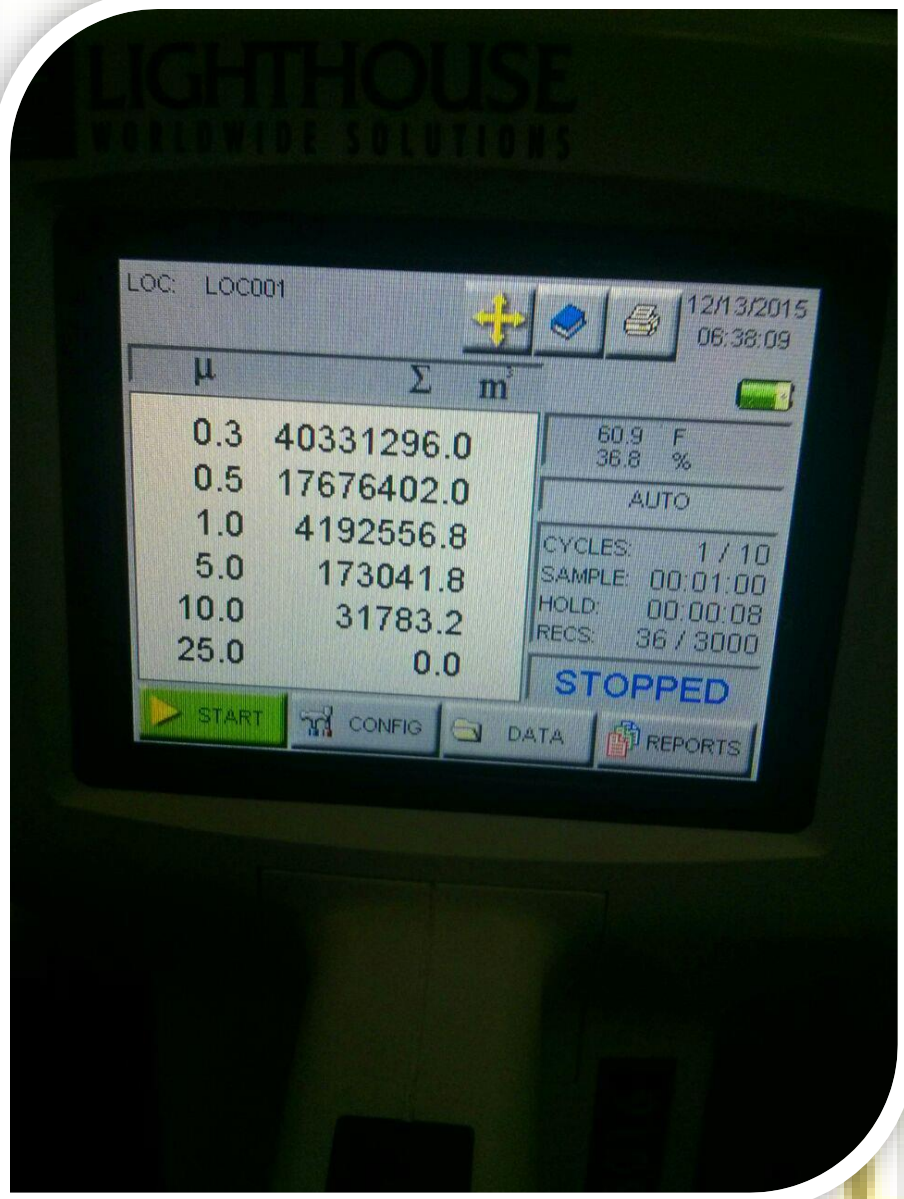
12/13/2015
06:21:03
μ Σ m³
0.3 79009496.0
0.5 9869036.0
1.0 3389501.3
5.0 109475.5
10.0 19776.2
25.0 0.0
74.1 F
25.5 %
AUTO
CYCLES: 1 / 10
SAMPLE: 00:01:00
HOLD: 00:00:09
RECS: 32 / 3000
STOPPED
START
CONFIG
DATA
REPORTS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0.5 17676402.0
1.0 4192556.8
5.0 173041.8
10.0 31783.2
25.0 0.0
60.9 F
36.8 %
AUTO
CYCLES: 1 / 10
SAMPLE: 00:01:00
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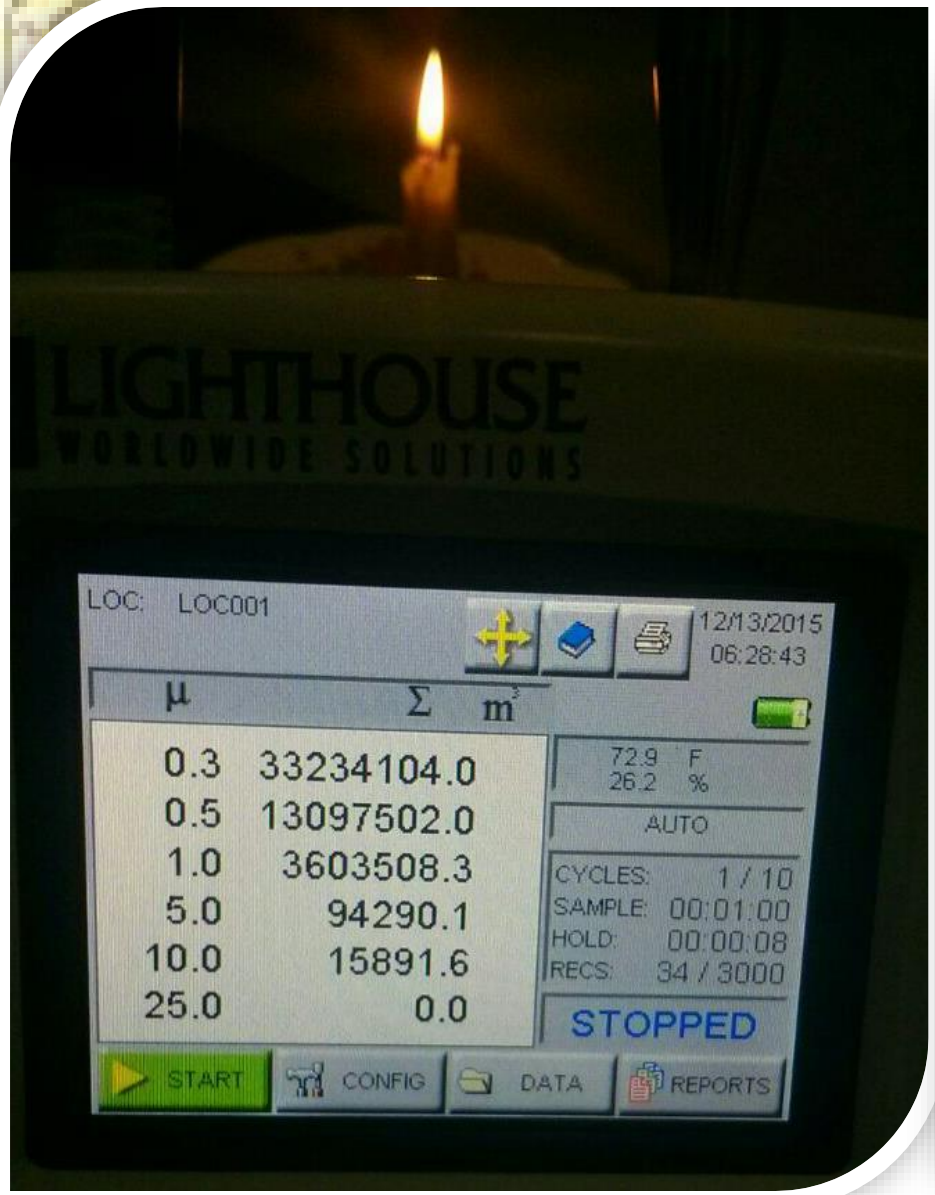
START
CONFIG
DATA
REPORTS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0.3 33234104.0
0.5 13097502.0
1.0 3603508.3
5.0 94290.1
10.0 15891.6
25.0 0.0
72.9 F
26.2 %
AUTO
CYCLES: 1 / 10
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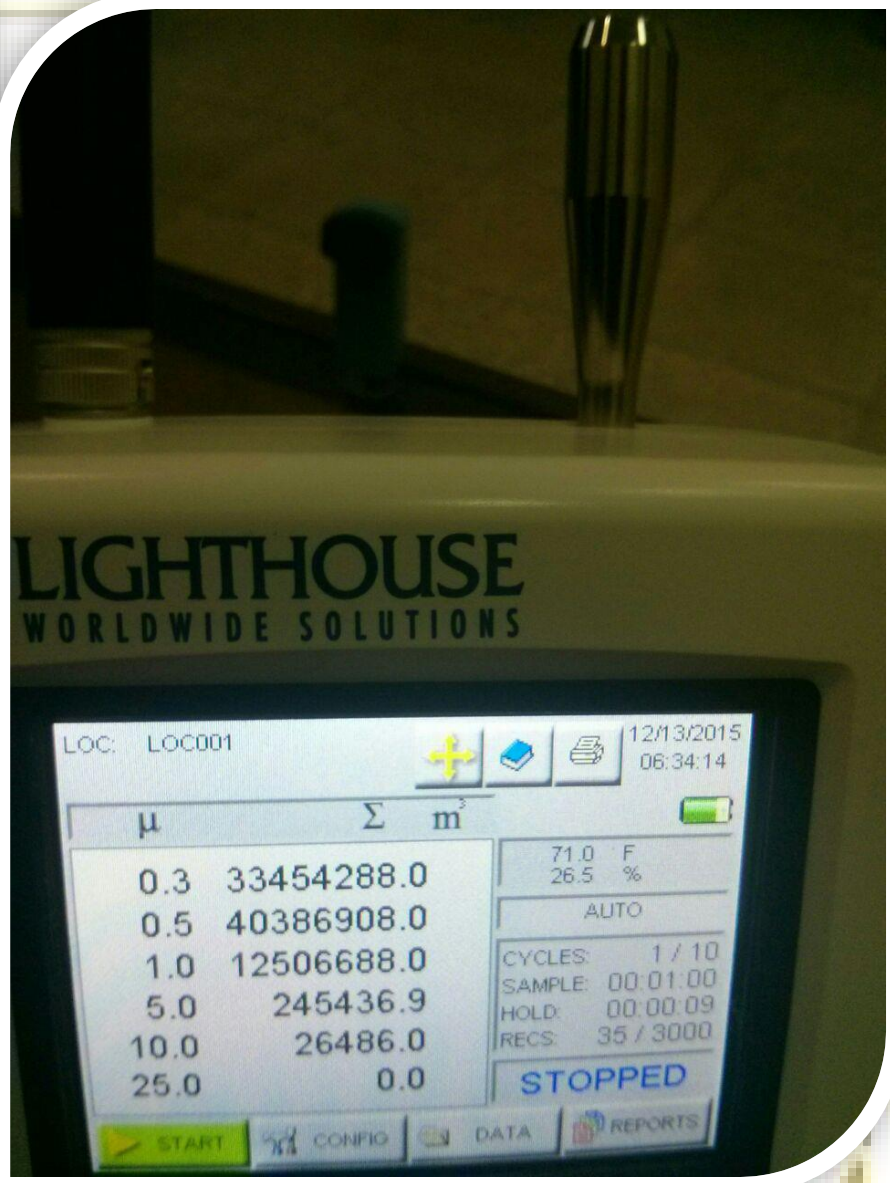
REPORTS


LIGHTHOUSE
WORLDWIDE SOLUTIONS
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12/13/2015
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μ Σ m³
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0.5 40386908.0
1.0 12506688.0
5.0 245436.9
10.0 26486.0
25.0 0.0
71.0 F
26.5 %
AUTO
CYCLES: 1 / 10
SAMPLE: 00:01:00
HOLD: 00:00:09
RECS: 35 / 3000
STOPPED
START
CONFIG
DATA
REPORTS

Urban Aerosol

Anthropogenic sources

Stationary sources: power plants, refinery plants, mines, etc.

Motor vehicles

Combustion – very important source

Particle concentration

A few tens of $\mu g/m^3$ to 1 mg/m^3 in heavily polluted areas

Hazes produced by the urban aerosol in Mumbai, India and Guangzhou, China

Data from: W.C. Hinds, Aerosol Technology, 2nd Edition

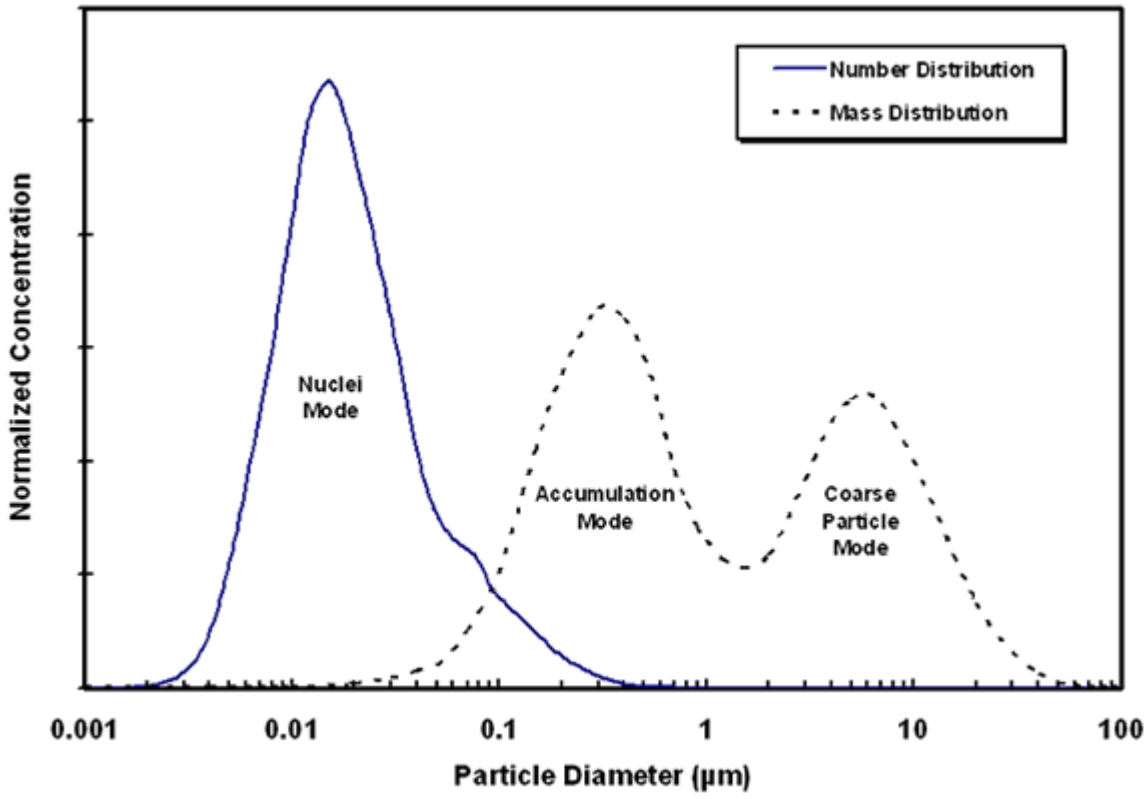
Urban Aerosol

Urban aerosol size distribution

Nuclei mode (0.001 – 0.1 μm)

Accumulation mode (0.1 – 2.5 μm)

Coarse-particle mode (2.5 – 100 μm)



Urban Aerosol

Nuclei Mode

Size: 0.001 – 0.1 μm

Combustion particles and gas-to-particle conversion

Location: near highways and combustion sources

High concentration

Rapid coagulation

Urban Aerosol

Accumulation Mode

Size: 0.1 – 2.5 μm

Combustion particles, smog particles, and coagulated nuclei mode particles

Slow coagulation

Accounts for most of the visibility effects

Fine particles

Nuclei + Accumulation mode

$PM_{2.5}$

Urban Aerosol

Coarse-Particle Mode

Size: 2.5 – 10 μm

Dusts, sea salts, particles from surface mining

Ready to settle down on the surface

$PM_{2.5}$, PM_{10}, and TSP

$PM_{2.5}$: < 2.5 μm

PM_{10}: <10 μm

TSP: total suspended particles

Which mode of aerosol has the longest lifetime in the atmosphere? Why?

Time For Particles to Fall 1 km

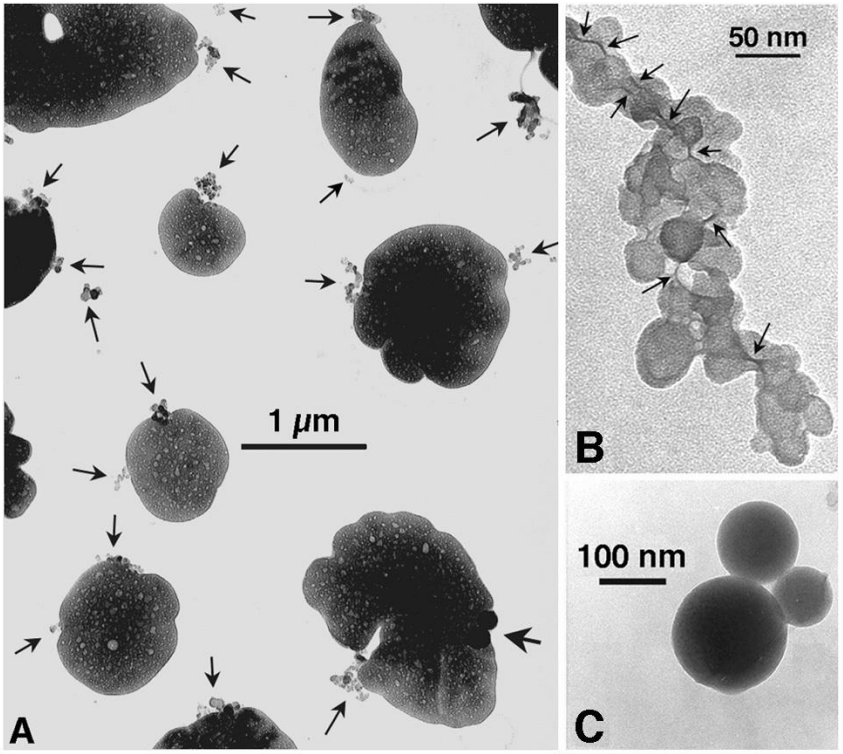
Particle Diameter (μm)	Time to Fall ١ km
٠/٠٢	٢٢٨ years
٠/١	٣٦ years
١/٠	٣٢٨ days
١٠/٠	٣/٦ days
١٠٠/٠	١/١ hours
١٠٠٠/٠	٤ minutes
٥٠٠٠/٠	١/٨ minutes

The spherical structures in image A are sulfates;

the arrows point to smaller chains of black carbon (image B).

Image C shows fly ash, a product of coal-combustion, that's often found in association with black carbon.

Electron Microscope



Credit: Peter Buseck, Arizona State University

There are many different types of atmospheric aerosol

chemical composition

physical properties

Dynamic Processes

Formation

Growth

Removal

Aerosols are ubiquitous and they have been the subjects of interest in many scientific investigations due to their dramatic effect on our environment

Importance

Aerosol particles are important components in the Earth's atmosphere

They can act as sites onto which cloud droplets and ice particles can form (precipitation)

Hygroscopic

Hydrophobic

They scatter and absorb radiation and so impact the heat balance of the atmosphere,

Adverse effect on human health in urban environments (pollutants)

Cloud Microphysics

Cloud condensation nuclei or CCNs or cloud seeds are small particles (typically 0.2 μm, or 1/100th the size of a cloud droplet) about which cloud droplets coalesce.

Water requires a non-gaseous surface to make the transition from a vapor to a liquid.

When no CCNs are present, water vapor can be supercooled below 0°C before droplets spontaneously form.

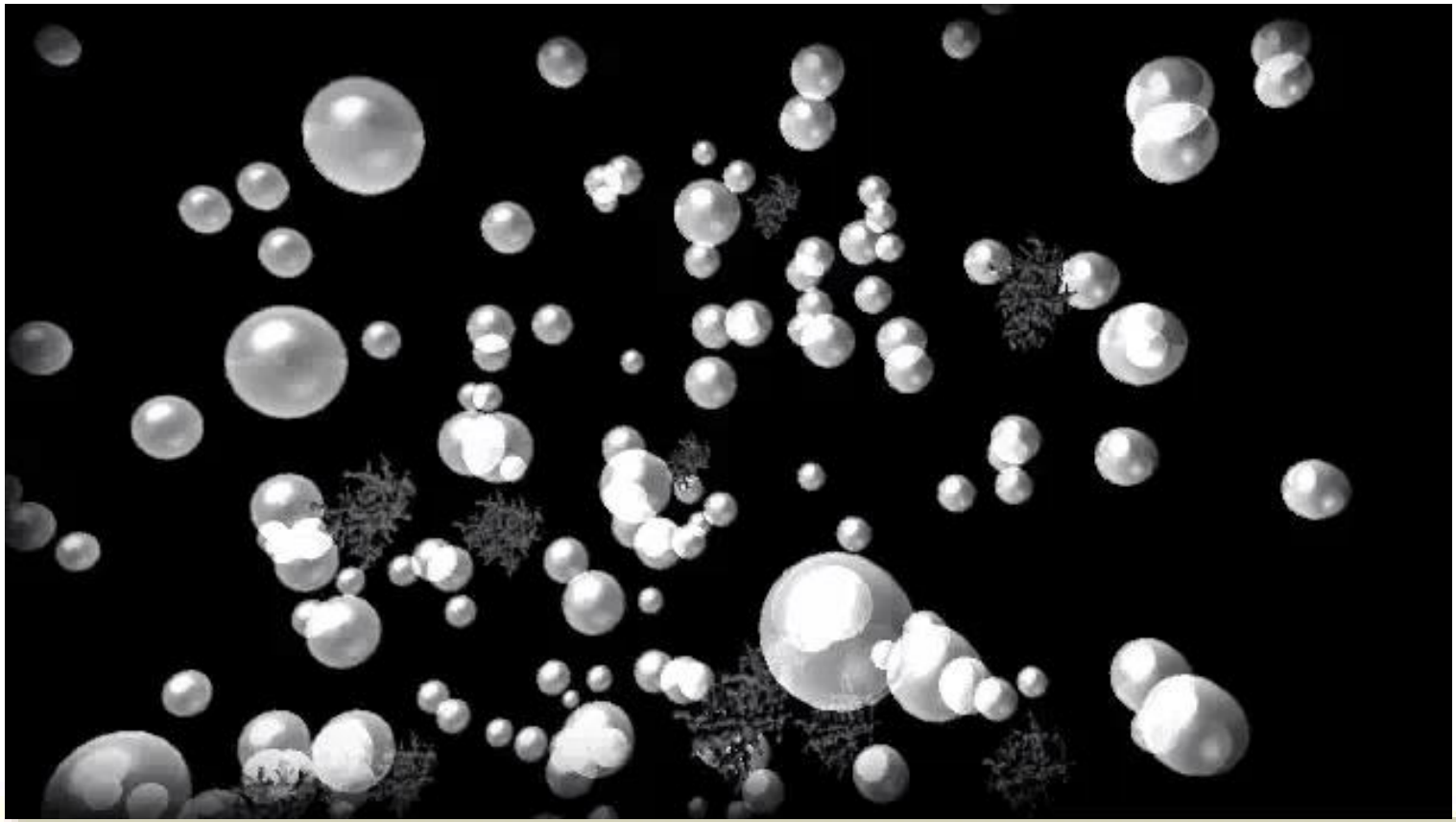
Cloud Condensation Nuclei - CCN

Comprises a small fraction of the total aerosol population

Sea salt is the predominant constituent of CCN with D > 1μm

For 0.1 μm < D < 1 μm, the main component is thought to be sulfate, which may be present as sulfuric acid, ammonium sulfate, or from phytoplankton produced dimethylsulfide (see Charlson et al., *Nature*, 326, 655-661).

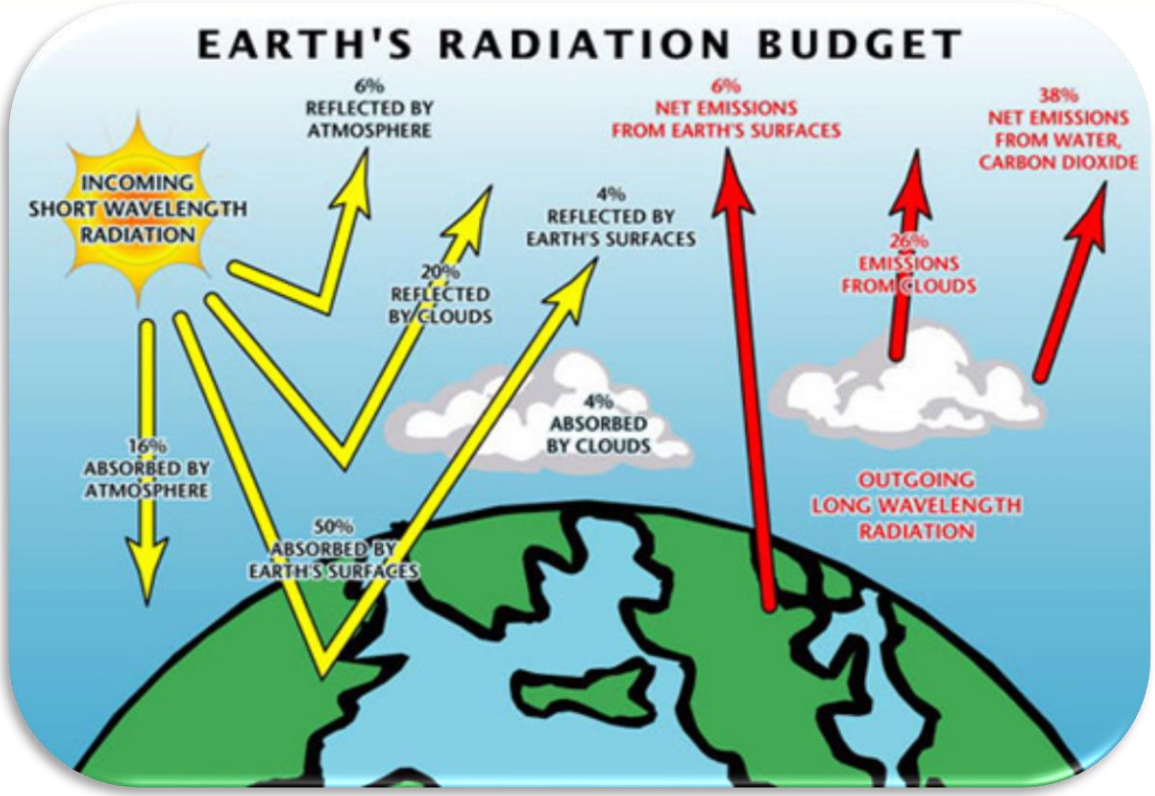
Water droplet cling to aerosol particles, creating a larger water droplet



Without the presence of aerosols

to act as CCN for water droplets,

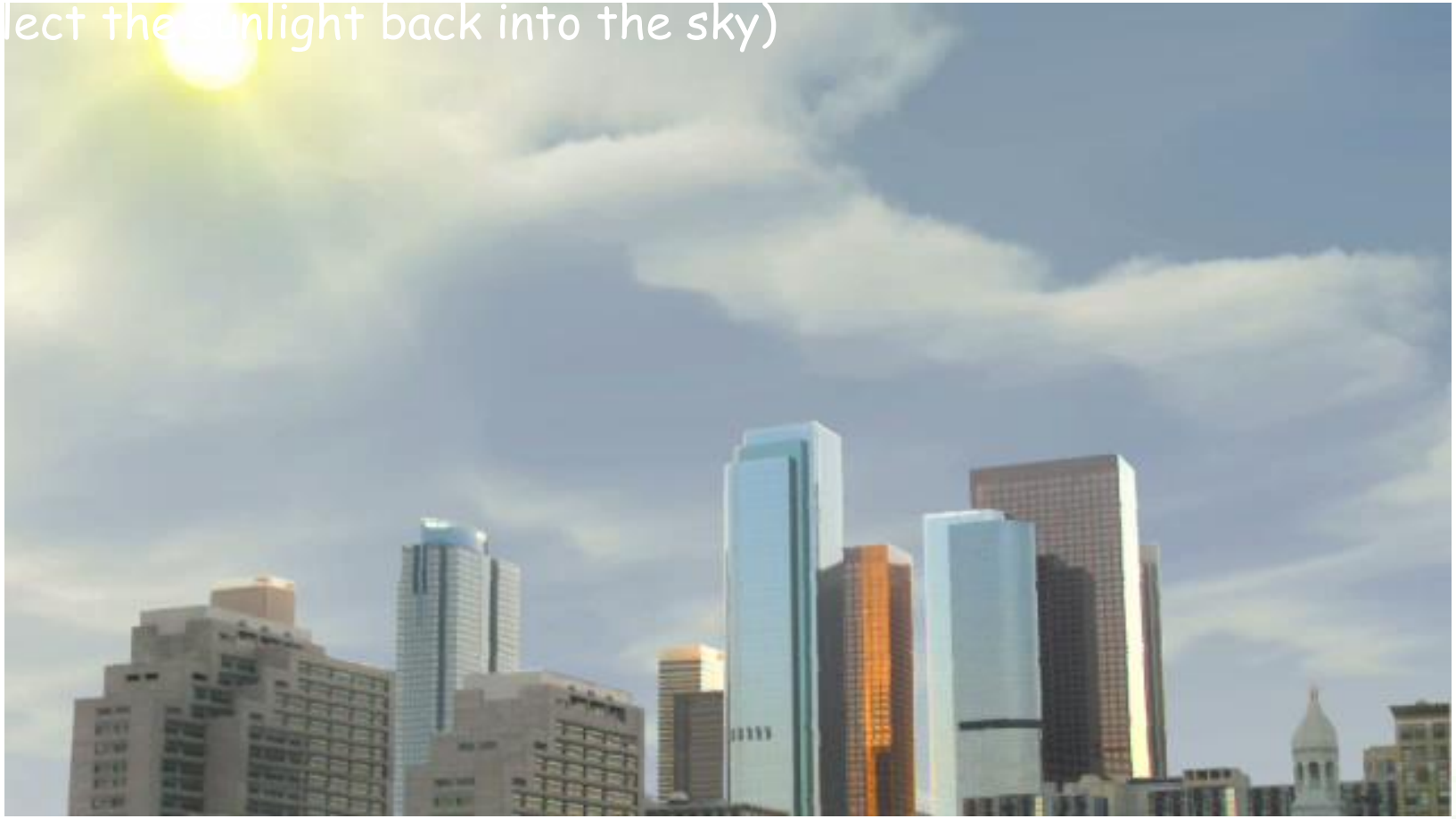
cloud could not form under normal atmospheric conditions



Both the indirect and direct radiation affects lead to a net cooling of the earth's surface, and thus are able to partially offset the greenhouse effect and global warming (Birmili et al., 1999).

Non-absorbing aerosols
scatter sunlight in various direction upwards

(reflect the sunlight back into the sky)



Organic aerosols - burning

soot – "elemental carbon"

- formed in flames
- little spectral dependence
- carbon-only

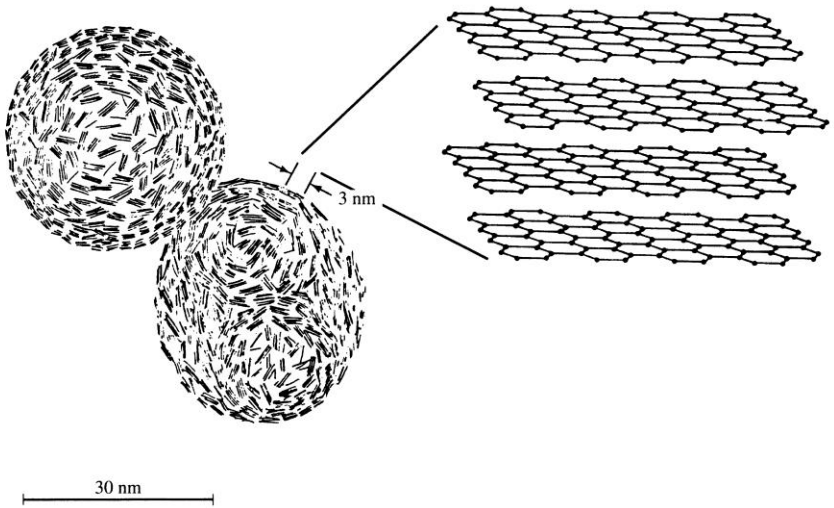
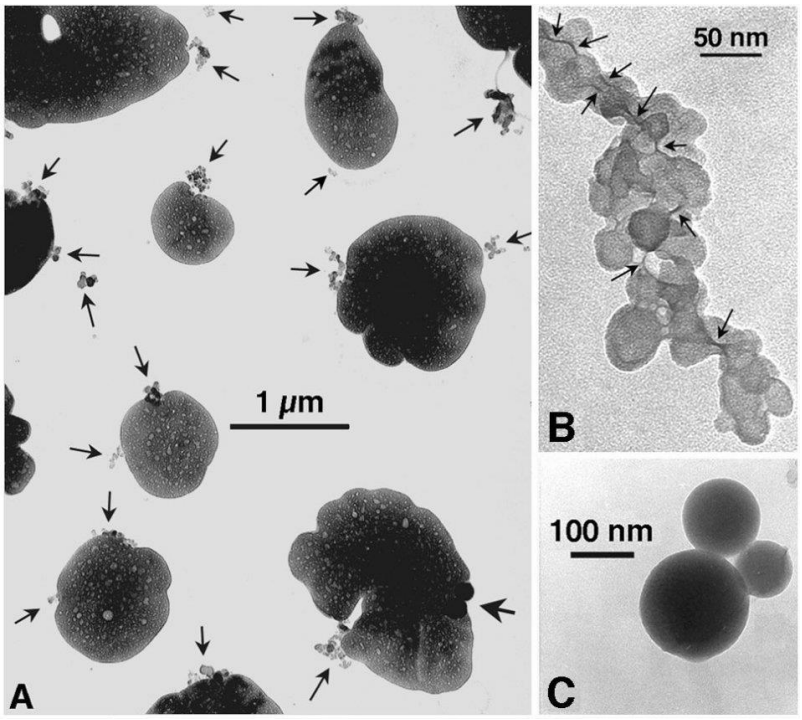


FIGURE 13.1 Schematic of soot microstructure.

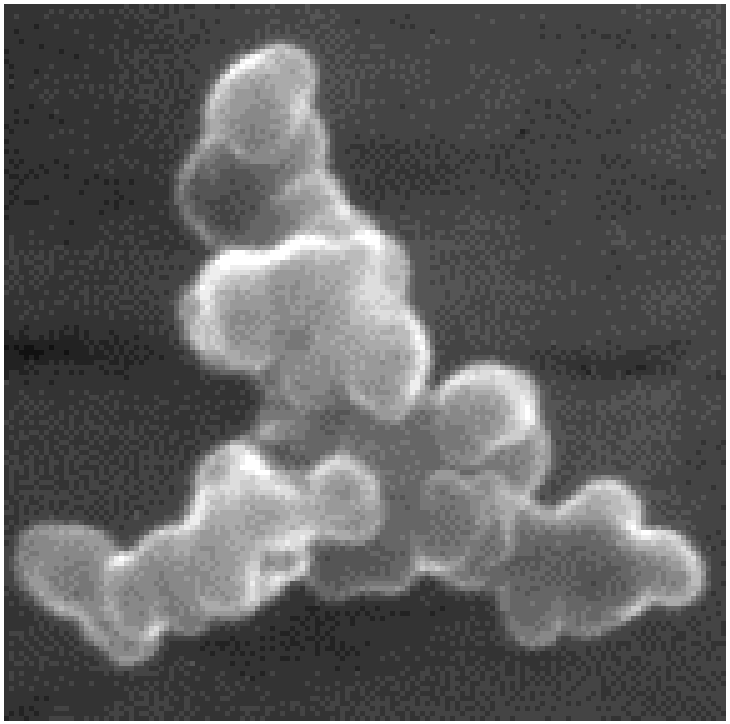
"brown carbon":

- sugars
- alcohols
- aromatics
- di/tri acids
- ketoacids
- hydroxyacids

Coated Soot Particles



Pósfai et al. (1999)

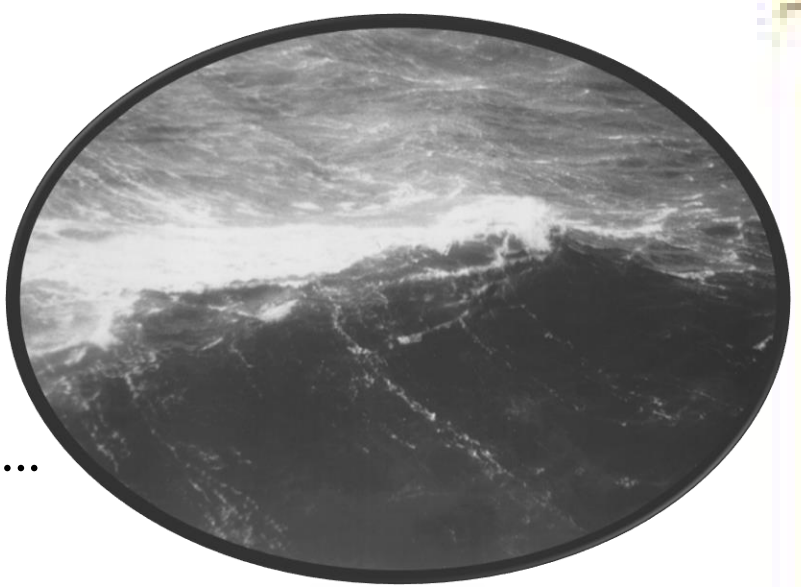


Strawa et al. (1999)

Seasalt aerosols

wind→ bubbles→ spray

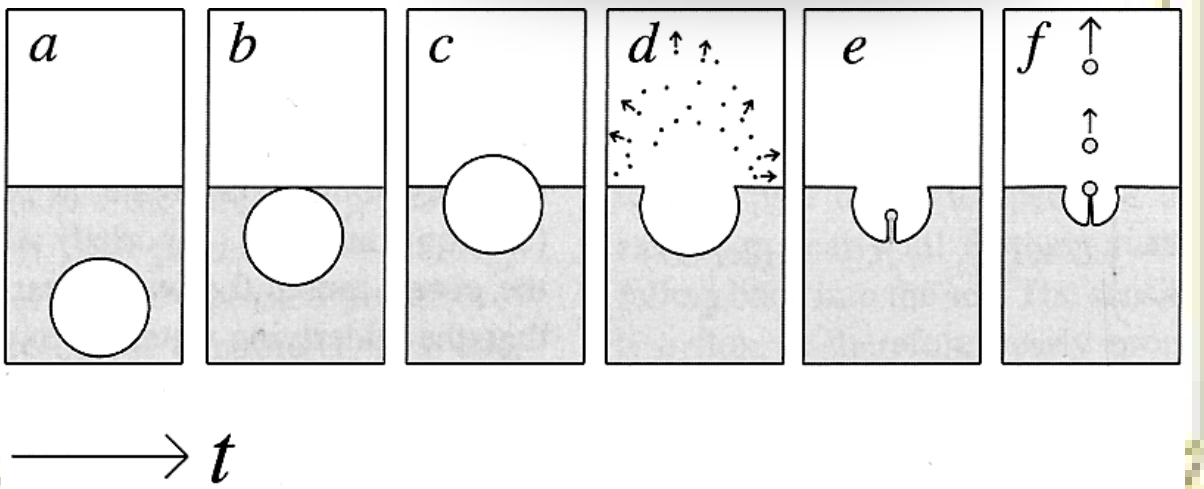
whitecap coverage W α U^{3+}



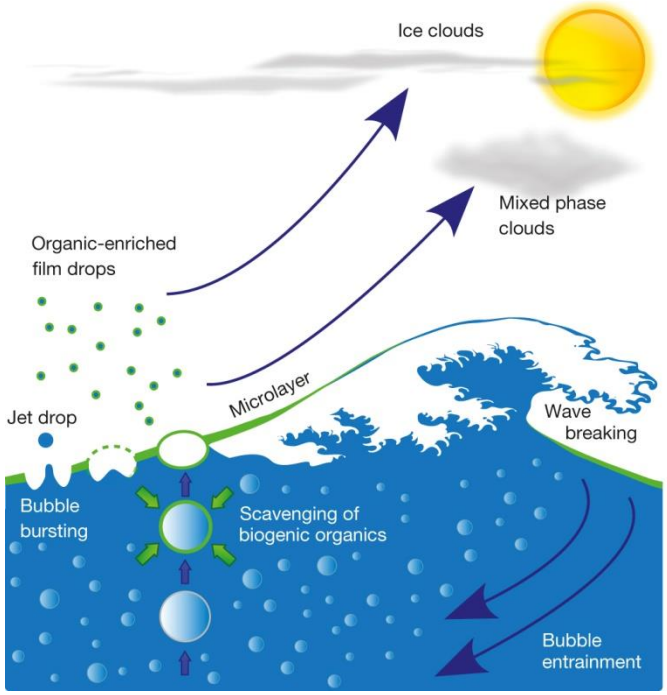
seasalt production via bubble bursting…

film drops (many, small, organics)

jet drops (fewer, larger)



Sea-spray aerosol particles enriched in organic material are generated when bubbles burst at the air–sea interface.

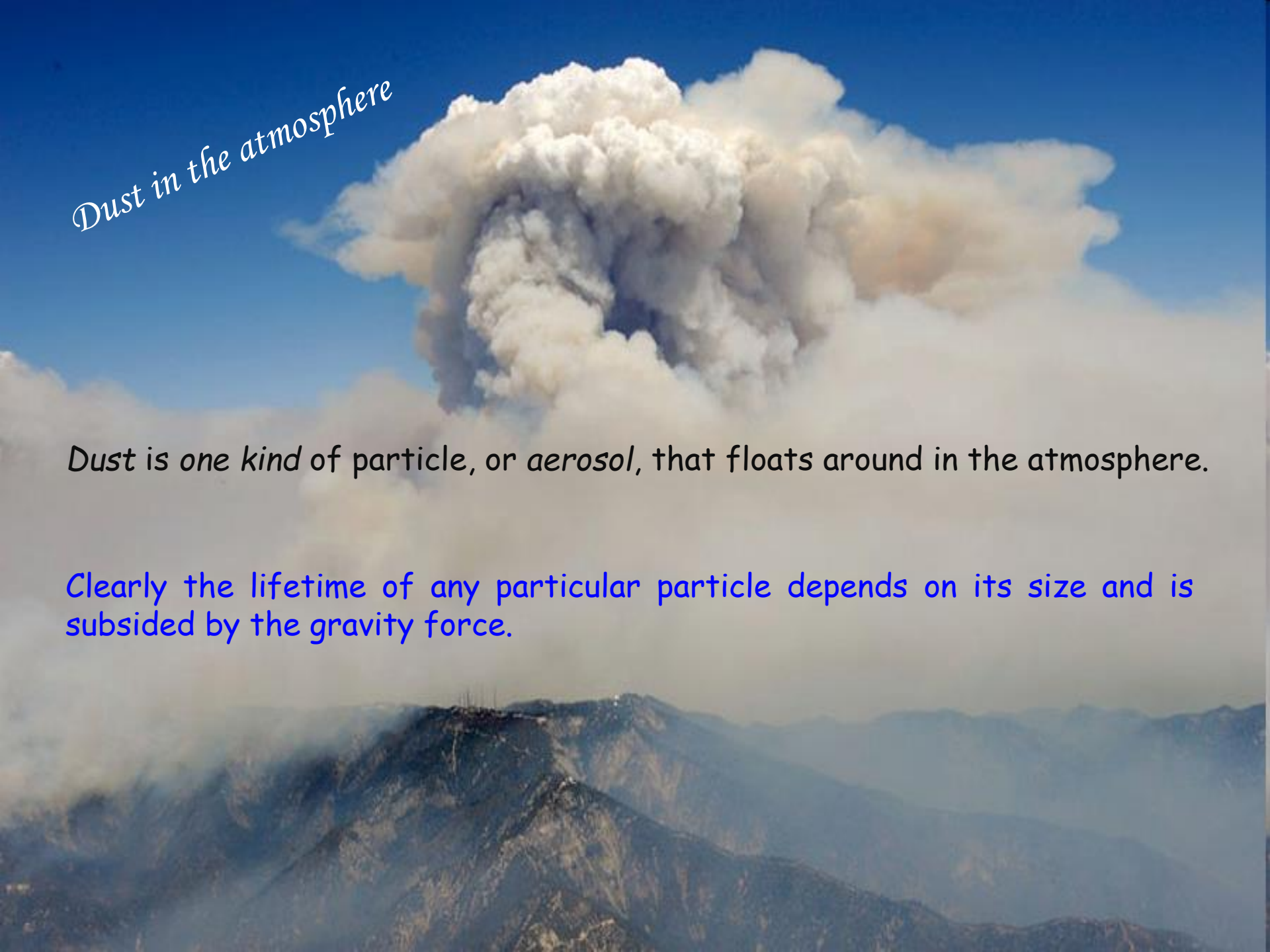


TW Wilson *et al. Nature* **525**, 234-238 (2015) doi:10.1038/nature14986

Constituents of Sea Water

Constituent	Mass Percent in Sea Water
Water	96.78
Sodium	1.05
Chlorine	1.88
Magnesium	0.125
Sulfur	0.0876
Calcium	0.0398
Potassium	0.0386
Carbon	0.0027

Dust in the atmosphere



Dust is *one kind* of particle, or *aerosol*, that floats around in the atmosphere.

Clearly the lifetime of any particular particle depends on its size and is subsided by the gravity force.

Visibility

PM_{10} = 2160 $\mu g/m^3$

(88/4/14)

Kermanshah

PM_{10} = 90 $\mu g/m^3$

(88/7/22)

Health, Welfare