662287

Aerosols - Tiny & Powerful

Pierre MADL, MSc.PhD.EE.

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH CONCERT

Lab practicals – **Aerosols 1/4**

Salzburg, 23rd till 27th of Jan. 2017

15-01-14 Madl

Aerosols in a nutshell: Nobody can escape it and it affects us all the time. Every day we inhale approx. 15 000 liter of air. Depending on the location we live in and the time of the year we are exposed to the effects of civilization in terms of sulfur- or nitric oxides, airborne particle matter and aromatic hydrocarbons. According to the WHO, about 7 million people die every year as a result to air-pollution related diseases. At first pollutants deposit in the deeper lung where they trigger bronchitis and even lung cancer. The smaller-sized pollution fraction even trespasses into the blood circulatory system drastically increasing the risk of heart attacks and strokes. Besides these known adverse effects, more hidden side-effects become evident that are attributable to air-pollution and include cancer pathologies outside the lungs, diabetes and epigenetic factors.

This lab-course material provides background information to aerosol dynamics, effects on climate and health. In addition it provides basic information on selected tools to measure and quantify aerosol inventories and how these data can be implemented into a computer code for lung deposition modeling. The core issue with air pollution: nobody can escape as it affects everyone. With a breathing turnover of 8.6kL a day (sedentary lifestyle at 12 Bpm, tidal volume 0.5L of an adult) and based upon the location we live in, we are exposed to the traces of civilization that include sulfur-, and nitrogen-oxides, ozone, particle matter as well as hydrocarbons.

Image: http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog
http://www.concert-h2020.eu/

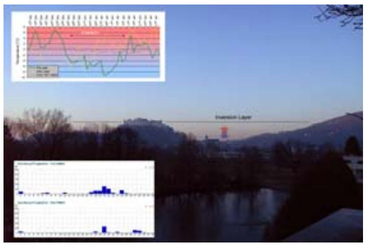
Pierre MADL
Dep. Physics & Biophysics @ University of Salzburg
Hellbrunnerstr. 34 / A-5020 Salzburg
pierre.madl@sbg.ac.at
http://biophysics.sbg.ac.at/talk/trott-2012.pdf

v.2020.01

Aerosol | Climate | Health | Tools | Model

Menu (1a/7)

Salzburg 26th Dec. – 15th Jan. 2008



Today's Menu:

PT-I: • **Aerosols** (Sizes, Properties, Characteristics, Definitions)

PT-II: • **Climate** and the effects associated to Aerosols

PT-III: • **Health** Effects (Inhalation, Toxicology, Modeling, Clearance)

PT-IV: • **Equipment** (common tools in ambient aerosol sampling)

PT-V: • **Modeling** (Lung deposition model inter-comparison, IDEAL-code)

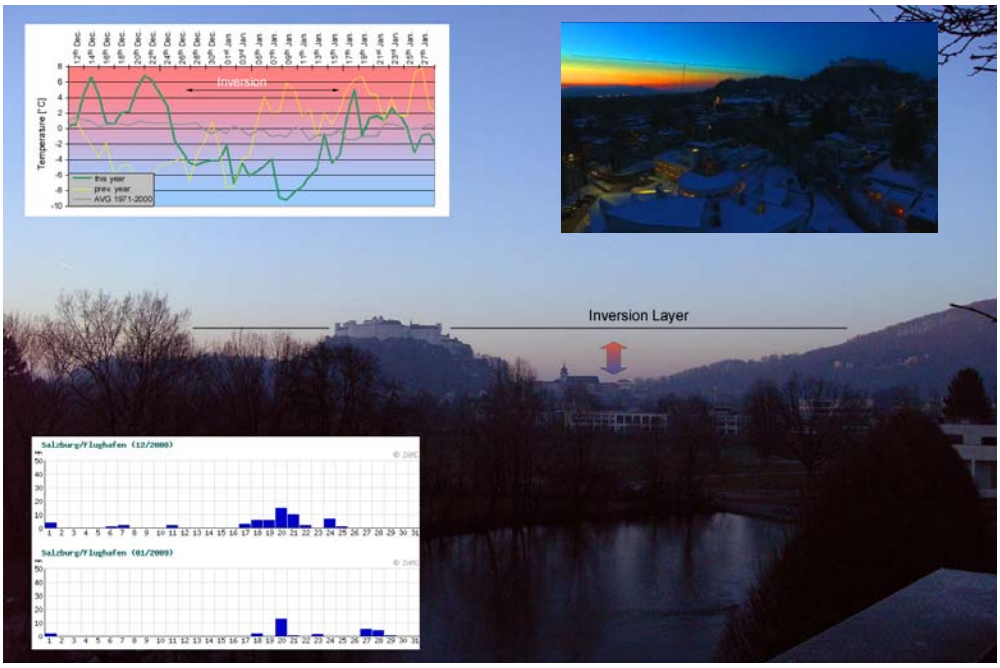
BeiJing 6th – 10th Aug. 2007

Coarse aerosols size distribution as observed in the BeiJing area derive from the gobi desert (below). This short 5 day long event cleared up as soon as the wind direction changed. In comparison the nano-aerosol inventory observed under stagnant atmospheric conditions (inversion layer, above).

Which of these two aerosol pollution events pose a greather threat to human health?

While coarse particle matter like this one affecting the BeiJing metropolitan area are quite large and are deposited in the upper respiratory airways (are relatively easily expelled via the clearance system of the bronchi and mucus - the latter either swallowed or excreted via sputum), the smaller nano-sized fraction (several magnitudes smaller in diameter than the coarse fraction) penetrates deep into the lung. There the only line of defense is the immune system, which van easily be overloaded. Clearance in the deep lung region is thus only possible via relocation of deposited particles into the blood circulatory and lymphatic system. Obviously, in that case we are flooding our organisms with nano-particles - similar with nitrogen gas that is a normal constituent of air. The only difference lies in the fact that the latter is well tolerated as a result of evolutionary tolerance, the former is a novel phenomenon and as such any exposed organism is subjected to an extra stress load. Hence, children, the elderly and those affected by respiratory ailments are particularly vulnerable to the toxic effects of nano-aerosol exposure.

Aerosol | Climate | Health | Tools | Model



Aerosol | Climate | Health | Tools | Model

Menu (2a/7)

Anthropogenic
Aerosols

- Global hotspots (data 1992)
- three key markers
  TSP: total suspended particles
  SO_2: sulfur dioxide
  O_3: ground-based ozone

While some places (industrialized world) improved, most indicators in Asia, Africa and South America became even worse.

Costa, 2001

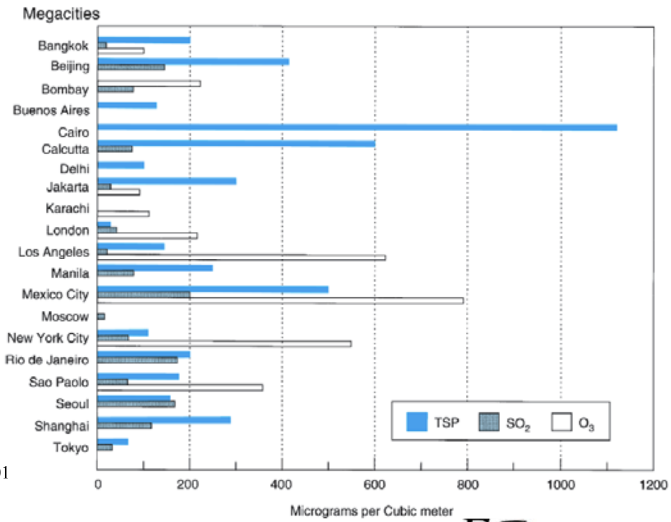


Image: Comparison of ambient levels of 1-h maximum ozone, annual average of total suspended particulate matter, and sulfur dioxide in selected cities from around the world to illustrate the variation in these levels from country to country with respect to the United States.

Image: http://www.arte.tv/guide/de/051861-001/hunger-durst

Source: Costa DL (2001) Air Pollution, Ch. 28. In: Klaassen CD (ed) Casarett and Doull's Toxicology. Basic Science of Poisons. 6th ed. MacGrawHill, New York, USA;

Aerosol | Climate | Health | Tools | Model

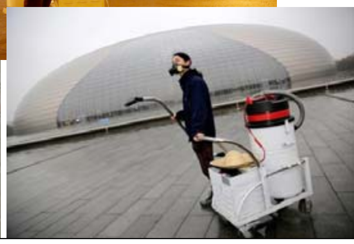
Menu (2b/7)

Anthropogenic
Aerosols

Taping BeiJing air to produce an aerosol-brick (particles >0.2µm) in just 100 days!

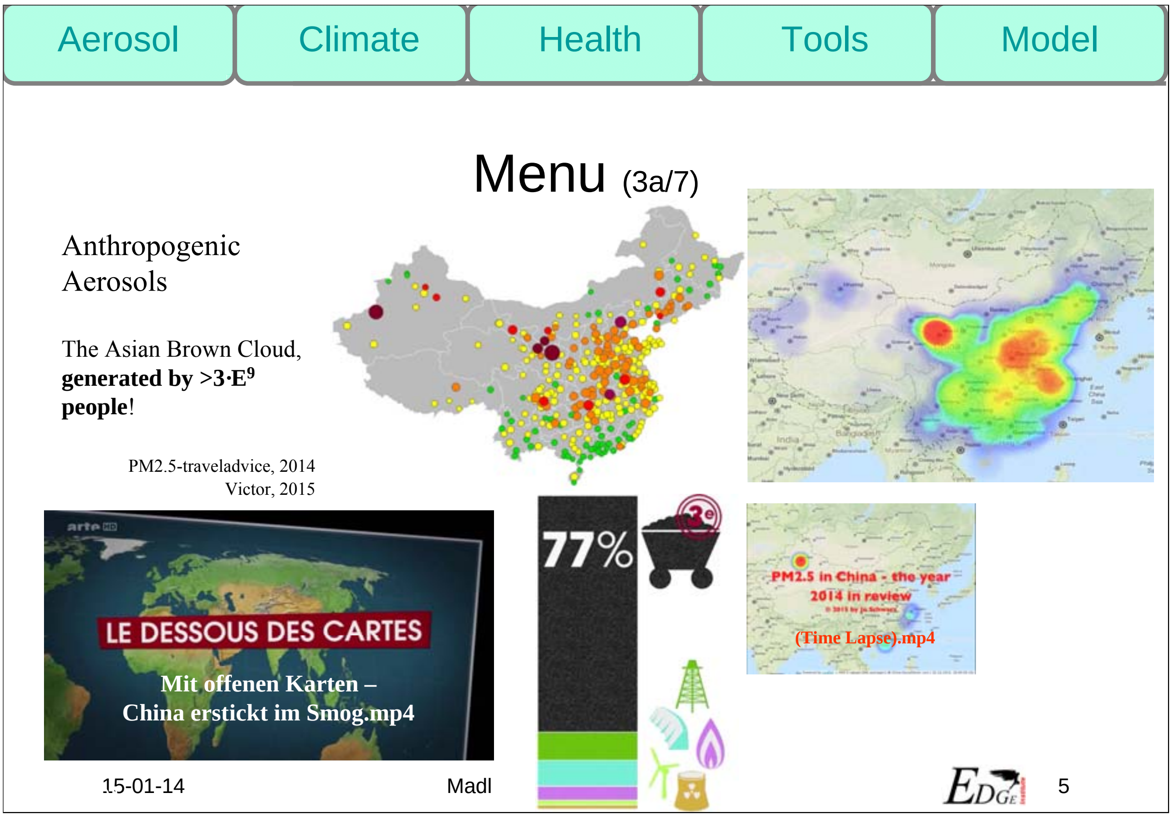
(Wang RenZheng 坚果兄弟, 2015)




It took just 100 days of traipsing around Beijing with a vacuum for a Chinese artist to collect enough dust to make the brick. The artist, who goes by the monicker ‘Nut Brother’, used an industrial vacuum to literally suck pollution out of the air to make the smog brick. He didn’t use your average hoover, though - the heavy duty vacuum is capable of sucking up any particulate matter with a diameter of over 0.2 microns. It was able to suck in air equivalent to the amount breathed in by 62 people per day. He was out collecting pollution during some of the city’s worst onsets of smog and haze, and he got the idea when Beijing was hit with severe smog back in 2013. He didn’t use your average hoover, though - the heavy duty vacuum is capable of sucking up any particulate matter with a diameter of over 0.2 microns. It was able to suck in air equivalent to the amount breathed in by 62 people per day. He was out collecting pollution during some of the city’s worst onsets of smog and haze, and he got the idea when Beijing was hit with severe smog back in 2013.

Source: This Is a Brick Made From The Dust In Beijing’s Smog
http://katesolomon.tumblr.com/post/134326092899/this-is-a-brick-made-from-the-dust-in-beijings#_=_
http://www.huffingtonpost.com/entry/china-air-pollution-brick_565dd024e4b08e945feca1fd



Die PM2.5-Feinstaubwerte und die aktuelle Luftqualität (AQI) in China

Aktuell hat unter den 366 Städten in China, von denen das Ministerium für Umweltschutz der Volksrepublik China (MEP, Ministry of Environmental Protection of China, chinesisch: 中华人民共和国环境保护部) stündlich die PM2.5-Feinstaubwerte veröffentlicht, die Stadt Xiangyang mit 229 µg/m³ die stärkste Feinstaubbelastung. Die geringste Feinstaubbelastung nach PM2.5 wurde aus der Stadt Longyan mit 13 µg/m³ gemeldet (Daten vom 2015-05-24, 05 Uhr). China ist derzeit für circa 24 % der weltweiten Kohlendioxid-Emissionen verantwortlich. Nur in etwa 1% der Städte in China erfüllt die Luftqualität denjenigen Standard (gemessen nach PM2.5), den die EU als sicher für die Bevölkerung betrachtet. Die größte Luftverschmutzung in China entsteht durch die Abgase der Fabriken. Der Kohlebrand der Kohlekraftwerke ist ein großer Verursacher der Feinstaubpartikel in der Luft. Autos und der damit steigende Individualverkehr haben sich zu einer großen Quelle der Luftverschmutzung entwickelt. In großen Städten wie Peking und Shanghai tragen sie 20 bis 25 Prozent zum Auftreten von PM 2.5 bei. Die Weltgesundheitsorganisation empfiehlt angesichts der vom Feinstaub ausgehenden Gesundheitsgefahren in ihren WHO-Luftgüte-Richtlinien einen Grenzwert von 10 µg/m³ nach PM2.5 im Jahresmittel. Das Tagesmittel liegt bei 25 µg/m³ ohne zulässige Tage, an denen eine Überschreitung möglich ist. China ist von solchen Werten nahezu flächendeckend weit entfernt. Im Dezember 2012 ergab eine Studie, dass 2010 mindestens 1,2 Millionen Menschen an den Folgen der Luftverschmutzung vorzeitig verstorben sind. Dies entspricht 40 Prozent der 3,2 Millionen Todesfälle, die weltweit auf die Ursache Smog zurückzuführen sind. Der wirtschaftliche Schaden wird mit rund 230 Milliarden US-Dollar (umgerechnet rund 175 Milliarden Euro) oder 3,5 Prozent des Bruttoinlandsprodukts des Landes pro Jahr beziffert. Große Teile der Bevölkerung in China sind sind nicht mehr gewillt, die Umstände der Luftverschmutzung einfach hinzunehmen. Neben der chinesischen Regierung darf niemand im Reich der Mitte PM2.5-Feinstaubwerte selbst messen oder gar veröffentlichen. Zuwiderhandlungen können mit harten Gefängnisstrafen verurteilt werden, da dies als eine "Gefährdung einer nationalen Sicherheit" eingestuft wird. Einzige Ausnahme ist die "US Environmental Protection Agency (EPA)", da diese die Daten auf dem Gelände der Botschaft in Peking und den Konsulaten in Guangzhou, Shanghai und Chengdu und damit nach internatinalem Recht auf amerikanischen Hoheitsgebiet, ermittelt. Diese Daten gelten für die genannten Städte als realistischer, da diese in den Stadtzentren und nicht in Randgebieten ermittelt werden.

Image: Aktuell hat die Stadt #Aksu mit 500 µg/m³ die höchste Feinstaub-belastung in China. Die geringste Luftverschmutzung nach $PM_{2.5}$ wurde aus der Stadt #Fangchenggang mit 22 µg/m³ gemeldet. Mehr auf http://pm25.china-reisefuehrer.com

Source: http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog .... & .... https://www.youtube.com/watch?v=hWbGBoK3oqY

http://pm25.china-reisefuehrer.com/ .... & https://plus.google.com/100229622781051585585/posts

Aerosol | Climate | Health | Tools | Model

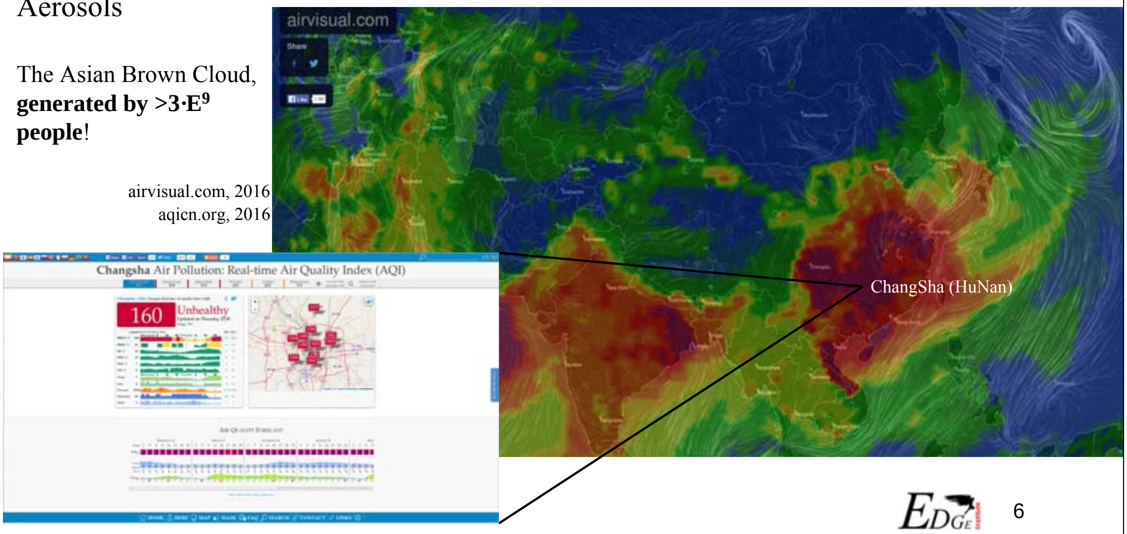
Menu (3b/7)

Anthropogenic Aerosols

The Asian Brown Cloud, **generated by >3·E^{9} people**!

airvisual.com, 2016
aqicn.org, 2016

.... see animated version @ https://airvisual.com/earth



EDGE 6

AQI, or Air Quality Index, is a system for reporting the severity of air quality levels in relatable terms to the public. The index ranges from 0 to 500, where higher index values indicate higher levels of air pollution and higher potential for adverse health effects. An AQI value of 0-50, for example, represents good air quality, while any value larger than 300 is considered to be hazardous. AQI is computed in different ways around the world. China and America, however, have the two most widely used indexes. Both are similar in that they include the same six criteria pollutants (ground-level ozone, $PM_{2.5}$, PM_{10}, carbon monoxide, sulphur dioxide and nitrogen dioxide to generate an overall AQI.

AQI: The Chinese AQI takes the highest of all 6 pollutant index values and declares that number the overall AQI. The American index, on the other hand, is calculated by weighing the six criteria pollutants in a fairly complex formula. Since the American method typically yields a higher AQI than Chinese method, it is thought to be more strenuous. It is for this reason, among others, that the American index has become the general world standard. Regardless of which index you use, both yield index values relatively close to one another so the advisory warnings do tend to be fairly consistent.

.... see also section « equipment » air quality monitor: NODE

Source: https://airvisual.com/earth
https://airvisual.com/air-quality/aqi
aqicn.org/city/beijing/ or aqicn.org/city/changsha/

Aerosol | Climate | Health | Tools | Model

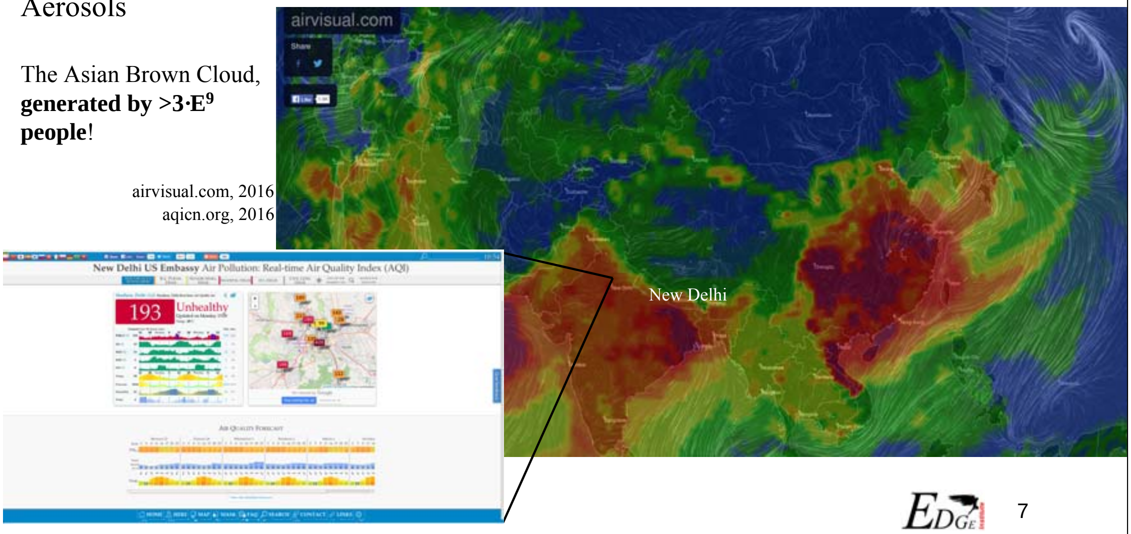
Menu (3c/7)

Anthropogenic Aerosols

The Asian Brown Cloud, **generated by >3·E^9 people**!

airvisual.com, 2016
aqicn.org, 2016

.... see animated version @ https://airvisual.com/earth



EDGE 7

AQI, or Air Quality Index, is a system for reporting the severity of air quality levels in relatable terms to the public. The index ranges from 0 to 500, where higher index values indicate higher levels of air pollution and higher potential for adverse health effects. An AQI value of 0-50, for example, represents good air quality, while any value larger than 300 is considered to be hazardous. AQI is computed in different ways around the world. China and America, however, have the two most widely used indexes. Both are similar in that they include the same six criteria pollutants (ground-level ozone, $PM_{2.5}$, PM_{10}, carbon monoxide, sulphur dioxide and nitrogen dioxide to generate an overall AQI.

AQI: The Chinese AQI takes the highest of all 6 pollutant index values and declares that number the overall AQI. The American index, on the other hand, is calculated by weighing the six criteria pollutants in a fairly complex formula. Since the American method typically yields a higher AQI than Chinese method, it is thought to be more strenuous. It is for this reason, among others, that the American index has become the general world standard. Regardless of which index you use, both yield index values relatively close to one another so the advisory warnings do tend to be fairly consistent.

.... see also section « equipment » air quality monitor: NODE

Source: https://airvisual.com/earth
https://airvisual.com/air-quality/aqi
aqicn.org/city/beijing/ or aqicn.org/city/changsha/

Aerosol | Climate | Health | Tools | Model

Menu (3b/7)

Anthropogenic
Aerosols

The Asian Brown Cloud,
generated by >3·E9
people!

Die PM2.5-Feinstaubwerte und die aktuelle Luftqualität (AQI) in China

Image: Aktuell hat die Stadt Aksu mit 500 µg/m³ die höchste Feinstaub-Belastung in China. Die geringste Luftverschmutzung nach $PM_{2.5}$ wurde aus der Stadt FangChengGang mit 22 µg/m³ gemeldet.

mehr auf http://pm25.china-reisefuehrer.com

Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)
https://www.youtube.com/watch?v=2T6BKJLl-2U
http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog

Aerosol | Climate | Health | Tools | Model

Menu (3c/7)

Anthropogenic
Aerosols

The Asian Brown Cloud, **generated by >3·E[9] people**!

Die PM2.5-Feinstaubwerte und die aktuelle Luftqualität (AQI) in China

Image: Aktuell hat die Stadt Aksu mit 500 µg/m³ die höchste Feinstaub-Belastung in China. Die geringste Luftverschmutzung nach $PM_{2.5}$ wurde aus der Stadt FangChengGang mit 22 µg/m³ gemeldet.

mehr auf http://pm25.china-reisefuehrer.com

Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)

https://www.youtube.com/watch?v=2T6BKJLl-2U

http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog

Die PM2.5-Feinstaubwerte und die aktuelle Luftqualität (AQI) in China

Image: Aktuell hat die Stadt Aksu mit 500 µg/m³ die höchste Feinstaub-Belastung in China. Die geringste Luftverschmutzung nach $PM_{2.5}$ wurde aus der Stadt FangChengGang mit 22 µg/m³ gemeldet.

mehr auf http://pm25.china-reisefuehrer.com

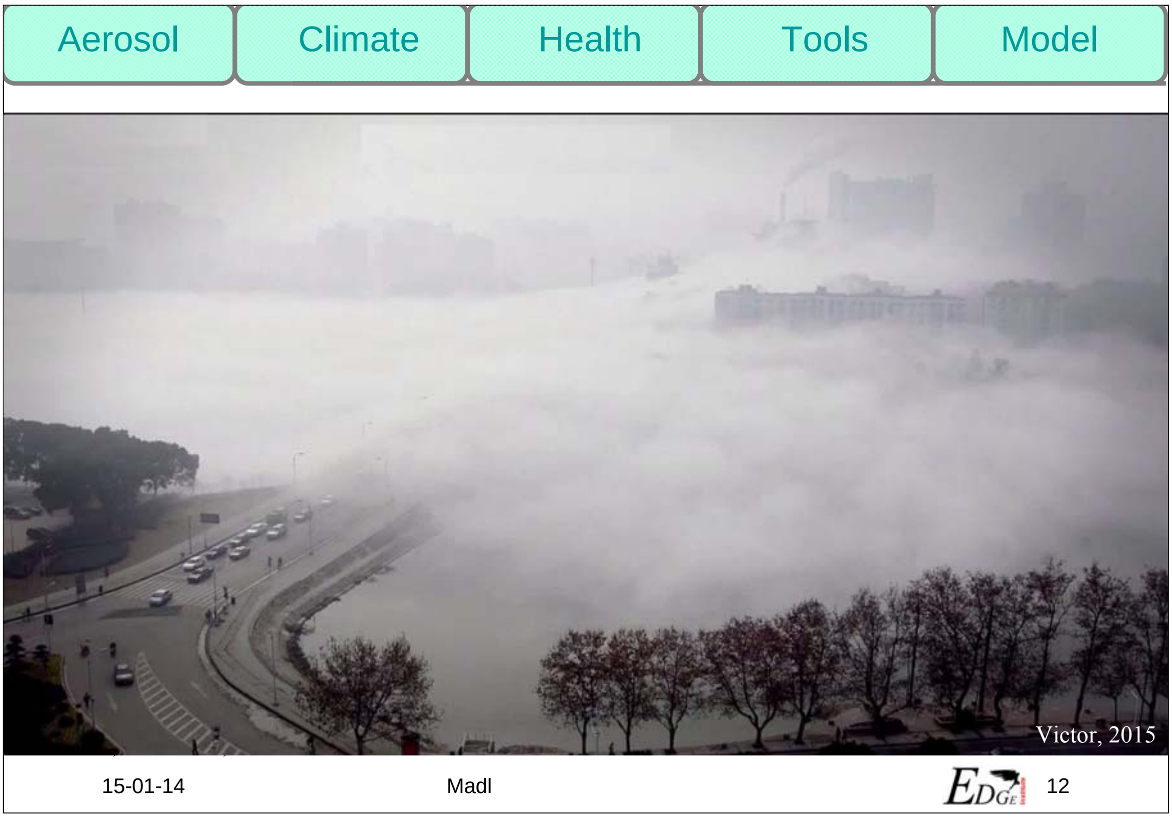
Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)
https://www.youtube.com/watch?v=2T6BKJLl-2U
http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog

Aerosol | Climate | Health | Tools | Model

15-01-14 Madl EDGE 11

Die Wirtschaftsgroßmacht China hat seit Jahrzehnten atemberaubende Wachstumsraten aufzuweisen. Dadurch konnten zwar große Teile der Bevölkerung der Armut entkommen, aber die wirtschaftliche Entwicklung des Landes hatte auch katastrophale Folgen für die Umwelt. MIT OFFENEN KARTEN beschäftigt sich heute mit den ökologischen Konsequenzen des chinesischen Wirtschaftswachstums.

Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)
https://www.youtube.com/watch?v=2T6BKJLl-2U
http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog



Die Wirtschaftsgroßmacht China hat seit Jahrzehnten atemberaubende Wachstumsraten aufzuweisen. Dadurch konnten zwar große Teile der Bevölkerung der Armut entkommen, aber die wirtschaftliche Entwicklung des Landes hatte auch katastrophale Folgen für die Umwelt. MIT OFFENEN KARTEN beschäftigt sich heute mit den ökologischen Konsequenzen des chinesischen Wirtschaftswachstums.

Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)
https://www.youtube.com/watch?v=2T6BKJLl-2U
http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog

Aerosol | Climate | Health | Tools | Model

Victor, 2015

15-01-14 Madl EDGE 13

Die Wirtschaftsgroßmacht China hat seit Jahrzehnten atemberaubende Wachstumsraten aufzuweisen. Dadurch konnten zwar große Teile der Bevölkerung der Armut entkommen, aber die wirtschaftliche Entwicklung des Landes hatte auch katastrophale Folgen für die Umwelt. MIT OFFENEN KARTEN beschäftigt sich heute mit den ökologischen Konsequenzen des chinesischen Wirtschaftswachstums.

Source: Victor JC (2015) China erstickt im Smog. Mit offenen Karten. Arte-TV (FRA-FRG)
https://www.youtube.com/watch?v=2T6BKJLl-2U
http://ddc.arte.tv/unsere-karten/china-erstickt-im-smog

Aerosol | Climate | Health | Tools | Model

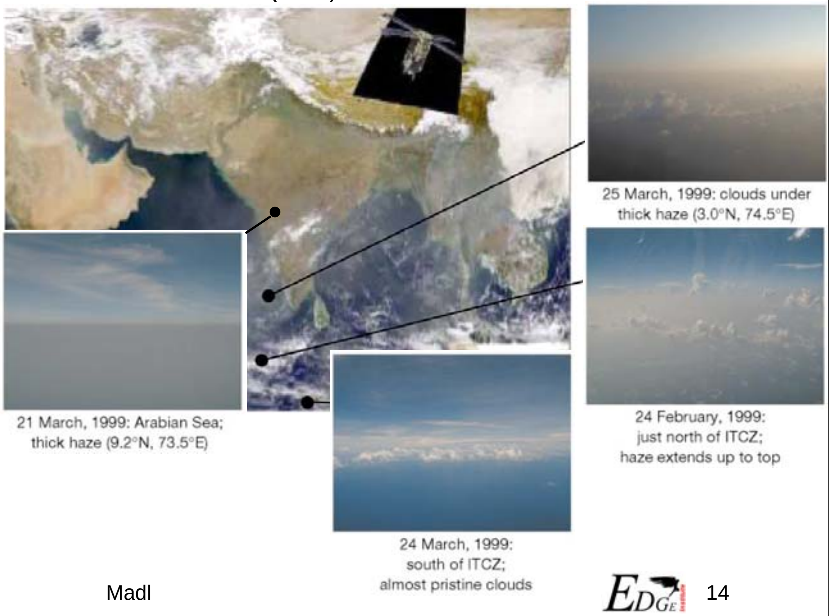
Intro (4a/7)

Anthropogenic Aerosols

The Asian Brown Cloud, **generated by >3·E[9] people**!

Cross-sectional view of
i) dense haze in the Arabian Sea (**visibility < 10km**),
i) trade cumuli embedded in the haze and
ii) pristine southern Indian Ocean.

Kuring, 2002



15-01-14 Madl 14

Asia and the Indian subcontinent, which together have a population of more than 2 billion people, emit large quantities of pollutants that can be carried to the Indian Ocean during the northern hemisphere winter by monsoon winds from the northeast. Researchers documented a human-produced brownish-gray haze layer of about 10 million square kilometers over the Indian-Asian region. The particles within the haze, the researchers discovered, were causing a three-fold decrease in solar radiation reaching the earth's surface as compared with the top of the atmosphere. The aerosols, typically in the submicrometer- to micrometer-size range, were a mixture of sulfates, nitrates, organic particles, fly ash, and mineral dust, formed by fossil fuel combustion and rural biomass burning [1] …. The haze is caused by high concentrations of small particles known as aerosols that are usually less than a few micrometers in diameter. Comprised primarily of soot, sulfates, nitrates, organic particles, fly ash and mineral dust, the particles often **reduced visibility over the open ocean to less than 10 kilometers**, a range typically found near polluted regions of the United States and Europe. The haze layer also contains relatively high concentrations of gases, including carbon monoxide, various organic compounds, and sulfur dioxide, providing conclusive evidence that the haze layer is caused by pollution. In contrast to the situation over the northern Indian Ocean, the lower atmosphere over the southern Indian Ocean remains remarkably clean, thanks to the Inter-Tropical Convergence Zone (ITCZ), which is found around 5-10 degrees south of the equator at this time of year. A narrow zone of deep and towering thunderstorms that form over the warmest part of the equatorial ocean, the ITCZ intercepts polluted air masses and removes much of the pollution as rainfall. But the ITCZ clouds can also move substantial amounts of pollutants into the upper atmosphere where they can be spread over large areas.

Image: Clouds in the presence of aerosol. Low clouds over the tropical Indian Ocean embedded within the aerosol layer: a, b) north of the ITCZ, c) near the ITCZ, and d) free of the haze south of the ITCZ. [2]

Source: http://explorations.ucsd.edu/indoex/news.cfm
http://www.theresilientearth.com/files/chapter_1.html
UNEP, 2002. The Asian Brown Cloud
[1] V. Ramanathan, P. J. Crutzen, J. T. Kiehl, D. Rosenfeld (2001). Aerosols, Climate, and the Hydrological Cycle. SCIENCE VOL 294 7 DECEMBER 2001
[2] Satheesh S.K., Ramanathan V (2000). Large differences in tropical aerosol forcing at the top of the atmosphere and Earth's surface. Nature, Vol. 405: 60-63.

Aerosol | Climate | Health | Tools | Model

Intro (4b/7)

Sources in Developing Metropolis

(Cairo, Mexico, BeiJing)

Source:
Gertler, in Favez et al., EAC 2007

15-01-14 Madl 15

Particles and the Human Respiratory System: The ideal gate for the penetration of air contaminants is the lung. Because of its small size, Fine Particle Matter (<$PM_{2.5}$) can be deposited deep into the lungs, where it can cause health problems and is known to alter lung functions [1]. NO_X and SO_2 are also major sources of fine PM. Recent studies have shown an association between PM and premature mortality from respiratory and cardiovascular disease, and increased incidence of respiratory illness, particularly in children and the elderly. For adults with heart or lung conditions, exposure to fine PM can cause more illness and in some cases premature death. More than 90 % of the particulates found in diesel exhaust are fine particles.

Source: [1] Ellenhorn (1996), CD-Rom
O.FAVEZ, J.SCIARE, H.CACHIER,M. ABDELWAHAB, T.YU, L.MARTINON, O. D'ARGOUGES, K.OIKONOMOU, R.SARDA-ESTEVE;
CairoCity image: http://www.wunderground.com/data/wximagenew/n/Nefertiti/0.jpg

Aerosol | Climate | Health | Tools | Model

Intro (4c/7)

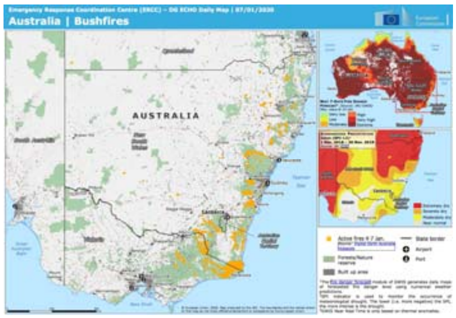
Anthropogenicaly aug-
-mented natural sources

Annual bushfire season - AUS

AMA 2020; ABC 2020

People sensitive to smoke include:
•people with heart or lung conditions (including asthma)
•children <14 years
•pregnant women, and
•people >65 years.

During bushfires, Canberra's air quality index is 23 times the hazardous rating, rivalling some of the worst in the world (!)



15-01-14 Madl 16

People sensitive to smoke …. should take extra care during these conditions:
-) people with heart or lung conditions (including asthma)
-) children aged less than 14 years
-) pregnant women, and
-) people over 65 years of age.

Evidence shows P2 and N95 masks do filter some smoke and are most commonly used in occupational settings where exposure to airborne particles occur on a regular basis. However, they cannot completely eliminate exposure to smoke, and as they can be difficult to fit and use appropriately, they are not recommended for use in the general community as an alternative to avoiding outdoor exposure.

Image: Members of the Walker and Holmes families shelter in the water next to a jetty at the Holmes' property at Dunalley, south east Tasmania, as a bushfire tore through the area on January 4, 2013.
The intense fires and resulting smoke continue to impact air quality in major Australian cities, including Sydney, Canberra, Melbourne and Adelaide.
Canberra's air quality index is 23 times the hazardous rating, rivalling some of the worst in the world

Source: https://ama.com.au/media/new-health-threats-escalating-bushfire-crisis
https://erccportal.jrc.ec.europa.eu/Maps/Daily-maps
https://www.abc.net.au/news/2013-01-08/dunalley-bushfire/4456548
https://www.abc.net.au/news/2020-01-01/smoke-shrouds-australia-as-nsw-bushfires-continue/11835734
https://www.abc.net.au/news/health/2020-01-07/prolonged-bushfire-smoke-creates-new-health-risks/11844934
https://www.flyingeze.com/wp-content/uploads/2020/01/Australia-bushfires-create-their-own-dangerous-weather-systems-experts-say-scaled.jpg

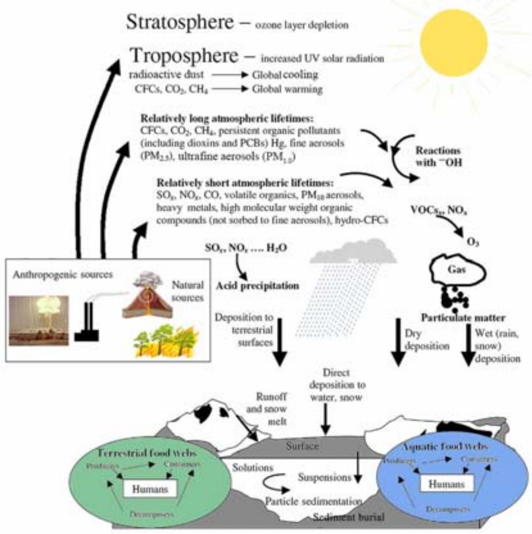
Aerosol	Climate	Health	Tools	Model

Intro (4d/7)

Sources, formation, relocation & secondary transformation

-) long range transport
-) photochemical alteration
-) inhalation & incorporation (via washout & introduction into food webs) → bio-accumulation
-) extra- & intracorporal microbial degradation
-) mineralization

Vallero, 2014



15-01-14 Madl 17

The general behavior of contaminants after they are released into the atmosphere. The movement of pollutants is known as transport. This is half of the often cited duo of environmental “fate and transport”. Fate is an expression of what contaminant becomes after all the physical, chemical, and biological processes of the environment have acted. It is the ultimate site of a pollutant after its release. The pollutant will undergo numerous changes in location and form before reaching its fate. Throughout the contaminant’s journey, it will be physically transported and undergo coincidental chemical processes, known as transformations, such as photochemical and biochemical reactions. Certainly, fate implies more than physical transport. The fate of an air pollutant depends on abiotic chemical reactions, such as photolysis, endothermic, and exothermic reactions, and mechanical separation processes, as well as biotic transformation, e.g. microbial degradation. Usually, in the discussions of fate and transport, the reactions are those that occur in the ambient environment …. In the soil, the microbially mediated transformations may change the chemical structure to a simpler molecule, e.g. by mineralization. This lighter molecule may have a sufficiently high vapor pressure, which allows it to again move into the atmosphere, where it undergoes additional photochemical transformation, increasing its aqueous solubility. This new compound is deposited onto the surface of the lake, where it is taken up by algae. The algae are food for fish, so this transformation product is bio-accumulated and further transformed in the fish. If the fish is eaten by humans, the ultimate fate of the original air pollutant released from the stacks and vents is in human tissue. Thus, the fate is a consequence of physics, chemistry, and biology.

Image: The physical movement and accumulation of contaminants after release.

Source: Vallero D (2014) Fundamentals of Air Pollution, 5th ed., Ch.16 (Mechanical Scale and Complexity) Academic Press, USA

Aerosol | Climate | Health | Tools | Model

Intro (5/7)

Thus AEROSOLS have access to tiny spaces, such as:

$CaCO_3(s) + H_2SO_4(l) \rightarrow CaSO_4(s) + H_2O(l) + CO_2(g)$

- micro-structure of ; e.g. architectonic Monuments

  passive ventilation by **diffusion / humidity gradients**

Source. Jambolsky et al, 2015

15-01-14 Madl 18

The primary concern in regard to air pollution damage to stone structures is the soiling and deterioration of limestone, which is widely used as a building material, and for its metamorphosed form, i.e. marble, in statuary. Many buildings in older cities have been exposed to urban smoke, SO_2, and CO_2 for decades or centuries. The surfaces have become soiled and are subjected to chemical attack by acid gases. Exterior building surfaces are also subjected to a wet-dry cycle induced by changes in rain and humidity. SO2 and water react with limestone ($CaCO_3$) to form calcium sulfate ($CaSO_4$) and gypsum ($CaSO_4$ x $2H_2O$). These two sul fates are fairly soluble in water, causing deterioration in blocks and in the mortar used to join the blocks. The soluble calcium sulfates can penetrate into the pores of the limestone and then recrystallize and expand, causing further deterioration of the stone. CO_2 in the presence of moisture forms carbonic acid. This acid converts the limestone into bicarbonate, which is also water soluble and can be leached away by rain. This mechanism is present in the deterioration of marble statues.

Source: Vallero D (2014) Fundamentals of Air Pollution, 5th ed., Ch.15 (Air Pollution's Impact on Materials and Structures) Academic Press, USA

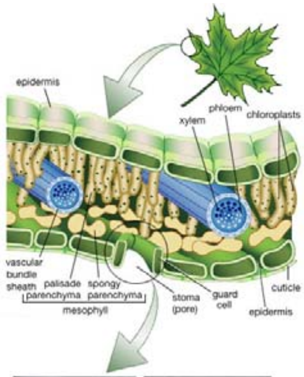
Jambolsky M. Pracht und Prunk an der Loire – Schloss Chambord; arte-france. http://www.arte.tv/guide/de/056815-000/pracht-und-prunk-an-der-loire-schloss-chambord

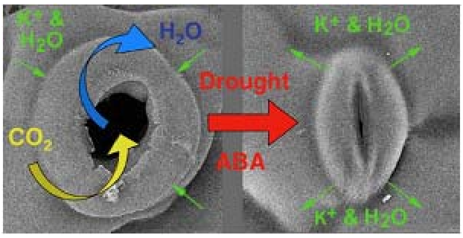
Aerosol | Climate | Health | Tools | Model

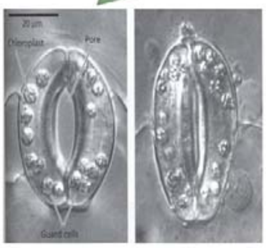
Intro (6a/7)

Thus AEROSOLS have access to tiny spaces, such as:

- Stomata of Leaves; e.g.
  passive ventilation by **diffusion**
  Arabidopsis thaliana (thale cress or mouse-ear cress)
  Tabernaemontana. divaricata (crape jasmine)
  Acer pseudoplatanus (maple leaf)
  Hamelia patens (firebush)







Botany LAB, Kean Uni, 2003

Structures of a leaf. The epidermis is often covered with a waxy protective cuticle that helps prevent water loss from inside the leaf. Oxygen, carbon dioxide, and water enter and exit the leaf through pores (stomata) scattered mostly along the lower epidermis. The stomata are opened and closed by the contraction and expansion of surrounding guard cells. The vascular, or conducting, tissues are known as xylem and phloem; water and minerals travel up to the leaves from the roots through the xylem, and sugars made by photosynthesis are transported to other parts of the plant through the phloem. Photosynthesis occurs within the chloroplast-containing mesophyll layer.

Stoma / stomata: the minute opening bordered by guard cells in the epidermis of leaves and stems through which gases pass; shown here is the surface view of the lower epidermis of a *Eucalyptus globulus* leaf taken with a SEM, flanked by two guard cells. Stomata sense environmental cues, like light, to open. These cues start a series of reactions that cause their guard cells to fill with water. Let’s follow a scenario where the sun is rising and a cotton plant is signaled to open its stomata:

1.Signal received: The blue light at dawn is the signal that is recognized by a receptor on the guard cell.

2.The receptor signals the H^+-ATPases on the guard cell’s plasma membrane to start pumping protons (H^+) out of the guard cell. This loss of positive charge creates a negative charge in the cell.

3.Potassium ions (K^+) enter the guard cell through channels in the membrane, moving toward its more negative interior.

4.As the potassium ions accumulate in the guard cell, the osmotic pressure is lowered.

5.A lower osmotic pressure attracts water to enter the cell.

6.As water enters the guard cell, its hydrostatic pressure increases.

7.The pressure causes the shape of the guard cells to change and a pore is formed, allowing gas exchange.

Stomata sense environmental cues, like light, to open. These cues start a series of reactions that cause their guard cells to fill with water. Let’s follow a scenario where the sun is rising and a cotton plant is signalled to open its stomata:

When the stoma is open, the stomata allow gas exchange, mainly CO_2 for photosynthesis and H_2O, between the leaf and the atmosphere. During a drought stress the plant has to close their stomata to limit water loss. ABA is the main actor of this response. Therefore, as a result of the reduction of the transpiration stream, stomatal closure leads to an increase of leaf temperature that can be measured very sensitively and non invasively by Infrared thermography (bottom image on the right).

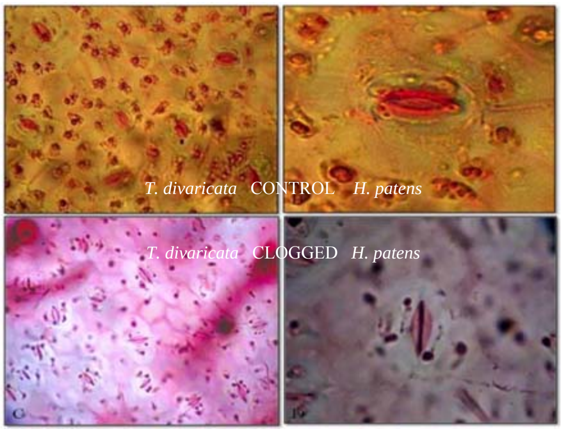
Source: Raven (1992) Biology of Plants; p.465
[2] Amulya L, Kumar NHK, Jagannath S (2015) Air pollution impact on micromorphological and biochemical response of *Tabernaemontana divaricata* L. (Gentianales: Apocynaceae) and *Hamelia patens* Jacq. (Gentianales: Rubiaceae)Brazilian Journal of Biological Sciences, Vol.2,(4): 287-294.
http://www.britannica.com/ebc/art-66079/Structures-of-a-leaf
http://plantandsoil.unl.edu/croptechnology2005/pagesincludes/printModule.jsp?informationModuleId=1092853841
http://www.plantsci.cam.ac.uk/Webb/images/stomata.jpg / http://www.isv.cnrs-gif.fr/jg/images/stomata.jpg

Aerosol | Climate | Health | Tools | Model

Intro (6b/7)

Thus AEROSOLS have access to tiny spaces, such as:

• Stomata of Leaves; e.g.
passive ventilation by **diffusion**
Arabidopsis thaliana (thale cress or mouse-ear cress)
Tabernaemontana. divaricata (crape jasmine)
Acer pseudoplatanus (maple leaf)
Hamelia patens (firebush)



Air pollution leads:
• stomatal closure and stomatal damage,
• leaf injury - decreased photosynthetic activity
• premature senescence, disturb membrane permeability
• reduced growth and yield (bonsai-like phenotype)

Amulya at al., 2015

15-01-14 Madl EDGE 20

In the present investigation an attempt was been made to assess the air pollution effects on micromorphological and biochemical parameters of *Tabernaemontana divaricata* (Gentianales: Apocynaceae) and *Hamelia patensi* (Gentianales: Rubiaceae). In polluted area the number of stomata and clogged stomata were found to be higher then control, where as the number of unclogged stomata are found to be very less in the control site.

Air pollution directly affects plants via leaves or indirectly via soil acidification. When exposed to air borne pollutants, most plants experienced physiological changes before exhibiting visible damage to leaves …. The atmospheric SO_2 adversely affects various morphological and physiological characteristics of plants. High soil moisture and high relative humidity aggravated SO_2 injury in plants …. Pollutants can cause leaf injury, stomatal damage, premature senescence, decreased photosynthetic activity, disturb membrane permeability and reduce growth and yield in sensitive plant species …. Air pollution stress leads to stomatal closure, which reduces CO_2 availability in leaves and inhibits carbon fixation. Net photosynthetic rate is a commonly used indicator of impact of increased air pollutants on tree growth …. The interaction between plants and different types of pollutants were influence of environmental pollution focus on physiological and ultra-structural aspects ….

Image: Stomata in leaf samples *T.divaricata* and *H.patens* from control and polluted areas. Note clogged stomata in leaf sample from polluted area. (A) *T. divaricata* from control area unclogged stomata; (B) *H. patens* from control area unclogged stomata; (C) *T. divaricata* from polluted area clogged stomata; and (D) *H. patens* from polluted area clogged stomata.

Source: Amulya L, Kumar NHK, Jagannath S (2015) Air pollution impact on micromorphological and biochemical response of *Tabernaemontana divaricata* L. (Gentianales: Apocynaceae) and *Hamelia patens* Jacq. (Gentianales: Rubiaceae)Brazilian Journal of Biological Sciences, Vol.2,(4): 287-294.

Aerosol | Climate | Health | Tools | Model

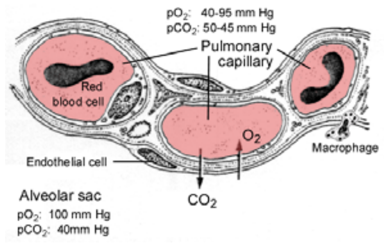
Intro (6c/7)

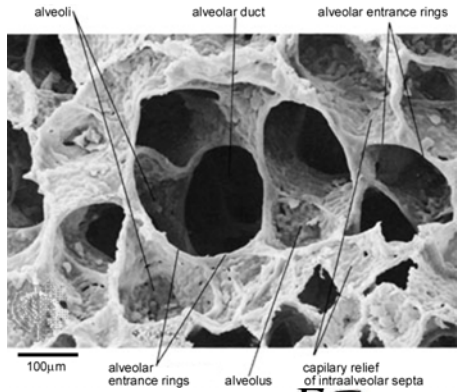
Thus AEROSOLS have access to tiny spaces, such as:

• Alveoli of the human Lung
active ventilation by **respiration**

Both stomata and alveoli are excellent AEROSOL filters;

Source. Encyclopedie Britannica, 1985





Alveolus / alveoli: the thin-walled saclike structure in the vertebrate lung where gas exchange takes place.

Scanning electron micrograph of the adult human lung showing alveolar duct with alveoli. Capillary relief of interalveolar septa is clearly visible because alveolar surfactant has not been preserved by fixation procedures.

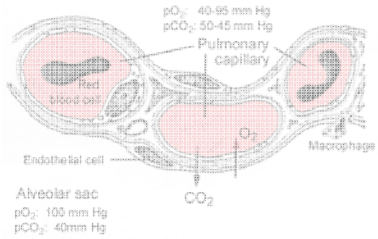
Source: http://http://concise.britannica.com/ebc/art-3362
http://www.mfn.unipmn.it/~pons/index_file/Page1171.htm

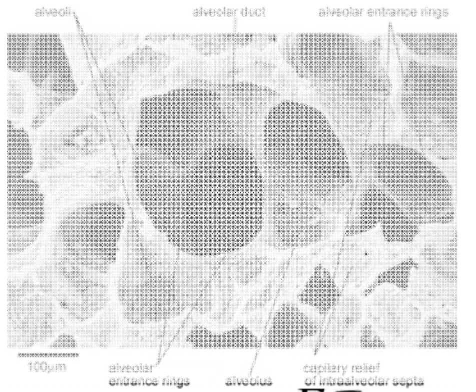
Aerosol	Climate	Health	Tools	Model

Intro (6c/7)

Thus AEROSOLS have access to tiny spaces, such as:

• Alveoli of the human Lung
active ventilation by **respiration**





Refer to part-III of this lecture series to obtain an in-depth look on health effects and related issues.

Prof. T.ürk - Antarctica, 2008

Part I

Aerosol Properties & Behavior

Aerosol Inventory (1/11)

An **Aerosol** is an assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement.
Generally, the sizes of aerosols are in the range from 0.001 to 100µm.






Dust | Smoke -Smog- Fume | Mist | Clouds ⇕ Fog | Blue Mountains - Effect

There is no such thing as a strict category;
there is a continuum of one size class to the next

Aerosols are tiny particles …. that scatter sunlight back to space and, thus, cause a regional cooling effect. The particles also can have an indirect cooling effect on climate by acting as seeds for cloud condensation and, thus, increasing the reflectivity, or albedo, of clouds. The effect of sulfate aerosols is equivalent to that of trillions of tiny mirrors floating in the sky, reflecting sunlight back to space. Concentrated predominantly over the industrial areas of the northern hemisphere, sulfates contribute to acid rain and haziness. In addition to sulfates, aerosols also include pollutants such as soot, organic carbon and mineral dust, and are produced both naturally and by human activities.

Aerosol: an assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement. Generally, the sizes of aerosols are in the range from 0.001 to 100µm. **Definitionen**: Der begriff wurde von Gibbs (1924) geprägt; er definierte es als zeitlich relativ konstante suspension von festen oder flüssigen teilchen in einem gas(förmigen) medium. **Particle**: small discrete objects - **Particulate**: a particle.

Dust: solid particles formed by crushing or other mechanical breakage of a parent material. These particles generally have irregular shapes and are typically around 0.5µm.

Fog & mist: liquid aerosol particle of 10µm – 100µm ion diameter.

Fume: particles that are usually the result of vapour condensation with subsequent agglomeration usually <0.05µm.

Smog: an aerosol consisting of solid and liquid particles, created at least in part, by the action of sunlight or vapour; thus <2mm.

Smoke: a solid or liquid aerosol, the result of incomplete combustion or condensation of supersaturated vapour; typically <1mm.

Nature of Aerosols:

Natural sources: soil and rock debris, forest fires, sea salt, volcanic debris, biogenic (pollen, viruses, bacteria, etc.). Meteoroligically spoken, invisible particles (<400nm) act as surfaces onto which water vapor can condense, which is an important function in the formation of clouds and fog. Interestingly only 0-4% of the lower troposphere is water (compared to 78% N_2 and 21% O_2), however, this amount coupled with the even lower percentage of aerosols accounts for the rain we get! **Blue Mountains:** The sky is blue because the air in the atmosphere scatters blue light. If the sky was not blue we would be looking out into space and we would see the deep black of space (just as on the moon). When we look at a distant object such as a mountain range we can also see the blue light scattered in the air. This is what gives distant maontains their blue colour. When you can see rows of ranges you will notice the further away the more blue the mountains appear. This is due to the furtherest maintains being viewed through a "thicker" atmoshperic stratum, resulting in more scattered blue light.

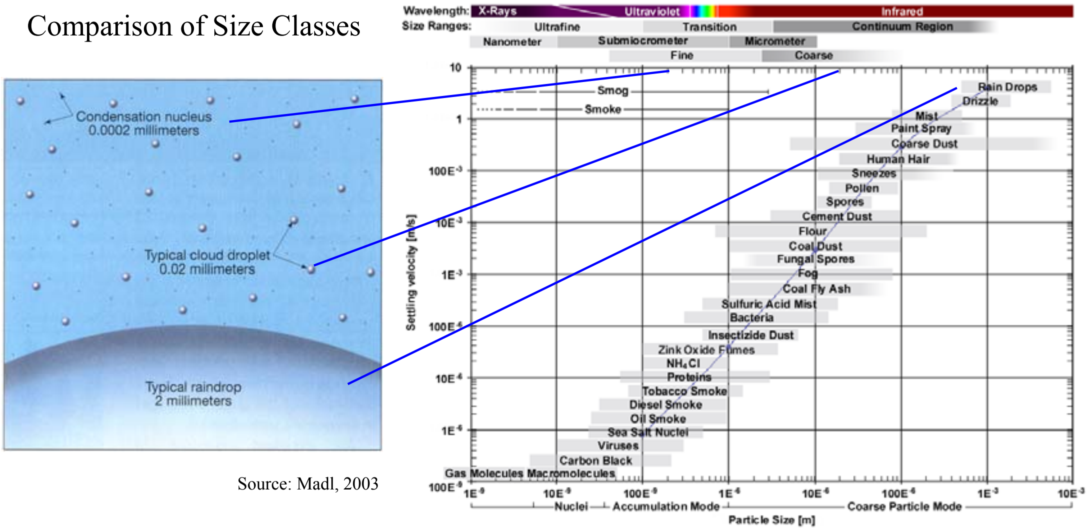
Anthropogenic sources: fuel combustion and industrial processes, industrial processes fugitive emissions, non-industrial fugitive emissions, transportation, etc.

Source: Lutgens & Tarbuk, 1998; p.7 / Cunningham & Cunningham, 2003; p.371 / http://www.zwei-m.ch/images/Brandung.jpg http://optics.kulgun.net/Blue-Mountains/

Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (2/11)

Comparison of Size Classes



Source: Madl, 2003

Aerosol: an assembly of liquid or solid particles suspended in a gaseous medium long enough to enable observation or measurement. Generally, the sizes of aerosols are in the range from 0.001 to 100µm.
Although visible dust sometimes clouds the sky, dust is relatively large and too heavy to stay in air for very long. Still many particles are microscopic and remain suspended for considerable periods of time.

Image: Comparison of the particle sizes of a sneeze exudate, human hair, pollen, fungal spores, bacteria, diesel soot and others, down to the viruses and biomolecules. The abscissa of the main image represents the size scale of an aerosol (1 nm to 10 mm). The sedimentation rate of the respective aerosol is plotted on the ordinate (100 nm/s to 10m/s). The 2nd abscissa in the upper part of the diagram depicts a rough classification of the corresponding electromagnetic spectrum; therein also the narrow band of "visible light" is visible.

RAIN: Formation of rain starts about the size of 200nm (condensation nuclei), while typical cloud droplets are 20 µm in size. Whereas the typical raindrop is 2mm in size,

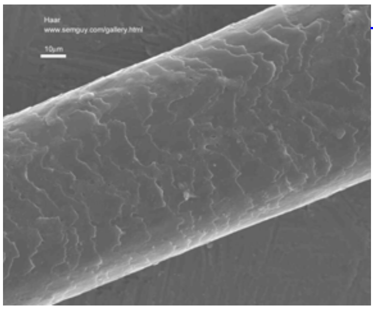
Source: Lutgens FK, Tarbuk EJ (1998) Atmosphere. Prentice Hall; p.7

Madl, 2003 modified after Colbeck 1998; Hinds 1999; and Stoker et al. 1972; Lutgens & Tarbuk, 1998; p.115

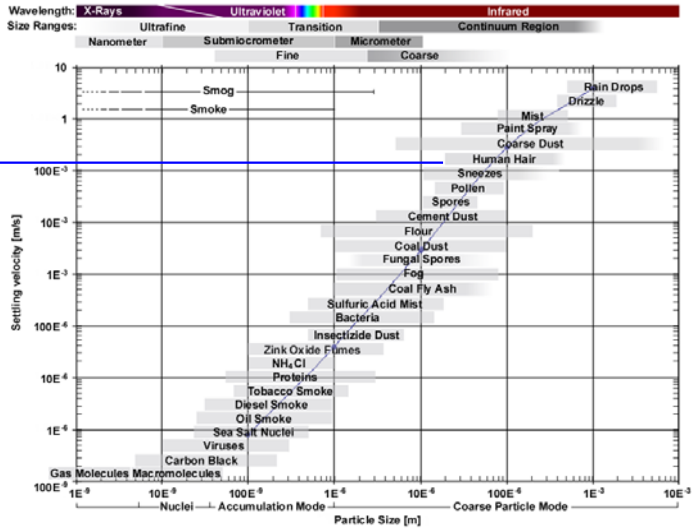
Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (3/11)

Comparison of Size Classes

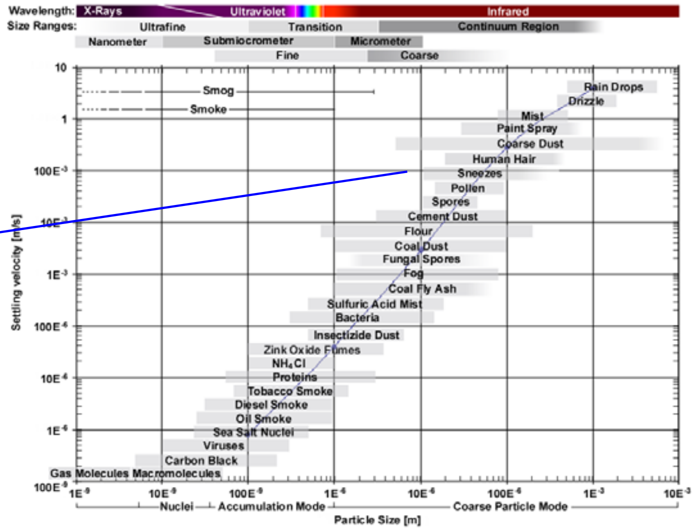


Source: Madl, 2003



Aerosol Inventory (4/11)

Comparison of Size Classes

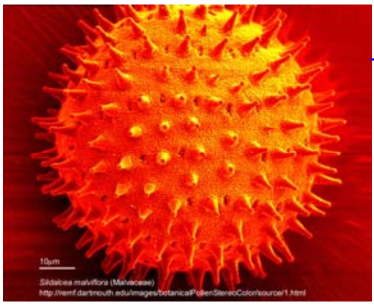


Source: Madl, 2003

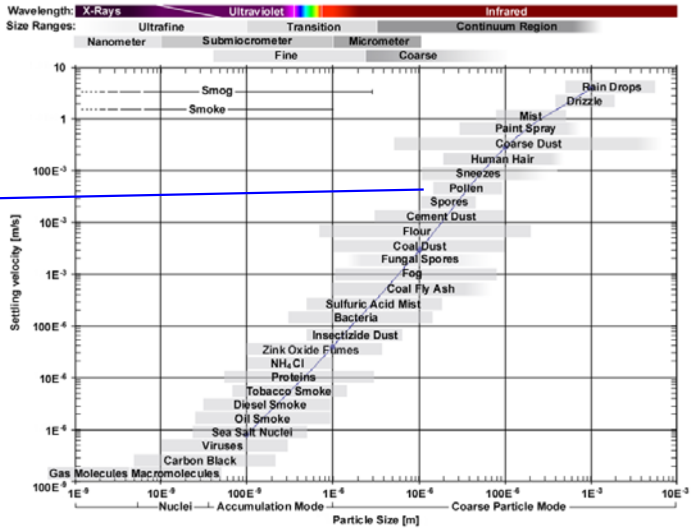
Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (5/11)

Comparison of Size Classes

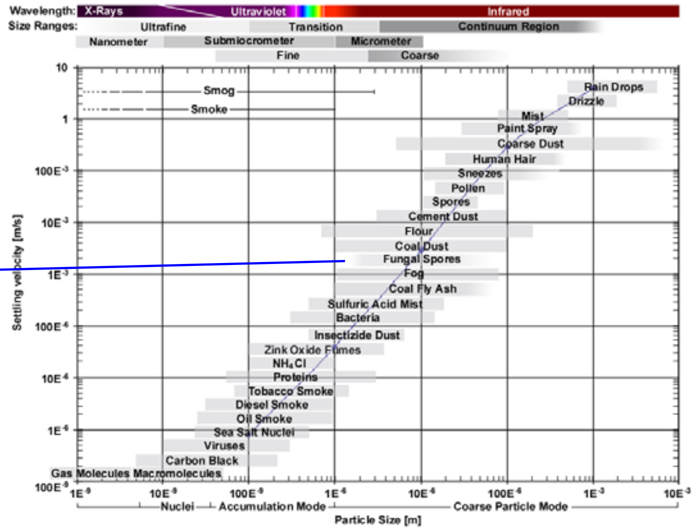


Source: Madl, 2003



Aerosol Inventory (6/11)

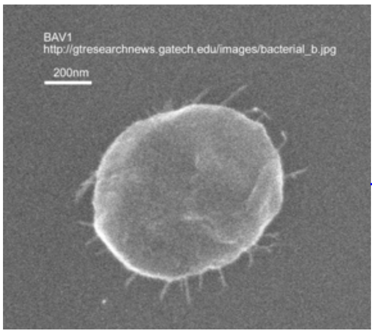
Comparison of Size Classes



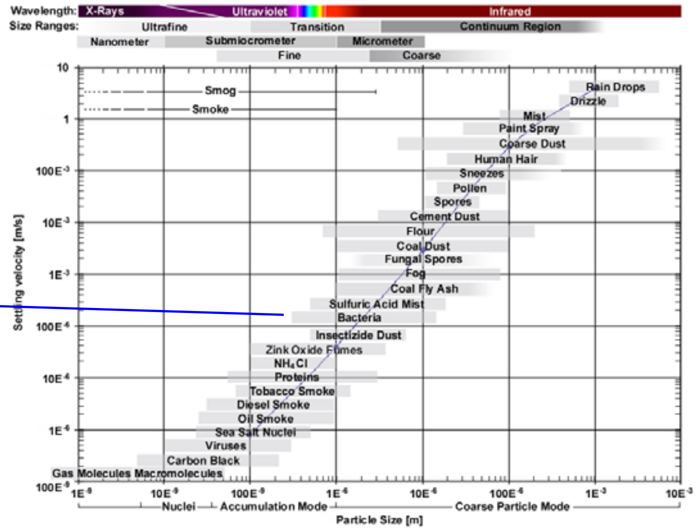
Source: Madl, 2003

Aerosol Inventory (7/11)

Comparison of Size Classes



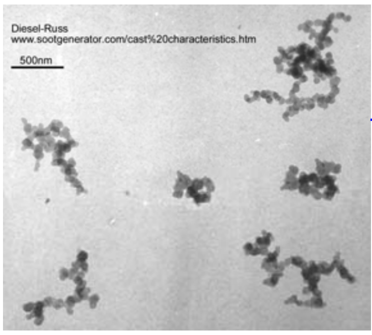
Source: Madl, 2003

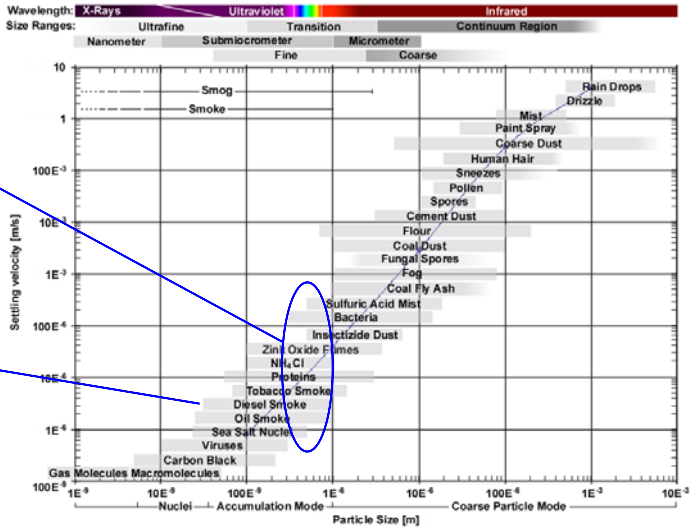


Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (8/11)

Comparison of Size Classes





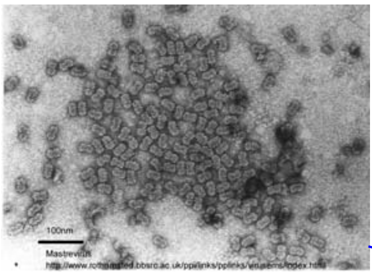
Madl

32

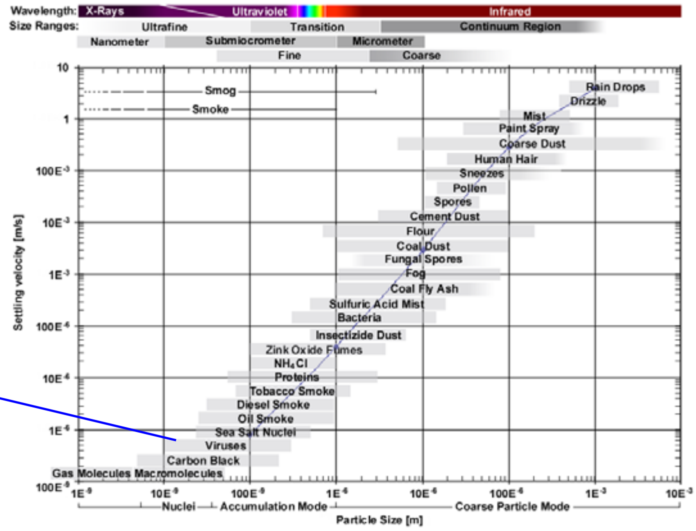
Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (9/11)

Comparison of Size Classes



Source: Madl, 2003



Aerosol	Climate	Health	Tools	Model

Aerosol Inventory (10/11)

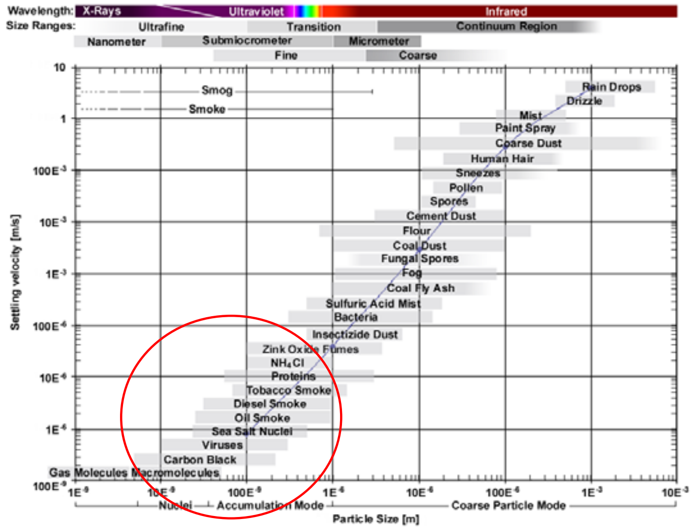
Comparison of Size Classes

There is no such thing as a strict category per se; rather we deal with a continuum of size classes that diffuses into each other.

The issues of concern are:

- surface area (invers. proportional to diameter)
- nano-aerosols (ultrafine-, sub-micrometer particles) are ideal for adsorption of e.g.VOC, radionucleides, isotopes, etc.

Madl, 2003



Although visible dust sometimes clouds the sky, dust is relatively large and too heavy to stay in air for very long. Still many particles are microscopic and remain suspended for considerable periods of time.
Grössenvergleich von Beispielobjekten, vom Niesaerosol, zum menschlichen Haar, über Pollen, Pilzsporen, Bakterien, Dieselruss bis hinunter zu den Viren.
Die horizontale Achse des zentral abgebildeten Diagramms stellt die Grössenskala eines Aerosols dar (1nm bis 10mm). Auf der vertikalen Achse ist die Absetzgeschwindigkeit des jeweiligen Aerosols aufgetragen (100nm/s bis 10m/s). Im obrigen Teil befindet sich auch eine Grobklassifizierung des dargestellten Spektrums in dem auch das kleine Band des "sichtbaren Lichts" abgebildet ist.

Sizes of Airborne Particles; superimposed are the settling velocities in still air at 0°C and 101.3kPa for particles having a density of 1g/cm^3 as a function of particle diameter[1].

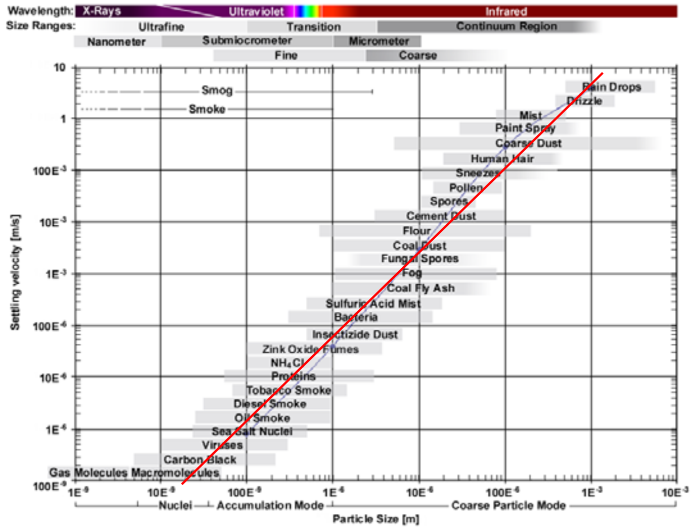
Source: [1] Madl P. (2003) Instrumental development and application of a thermodenuder. MSc-thesis, Queensland University of Technology, Brisbane & Paris Lodron University of Salzburg. Available online: http://www.ubs.sbg.ac.at/pdf/AC04556571.pdf

Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (11/11a)

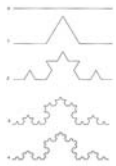
Comparison of Size Classes

There is no such thing as a strict category per se; rather we deal with a continuum of size classes that diffuses into each other.



Aerosol Fractal Properties

- log-log relationship
-



Madl, 2003

15-01-14 Madl 35

When looking at nature one wonders why it is must be so complex, why all these manifold expressions in form of species and climatic diversity. Yet a closer look, similar to the approach done in the previous section reveals that it is somehow inter-related, yet mankind took a long way to realize what these underlying links might be.

One of this mysterious network agents is not a thing but a property in which self-similar phenomenological patterns appear at different levels of organization. Nowadays we call this property a fractal behavior. A fractality, or simpler self-similarity does just that – it is a pattern that repeats itself on every level of magnification. A simple version of this is the Koch-curve - a classic iterated fractal curve. This curve is a theoretical construct that is made by iteratively scaling a starting segment. As shown, each new segment is scaled by 1/3 into 4 new pieces laid end to end with 2 middle pieces leaning toward each other between the other two pieces, so that if they were a triangle its base would be the length of the middle piece, so that the whole new segment fits across the traditionally measured length between the endpoints of the previous segment. Whereas the animation only shows a few iterations, the theoretical curve is scaled in this way infinitely.

Source: Madl P (2017) Organisational Bionics - Why nature is the better entrepreneur. BiPa Magazine Vol.5:xx-yy (in preparation)

Aerosol | Climate | Health | Tools | Model

Aerosol Inventory (11/11b)

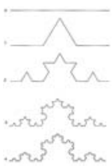
Comparison of Size Classes

There is no such thing as a strict category per se; rather we deal with a continuum of size classes that diffuses into each other.

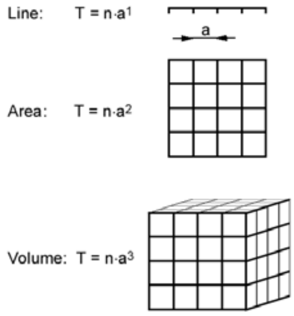
Koch curve

Aerosol Fractal Properties

- log-log relationship
- slope of log-log plot yields fractal dimension (δ)
- self-similarity



Reist, 1993



$(A_S)^{1/\delta} \propto V^{1/3}$,

15-01-14 Madl 36

Clouds, trees, plant root systems, and even the human lung are all examples of structures which can be described as fractals, as are random agglomerates of many small spherical particles which form into one large particle of a highly irregular shape. Many metal fumes are observed to be large numbers of these large, irregular particles. Because these fume particles lack a specific definable shape, it is hard to describe them quantitatively by diameter or area and even more difficult to predict their aerodynamic properties. Fractal geometry offers a method whereby descriptors can be assigned to these particles, thus permitting their quantitative study. There are several ways to consider the definition of a fractal. For example, consider a line, square, and cube. In each case the shape can be considered to be completely "filled“ – the line filled with line segments, the area with squares, and the volume with cubes. These three equations can be written as $\mathbf{T = n{\cdot}a^{\delta}}$, where δ could be 1, 2, or 3.

Considering what a non-integer implies that the shape is only partially filled, the degree of filling being greater as the value of δ becomes greater. Thus an irregular particle with many internal interstices could have its volume described by the factor δ, which would imply something about how loosely or tightly packed the particle was. The factor δ in this case is called by Mandelbrot the **fractal dimension** of the particle. A perfectly filled geometric shape such as a sphere or cube has a fractal dimension of 3, whereas an irregular shape such as a particle agglomerate might have a fractal dimension of 2.43, indicating that there is some openness in the particle. Plotting the logarithm of the particle perimeter length as a function of the logarithm of the ruler length gives a straight line. And 1 minus the slope of this line gives the fractal dimension, as defined above. Again the fractal dimension δ is indicative of the space-filling ability of the curve.

Mandelbrot defines the surface area fractal dimension δ as $\mathbf{(A_S)^{1/\delta} \propto V^{1/3}}$, where ***A.* is the surface area of a fractal object of volume V**. For natural objects this relationship holds only over some “ structural range“, with the upper limit related to the finite size of the agglomerating structure and the lower limit related to the size of the fundamental units that make up the object. For agglomerated aerosols that are natural fractals, the lower size limit is thought to be the size of the primary particle …. One important quality of fractal objects with the same fractal dimensions is that they are all self-similar; i.e. they possess no descriptive length scale at all …. Thus for a set of fractal objects having the same source and same fractal dimension, it is impossible to say which are the big ones or which are the small ones without some other frame of reference. Thus fractal dimensions must be used in conjunction with some other, more familiar particle measure

Source: Reist PC (1993) Aerosol Science and Technology, 2nd ed. McGraw-Hill Inc. New York (USA)

Animation: http://en.wikipedia.org/wiki/Fractal_dimension

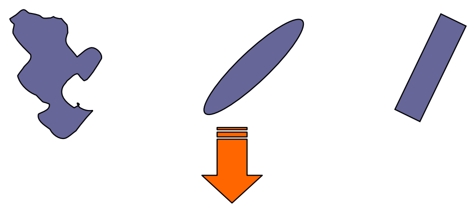
Aerosol | Climate | Health | Tools | Model

Particle Diameter

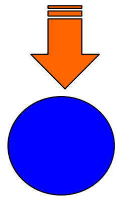
Particle diameter is not a static property – it changes according to the reaction dynamics;

- Particle **growth** due to agglomeration;
- Particle **fragmentation** due to photo-chemical stress;

The complex particle morphology, forces us to operate with an idealized spherical substitute!



e.g. math. conversion for particles <1µm:



$$d_a = \sqrt{\frac{C_c \cdot (d_p)}{C_c \cdot (d_a)}} \cdot \sqrt{\rho_p} \cdot d_p$$

The equivalent particle diameter is the diameter of a sphere having the same value of a physical property as the irregularly shaped particle being measured. It relates to particle behaviour (such as inertia, electrical or magnetic mobility, light scattering, radioactivity or Brownian motion) or to particle properties (such as chemical or elemental concentration, cross-sectional area, volume to surface ratio)

- Density
- Number (count)
- Mass
- Size and size distribution
- Shape and surface area
- Electric charge

For particles <1µm :

d_a aerodynamic diameter [m]

is the diameter of a unit-density sphere (1g/cm^3) having the same gravitational settling velocity as the particle being measured.

d_p physical particle diameter [m]

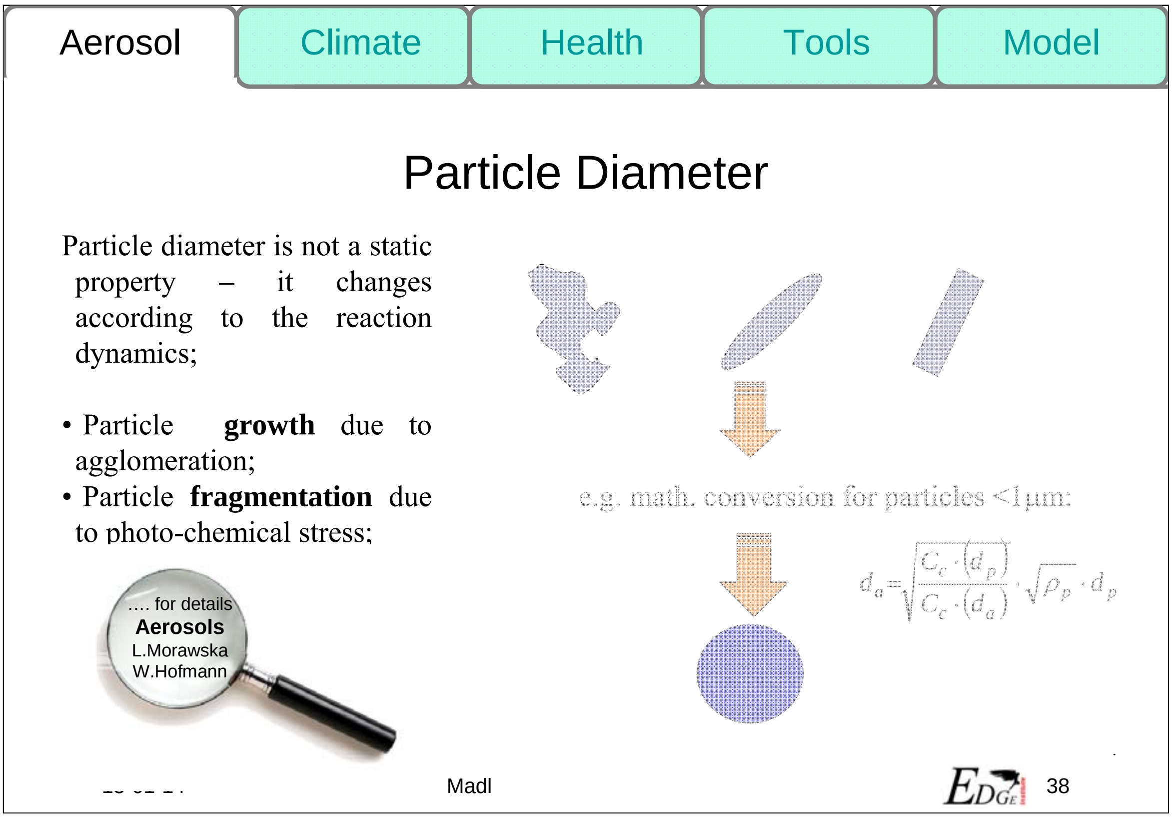
C_c Cunningham slip correct. [-]

it is assumed that the particle is still moving in the continuum gas flow

(λ, β and γ are empirical parameters)

ρ_p, particle density [g/m^3]

Source: Morawska, 2003



For details on aerosol physics see scripts from:
Prof. Lidia Morawska: biophysics.sbg.ac.at/transcript/aerosol2.pdf
Prof. Werner Hofmann: biophysics.sbg.ac.at/transcript/aerosol1.pdf

Aerosol | Climate | Health | Tools | Model

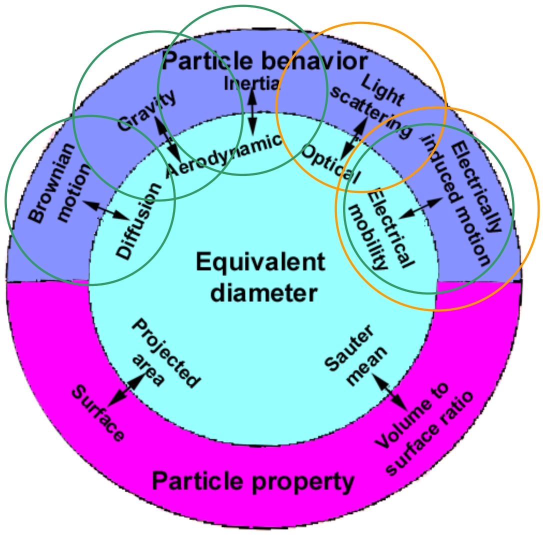
Particle Diameter (cont'd)

According to the parameter of interest (property / behavior) the equivalent diameter is biased as follows:

Particle Deposition in the Lung:
- Inertia (naso-tracheal)
- Gravity (tracheo-bronchial)
- Diffusion (bronchio-alveolar)

Particle Detection with SMPS / OPC
- Electrical (quality)
- Optical (quantity)

Particle Detection with LPBI / ELPI
- Inertia (quantity)



Source: Willeke, 1993

15-01-14 Madl 39

Particle equivalent diameter: is the diameter of a sphere having the same value of a physical property as the irregularly shaped particle being measured, it relates to particle behaviour (such as inertia, electrical or magnetic mobility, light scattering, radioactivity or Brownian motion) or to particle properties (such as chemical or elemental concentration, cross-sectional area, volume to surface ratio).

Aerodynamic (equivalent) **diameter** is the diameter of a unit-density sphere ($1 g/cm^3$) having the same gravitational settling velocity as the particle being measured.

Particle size definitions that depend on observation of particle properties or behaviour

The **Sauter mean diameter** (SMD) is defined as the diameter of a sphere that has the same volume/surface area ratio as a particle of interest. Originally developed by German scientist, J. Sauter in the late 1920s. The SMD is common measure in fluid dynamics as a way estimating the average particle size. Several methods have been devised to obtain a good estimate of the SMD. The SMD is typically defined in terms of the surface diameter;

Source: Baron BA, Willeke K (2001) Aerosol Measurement Principles, Techniques, & Applications, 2^{nd} ed; J Wiley & Sons, USA

http://en.wikipedia.org/wiki/Sauter_diameter

Particle Diameter (cont'd)

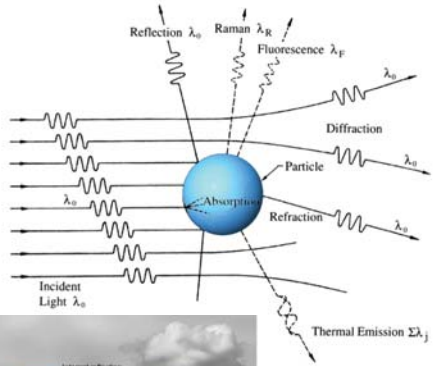
According to the parameter of interest (property / behavior) the equivalent diameter is biased as follows:

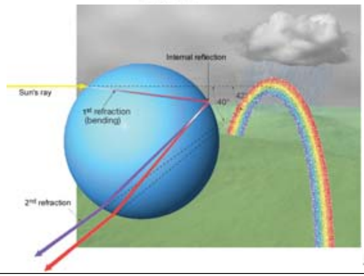
Particle Deposition in the Lung:
- Inertia (naso-tracheal)
- Gravity (tracheo-bronchial)
- Diffusion (bronchio-alveolar)

Particle Detection with SMPS / OPC
- Electrical (quality)
- Optical (quantity)

Particle Detection with LPBI / ELPI
- Inertia (quantity)

Source: Willeke, 1993





The various processes that can occur when radiation of wavelength λ_0 interacts with a particle. Inelastic scattering processes include Raman scattering and fluorescence. For the interaction of solar radiation with atmospheric aerosols, elastic light scattering is the process of interest. The absorption and elastic scattering of light by a spherical particle is a classical problem in physics, the mathematical formalism of which is called Mie theory (sometimes also Mie–Debye–Lorenz theory). It is a beautiful and elegant theory, which is the subject of entire treatises. In particular, we refer the reader to Kerker (1969) and Bohren and Huffman (1983). The key parameters that govern the scattering and absorption of light by a particle are (1) the wavelength λ of the incident radiation; (2) the size of the particle, usually expressed as a dimensionless size parameter. the ratio of the circumference of the particle to the wavelength of light; and (3) the particle optical property relative to the surrounding medium.[1]

$$\alpha = \pi \cdot D_p / \lambda \ [-]$$

Image: Mechanisms of interaction between incident radiation and a particle.[1] Color separation during formation of a primary rainbow results when sunlight is refracted as it enters a raindrop and again when it leaves the raindrop. This results in the colors of the rainbow. It takes millions of raindrops to produce a rainbow. Each observer sees only one color from each of these raindrops.[2]

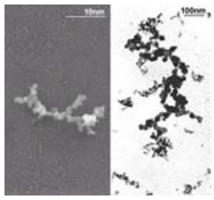
Source: [1] Seinfeld J, Pandis S (2016). Interaction of Aerosols with Radiation, In: Atmospheric Chemistry and Physics, Ch.15; 3rd ed, *John Wiley & Sons*, Hoboken (NJ), USA

[2] Lutgens FK, Tarbuck EJ (2013) Optical Phenomena in the Atmosphere, Ch.16. In: The Atmosphere – Introduction to Meteorology, 12th ed. Pearson Education Inc. Glenview (IL) USA.

Aerosol | Climate | Health | Tools | Model

Surface (1/3)

Petrol versus Diesel



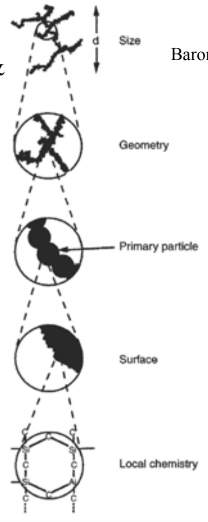
Surface-Effects

Inter-particle forces characterize **ad- & ab-sorption**; determined by

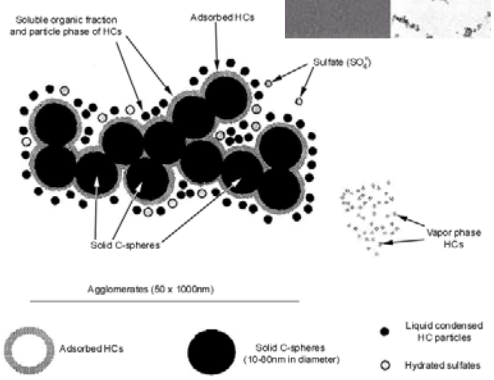
- size
- shape
- roughness
- chemistry (bonding, ionic/covalent)
- charges (dipols)
- hydro- / lipo-phobicity
- vapor pressure

Properties of **surrounding**

- T (thermophoresis), aerosol separator;
- E (photophoresis), acoust.cavity spectrom.;
- humidity (fluid film), CPC; growth;
- conductivity (epiphanom., AES)
- rel.particle velocity
- contact time
- biological reactivity



Baron & Willeke, 2001



15-01-14 Madl EDGE 41

Calculation of lognormal distributions with discrete size distribution intervals. Surface area and volume distributions are calculated assuming spherical particles. A simulation of random number count errors is included, as well as calculation of respirable, thoracic, inhalable, and PM_{10} dust fractions. [1] …. Even if all these particles have the same microscopically observed diameter, the mass, surface area, and other properties of each particle are likely to be quite different …. In addition, the chemistry, surface area, and fibrosity of the particles may indicate their interactions with the lung tissues once they are deposited.[2] ….

Vertical Image: Schematic structure of an agglomerate in two-dimensional space. Scanning down the figure corresponds to viewing the particle at ever higher magnification. Such an agglomerate might be observed at several magnifications, ranging from the structure of the entire particle down to the chemical structure of the surface. Thus, at lowest magnifications, the complex structure can be represented by a fractal dimension; at an intermediate magnification, the spherules have nearly integral dimension; at higher magnification still, the spherule surface may be rough and characterized by another fractal dimension. The intra- and interparticle forces that hold particles together …. are difficult to quantitate. These forces may depend on particle bulk and surface parameters (size, shape, roughness, chemistry), the properties of the surrounding gas (temperature, humidity) and the mechanics of the contacting particles (relative particle velocity, contact time) …. adhesion. At high humidity, liquid molecules are adsorbed on the particle surface and fill the capillary spaces at and near the point of contact. The surface tension of this liquid layer increases the adhesion between the two surfaces …. Particle adhesion on impact is an especially critical factor in inertial collection devices.[3] …. In evaporation-condensation-reaction processes, reactions take place at the newly formed particle surface altering the chemical and/or phase composition of the particles.[7]

Thermophoresis: Particles in a thermal gradient are bombarded more strongly by gas molecules on the hotter side and are therefore forced away from a heat source. Thus, heated surfaces tend to remain clean, while relatively cool surfaces tend to collect particles.[4] ….

Photophoresis: is similar to thermophoresis in that particle motion is caused by thermal gradients at the particle surface except that in this case the heating is caused by light absorption by the particle rather than by an external source …. Thus, in the former case the particle will be repelled from the light source, while in the latter.

SurfaceAreaMeter: The epiphaniometer exposes the aerosol to a radioactive gas that decays to radioactive metal atoms, which diffuse to the aerosol particles' surface. The gas is removed before detection, and the resulting radiation detected is indicative of the total particle surface area. Another approach uses short wavelength light to produce electron emission from the surface of the aerosol particles. The charge detected is a function of surface area and may also be specific for certain chemical species.[5]

Auger electron spectroscopy (AES) is a surface sensitive method for determination of the chemical composition of materials. This method requires an ultrahigh vacuum chamber and involves directing an electron beam at a sample which results in emission of electrons with energies that are characteristic of the elements in the sample. Depth profiling can be obtained in combination with sputtering for solid samples. This method is surface sensitive with a penetration depth of 0.5 to 2nm and can detect elements from Li through U with up to 0.3% sensitivity. Instruments with 100nm spatial resolution are available. Since even single particles can be examined, the amount of material required is very small.[8]

Bio. Reactivity: Although particle aerodynamic diameter dominates deposition within the respiratory tract, the subsequent effect on health is a combination of physical particle characteristics and biological response. On deposition, the body may react to the chemical substances contained within the particle, interact with the particle surface, or be influenced by physical parameters such as size and morphology.[6]

Source: B.A.Baron & K.Willeke (2001). Aerosol Measurement Principles, Techniques and Applications, 2nd e.d; [1] p.35; [2] p.45-46; [3] p.56-58; [4] p.79-; [5] p.123; [6] p.781; [7] p.936; [8] p.950; / [2] Horstman *et al*. (2003), transcript. [3] p.56-58; / [3] AKPF (2000), p.2.

Aerosol | Climate | Health | Tools | Model

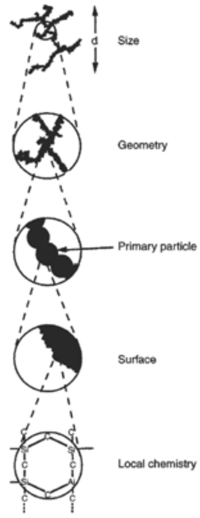
Surface (2/2)

Surface-Effects

Greater surface area per mass renders nanoparticles more ....

- biologically active;
- surface area to total number of atoms increases exponentially!

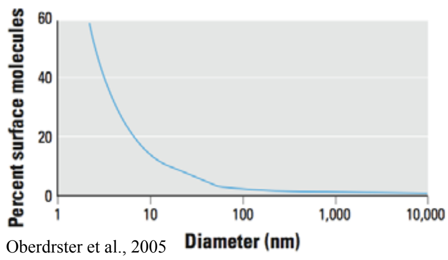
e.g. exposure to 10µg/m^3 (EU threshold values: 50µg/m^3)
- i.e. **high number concentration**
- w/ **exorbitantly high** surface area (e.g. as in charcoal-filters!)



Baron & Willeke, 2001

Table 2. Particle number and particle surface area per 10 µg/m^3 airborne particles.

Particle diameter (µm)	Particle no. (cm^{-3})	Particle surface area (µm^2/cm^3)
5	153,000,000	12,000
20	2,400,000	3,016
250	1,200	240
5,000	0.15	12



Oberdrster et al., 2005

15-01-14 Madl 42

The greater surface area per mass compared with larger-sized particles of the same chemistry renders nanoparticles more active biologically [1] .... Likewise, their increased surface area per unit mass can be toxicologically important if other characteristics such as surface chemistry and bulk chemistry are the same .... The importance of surface area becomes evident when considering that surface atoms or molecules play a dominant role in determining bulk properties; the ratio of surface to total atoms or molecules increases exponentially with decreasing particle size [2] ....

Even very low concentrations of nanosized materials in the air represent very high particle number concentrations .... Surface molecules increase exponentially when particle size decreases <100nm, reflecting the importance of surface area for increchemical and biologic activity of nanoparticles [3] ....

Source: Oberdörster G., Oberdörster E., Oberdörster J. (2005). Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles; Environmental Health Perspective Vol. 113, No.7: 823-839, [1] p.823; [2] p. 824; [3] p.825;

Aerosol | Climate | Health | Tools | Model

Surface (3/3)

Surface-Effects

Greater surface area per mass renders nanoparticles more ....

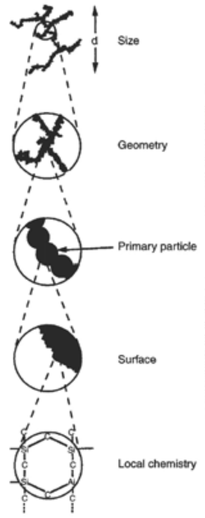
- biologically active;
- surface area to total number of atoms increases exponentially!

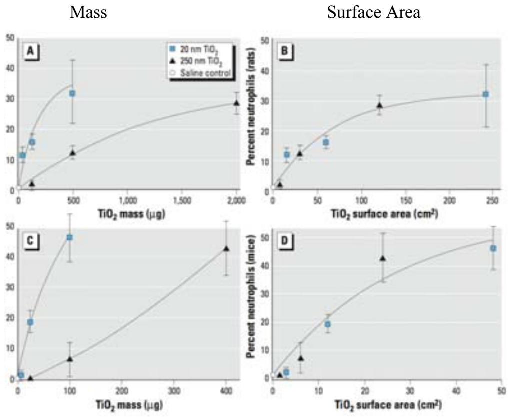
Surface area is a much better indicator than

- particle mass and even
- particle number concentration ….

However, particle number is required to determine surface area

Baron & Willeke, 2001





Oberdörster et al., 2005

However, when the instilled dose was expressed as particle surface area, it became obvious that the neutrophil response in the lung for both ultra- fine and fine TiO_2 fitted the same dose-response curve, suggesting that particle surface area for particles of different sizes but of the same chemistry, such as TiO_2, is a better dosemetric than is particle mass or particle number concentration [1] ....

Figure 4. Percentage of neutrophils in lung lavage of rats (A,B) and mice (C,D) as indicators of inflammation 24hr after intratracheal instillation of different mass doses of 20-nm and 250-nm TiO_2 particles in rats and mice.

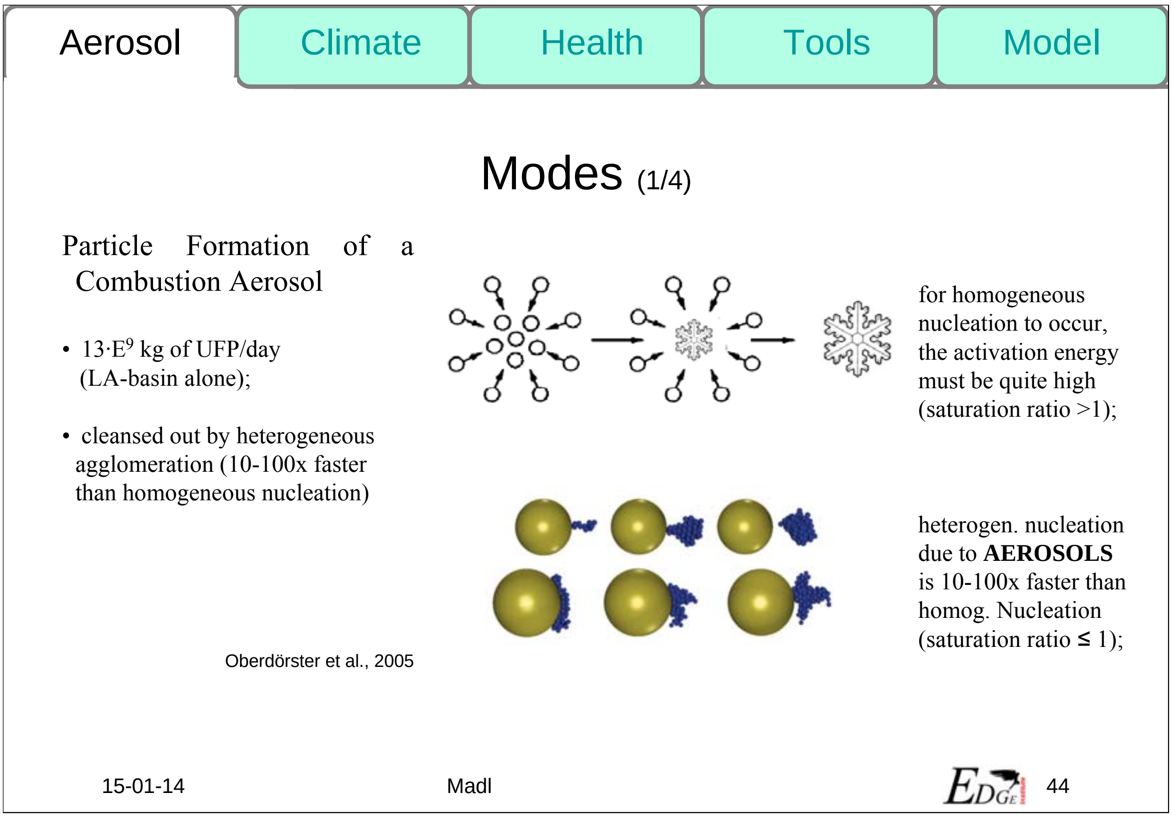
(A,C) The steeper dose response of nanosized TiO_2 is obvious when the dose is expressed as mass.

(B,D) The same dose response relationship as in (A,C) but with dose expressed as particle surface area;

The latter indicates that particle surface area seems to be a more appropriate dosimetric indicator for comparing effects of different-sized particles, provided they are of the same chemical structure (anatase TiO_2 in this case).

Data show mean +/-SD.

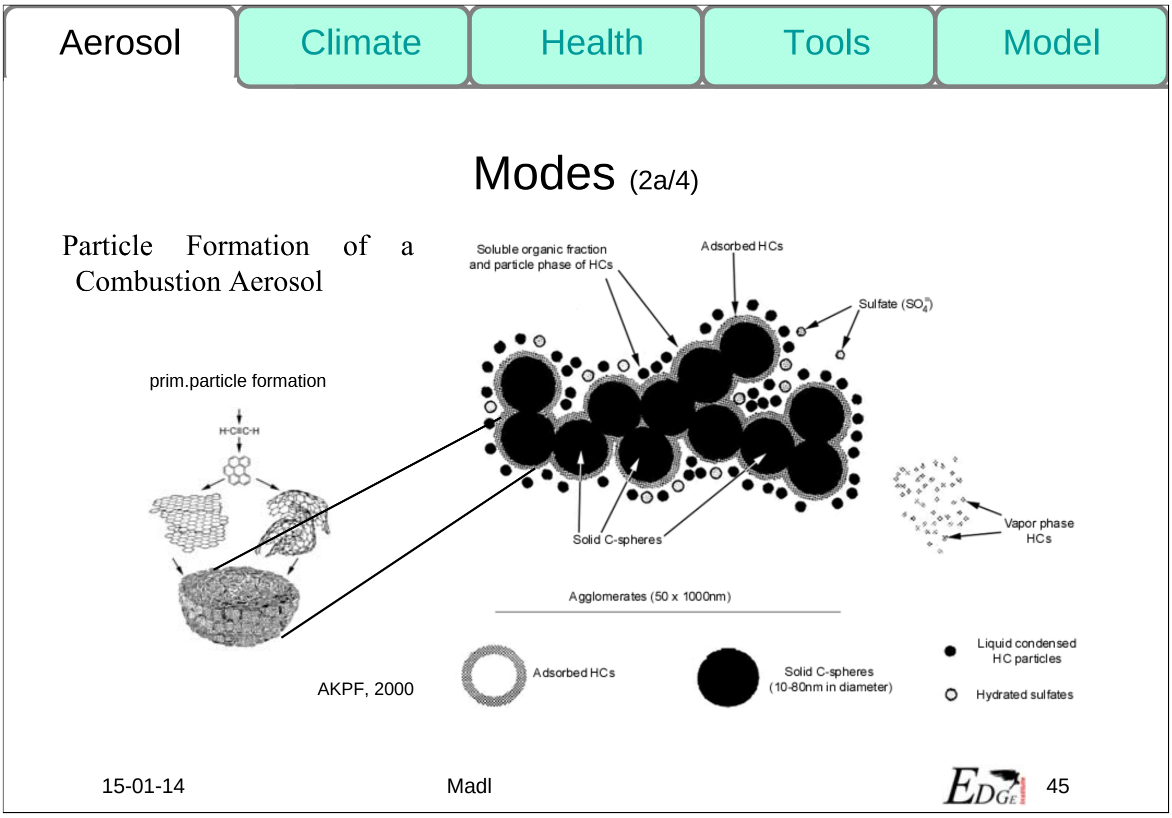
Source: Oberdörster G., Oberdörster E., Oberdörster J. (2005). Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles; Environmental Health Perspective Vol. 113, No.7: 823-839, [1] p.826;



UFP are ubiquitous in indoor and outdoor air. Indeed, a source emission inventory for the South Coast Air Basin surrounding Los Angeles (USA) estimated a primary UFP emission rate of 13 tons per day (Cass et al. 2000). However, due to heterogeneous and homogeneous coagulation, UFP numbers decrease at higher concentrations rapidly by factors of 10 and more; for example, with increasing distances from highways (Zhu et al. 2002), or with increasing aging times of aerosols .... Cleaning up the air by reducing the number of larger accumulation mode particles significantly may cause a longer persistence and thereby increase of the ultrafine mode since the sink for their effective elimination is no longer present.

Source: Oberdörster G., Oberdörster E., Oberdörster J. (2005). Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles; Environmental Health Perspective Vol. 113, No.7: 823-839, [3] p.830; [4] p.834;

Supplemental Material available online (http://ehp.niehs.nih.gov/members/2005/7339/supplemental.pdf) p.3-4;



The physical characteristics of soot are inert, odourless, and insoluble in water and in organic solutions. It is, however, a high adsorbent for hydrocarbons, aldehydes, oxygen-containing odour compounds and sulfur containing molecules. The $SO_4^=$ fraction of diesel exhaust particles is composed primarily of the sulfuric acid (H_2SO_4) formed from the sulfur contained in the fuel and or the lubricating oil. It is generated when SO_2 is oxidized to sulfur trioxide (SO_3^-). Upon exposure with water vapor (likewise a by-product of the combustion process) it converts to H_2SO_3 and eventually to H_2SO_4 [1]. These H_2SO_4 particles adhere to the carbonaceous structure. Formation of H_2SO_4 is widely load-dependent; only a small amount is produced in low load conditions, while more of it occurs at high load operation conditions. As sulfur content in diesel has a detrimental effect on diesel fume purification, it is a major player in the negative health effects on humans of diesel exhaust. Unfortunately, the sulfur content in the exhaust stream makes catalysts useless, as it interferes with the precious metals or oxides the catalyst is coated with[2]. To really deal with the particle problem, the sulfur in the fuel has to be gotten rid off at the refinery. Reducing sulfur content to 5 ppm or lower brings dramatic improvements, by eliminating the sulfur nanoparticles. Only then can the exhaust particle stream react with the metal-coated substrate of the catalysts to further oxide them while the solid fraction could be trapped in particle filters[3].

The chemistry of ambient UFP depend on particle size and source of origin. The smaller ambient ultrafine particles approaching 10 nm consist increasingly of organic compounds (Kittelson 1998) which are lipid or water soluble[4].

Source: [1] Atkins, (1997), p.534. /
[2] Horstman *et al*. (2003), transcript. /
[3] AKPF (2000), p.2. /
[4] Oberdörster G., Oberdörster E., Oberdörster J. (2005). Nanotoxicology: An Emerging Discipline Evolving from Studies of Ultrafine Particles; Environmental Health Perspective Vol. 113, No.7: 823-839; Supplemental Material available online (http://ehp.niehs.nih.gov/members/2005/7339/supplemental.pdf) p.19;

Aerosol | Climate | Health | Tools | Model

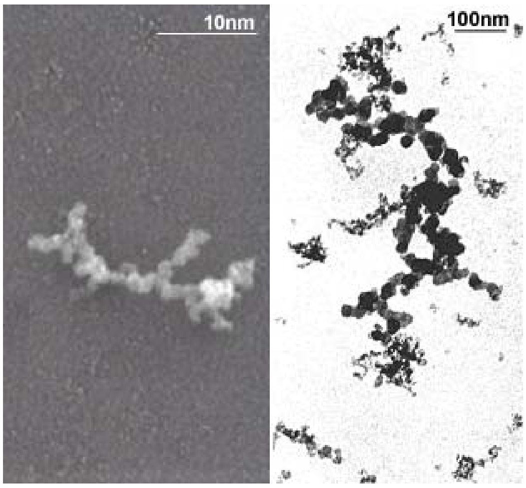
Modes (2b/4)

Particle Formation of a Combustion Aerosol
e.g. combustion aerosol

- Micrograph of petrol (left)
- Agglomerate of soot (right)

Nucleation-mode particles in traffic exhaust consist mostly of semi-volatile and evaporate ….

…. due to their fractal nature, the surface area (and thus absorbance) of such a cluster is enourmous!



Size - determines, in part, the lung deposition
Solubility:
soluble particles - generally have low or no lung toxicity
can have systemic toxicity
insoluble particles – more likely to be toxic
exhibit a wide range of toxicities
dependent on other particle characteristics

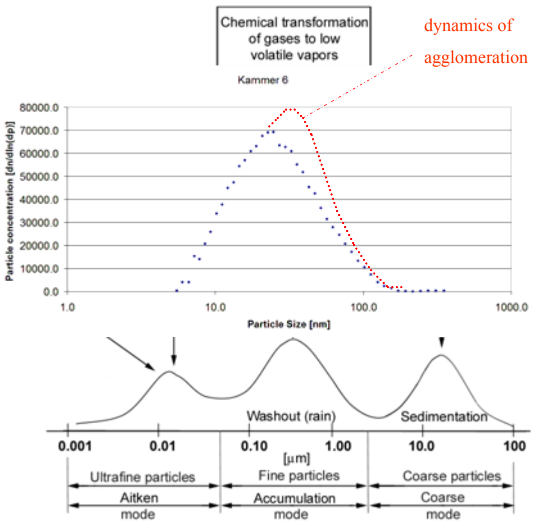
Source: Morawska, 2003
Dall'Osto M, Thorpe A, Beddows DCS, Harrison RM, Barlow JF, Dunbar T, Williams PI, Coe H (2011) Remarkable Dynamics of Nanoparticles in the Urban Atmosphere, Atmos. Chem. Phys., Vol.11: 6623-6637.

Aerosol | Climate | Health | Tools | Model

Modes (3a/4)

Aerosol Dynamics

- Nucleation Mode
  (new particle formation, primary particles)
- Aitken Mode
  (subsequent agglomeration of nucleation)
- Accumulation Mode
- Coarse Mode
  (mechanically generated)



NaCl-animation: Madl & Kwasny, 2006

Madl, 2003

Aerosols modes and their Dynamics: Tropospheric condensation nuclei are typically very small and cover a range from a few nanometers to less than 100 nm. Under favorable abiotic conditions, these aerosols can rapidly agglomerate to larger clusters that characterize the Aitken mode (see Fig). Condensation nuclei are particles directly emitted into the atmosphere or formed there by gas-to-particle conversion. This mode is not always present, but is usually found in the upper troposphere or near combustion sources. Because of their high number concentration, especially near their source, these tiny nano-particles coagulate rapidly with each other and give rise to the Aitken mode. Consequently, nucleation particles have relatively short lifetimes in the atmosphere and eventually agglomerate to larger clusters, which are then grouped into the accumulation mode.[1]

Image: Schematic of a typical size distribution It shows the mass weighted formation mechanisms for atmospheric particles.[2] Animation: revealing the dynamics of an atomized NaCl-sample in a closed setting (hermetically sealed stainless steel tank) as time passes [3];

•Animation covers a time window of 140min;

•Duration of injection: 60secs

•Holding capacity of tank: 800L

Source: [1] Hinds W.C. (1999). Aerosol Technology – Properties, Behavior and Measurement of Airborne Particles, 2nd ed. John Wiley & Sons – USA.
[2] Madl P. (2003) Instrumental development and application of a thermodenuder. MSc-thesis, Queensland University of Technology, Brisbane & Paris Lodron University of Salzburg. Available online: http://www.ubs.sbg.ac.at/pdf/AC04556571.pdf
[3] Madl & Kwasny, 2006;

Aerosol | Climate | Health | Tools | Model

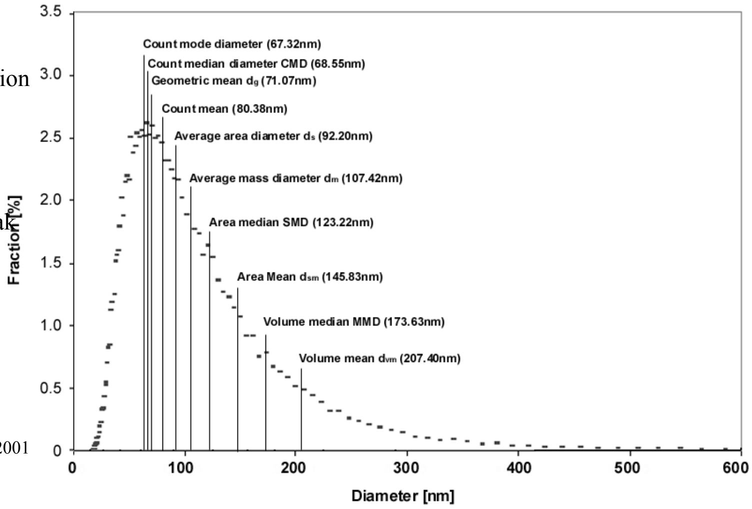
Modes (3b/4)

Aerosol Characterisation:

Monodisperse Size distrubution Modes:

- Mean: arithmetic avg $d_{particle}$
- Mode: size class w/highest count
- Median: 50% on either side of peak of
- numeric modes
- surface area modes
- volumentric modes
  (& density modes)

Baron & Willeke, 2001



15-01-14 Madl 48

The function obtained in this way displays a pattern in which data points at the smaller end of the spectrum are closely spaced, while those at the larger end of it are further spaced. The result is shown in the figure. It displays a particle size distribution curve that is the graphical representation of the frequency function. It is also known as a probability density function [2].

Such a modified chart has the advantage of showing at a glance what the particle size distribution of an aerosol looks like and is perhaps the best way of visually representing complex size distribution data. The same figure also shows various diameters that characterize this arithmetic plot. Whether the distribution is plotted as number, area, mass or volume distribution, the form of the size distribution can look very different.

The reason for this is rooted in the fact that particles at the smaller end of the size spectrum can be very abundant in number, but because area is proportional to the square and mass (or volume) to the cube of the diameter, such particles may contribute only to a small extent to the total area, mass, or volume respectively. Commonly used quantities for defining the location of a distribution are the mean, median, mode, geometric mean, etc. In order to better comprehend these diametric entries, the following section provides a short overview.

Source: [1] B.A.Baron & K.Willeke (2001). Aerosol Measurement Principles, Techniques and Applications, 2nd ed.; p.50;

[2] Hinds (1999) Aerosol Technology – Properties, Behavior and Measurements of Airborne Pasrticles 2nd ed. Wiley Publ. New York; p.78.

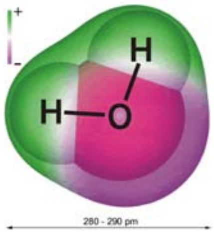
For a step-by-step description in the build up of a histogram, see Hinds p.75.

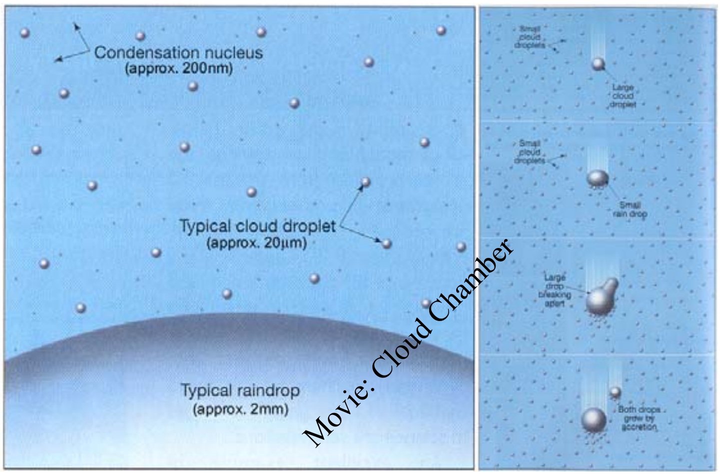
Aerosol | Climate | Health | Tools | Model

Modes (4a/4)

Particle Growth

e.g. rain droplets (**sperical**)
Nucleation principle:
- Heterogeneous (soluble or insoluble seedling)
- Homogeneous (supersaterat.)





Source: Chaplin M., 2007; Lutgens & Tarbuk, 1998,

15-01-14 Madl 49

Comparative diameters of particles involved in condensation end precipitation processes. Water clusters form by hydratation processes around a nucleation seedling – e.g. a suspended particle, i.e. an aerosol.

The collision-coalescence process: most cloud droplets are so small that the motion of the air keeps them suspended. Because large cloud droplets fall more rapidly than smaller droplets, they are able to sweep up the smaller ones in their path and grow.

In comparison the diameter of a single H_2O-molecule amounts to approx. 2.85Å (or 285pm).

Source: Lutgens & TArbuk, 1998, p.115 & 118
Chaplin M., 2007; http://www.lsbu.ac.uk/water/index2.html
http://de.wikipedia.org/wiki/%C3%85ngstr%C3%B6m_%28Einheit%29

Aerosol | Climate | Health | Tools | Model

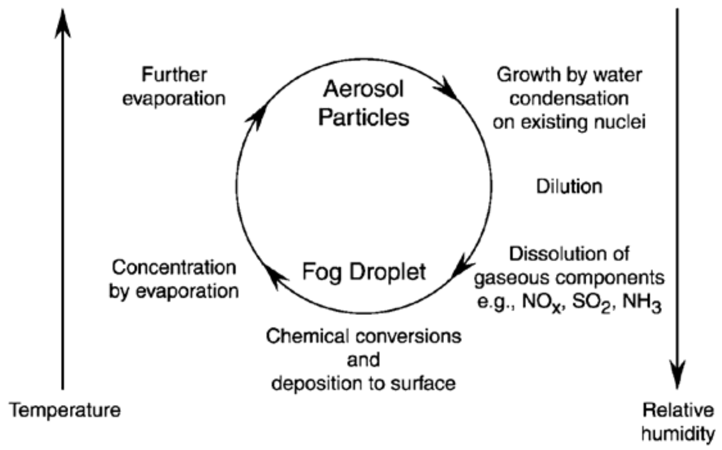
Modes (4b/4)

Particle Growth

e.g. condensation dynamics

Dynamic balance b/w:

- rel. humidity
- Temperature
- heterogeneus induction of growth
- presence of trace pollutants



Finlayson & Pitts, 2000

15-01-14 Madl 50

The reason that the aqueous-phase concentrations in fogs can be so high is related in part to the liquid water content (LWC), which is a major difference between clouds and fogs. The liquid water content for fogs is typically of the order of 0.1 $g \cdot m^{-3}$ of air, whereas that for clouds is about an order of magnitude higher. This small LWC in fogs corresponds to increased solute concentrations. A second reason for the higher concentrations in fogwater is the relatively rapid condensation and evaporation of water vapor onto preexisting particles as the fog forms and then dissipates. The image above is a schematic of this process. Aerosol particles, which typically contain sulfate and nitrate as well as a variety of other species, act as condensation nuclei for the condensation of water as the relative humidity increases during fog formation. As more water condenses, the particle components become increasingly diluted. Simultaneously, the solution can take up gases such as SO_2, HNO_3, and NH_3, and chemical reactions such as the oxidation of S(IV) to sulfate can occur in the droplet. Both the initial sulfate in the particle on which water condensed and sulfate formed by oxidation of S(IV) in the fog aqueous phase can contribute significantly to the total sulfate deposition …. It is estimated that in a typical Arctic radiation fog, preexisting sulfate aerosol accounts for about 60% of the sulfate deposition and oxidation of S(IV) in the aqueous phase the remaining 40%.

Image: Schematic of role of atmospheric aerosols in fog formation and evaporation

Source: Finlayson-Pitts BJ, Pitts JN (2000) Chemistry of the Upper and Lower Atmosphere - Theory, Experiments, and Applications. Academic Press, San Diego, California, USA

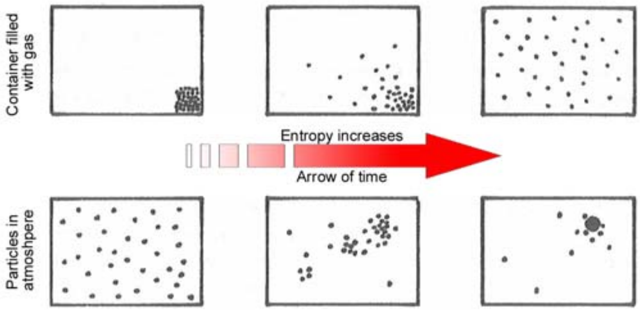
Kinetics (1/5)

Aerosol Kinetics – main Modi:

- Entropy & the arrow of time under the influence of $E = k{\cdot}T$:
- Entropy (measure of randomness) as defined by Boltzmann $S = k \cdot lnW_{DoF}$
  vs.
- free (useful) energy as defined by Gibbs

$$\Delta G = \Delta H - T{\cdot}\Delta S$$

modified after Penrose 2004
see also Rossi et al., 2015



….in the latter case, it seems that *DoF*s ….
and with it *S* is decreasing with time creating ORDER!

So what drives systems in their evolution towards irreversibility? Random forces omnipresent within the universe tend to push systems towards a thermodynamic equilibrium. However and under specific conditions, these operate to establish robust steady states, with high information contents that are far from equilibrium. Paradoxically, these forces have a common origin, namely *Gibbs Free Energy*. It characterizes the “useful” energetic content of a thermodynamic system to do work (under constant pressure and temperature conditions).

In statistical mechanics, Boltzmann's equation is a probability equation relating the entropy *S* of an ideal gas to the quantity W_{DoF}, which is the number of microstates (Degrees of Freedom, DoF) corresponding to a given macrostate: $S = k{\cdot}lnW_{DoF}$, where *k* is the Boltzmann's constant, (1.38065 × 10−23 J/K).

In thermodynamics, Gibbs energy is a thermodynamic potential that measures the "usefulness" or process-initiating work obtainable from a thermodynamic system at a constant temperature and pressure (isothermal, isobaric). $\Delta G\ (p,T) = \Delta H - T{\cdot}\Delta S$, where *H* is the enthalpy (J), *T* is the temperature (K), and *S* the entropy (J/K).

Image: Increasing entropy along the arrow of time depicted in a container of gas (top) and earth’s atmosphere under the influence of gravity (bottom). While the former (under the influence of *kT*) starts to spread throughout the box thereby reaching a uniform state of thermal equilibrium, in the latter case gravity tends to achieve the reverse (modified after Penrose, 2004).

Source: Penrose R (2004). The Road to Reality – a complete guide to the laws of the Universe. A.A. Knopf eds. (NY) USA;
Rossi C, Madl P, Foletti A, Mocenni C, (2015) Chapter 4 - Energy flow and dissipative structures. In: Field of the Cells Volume 1. Kerala, IND: Research Signpost, 71-94

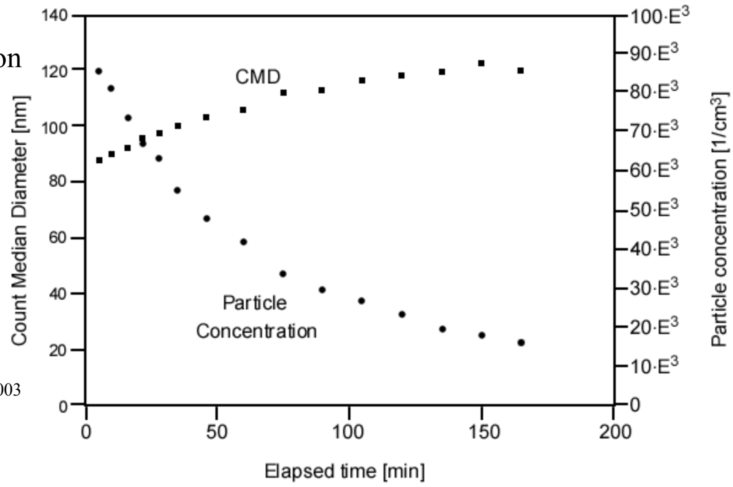
Aerosol | Climate | Health | Tools | Model

Kinetics (2/5)

Aerosol Kinetics – main Modi:

- Formation of accumulation mode in ETS

Source: Morawska 2003



Change in the Count Median Mean (logarithmic average) as time passes in a smoke-loaded closed environment of an Australian pub;

Source: lecturing script, Morawska, 2003;

Aerosol | Climate | Health | Tools | Model

Kinetics (3/5)

Aerosol Kinetics – main Modi:

- Aitken & Accumulation o combustion aerosols

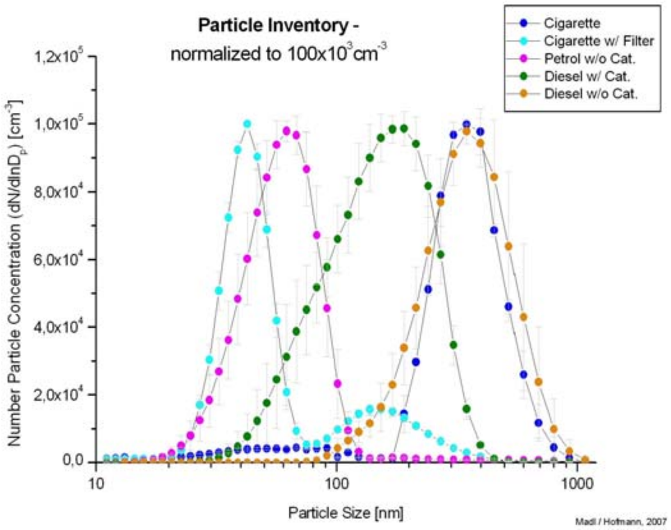
Exhaust fumes (samples taken w/ Tedlar bag, normalized to 100·E^{3}cm^{-3}):

Diesel w/o cat

Petrol w/o cat

Diesel w/o cat

ETS-filter & w/o



Source: Madl, 200.

Exhaust fumes of “dirty” combustions processes generate a broad polydisperse particle size spectrum, favouring the agglomeration of smaller particle fractions of the nucleation regime onto the forming cluster;

So-called cleaned exhaust fumes (using catalytic converters and/or filters) lack

- the necessary concentration of larger particle fraction onto which the smaller can condense onto;
- lack the time required to form larger aggregates before leaving the exhaust system;

Source: lecturing script, Morawska, 2003;

Aerosol | Climate | Health | Tools | Model

Kinetics (4/5)

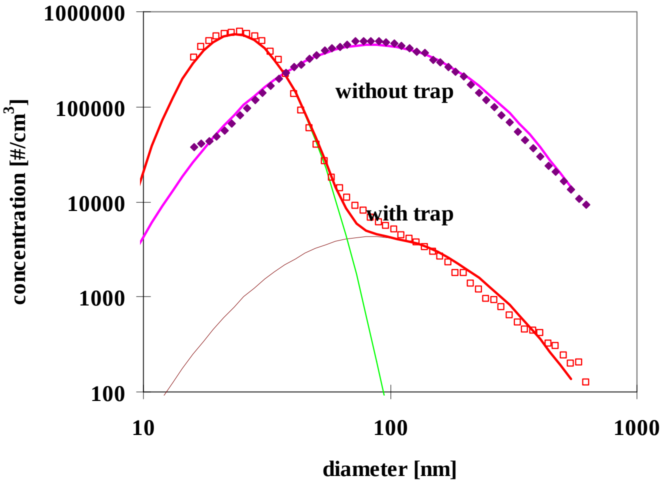
Aerosol Kinetics – main Modi:

- Aitken & Accumulation o combustion aerosols

Tailpipe aerosol sample of a Diesel engine:

w/o DPF (Diesel Particle Filter)

w/ DPF



Source: Majewski, 201

Diesel particulate filters capture particle emissions through a combination of filtration mechanisms, such as diffusional deposition, inertial deposition, or flow-line interception. Collected particulates are removed from the filter, continuously or periodically, through thermal regeneration. Diesel filters are highly effective in controlling solid particulate emissions - including solid particle numbers - but may be ineffective in controlling liquid fractions of PM emission. Filters were first commercialized as retrofit devices, followed by a wide scale adoption on new light-duty and heavy-duty diesel engines in both highway and non-road applications.

Exhaust fumes of “dirty” combustions processes generate a broad polydisperse particle size spectrum, favouring the agglomeration of smaller particle fractions of the nucleation regime onto the forming cluster;

So-called cleaned exhaust fumes (using catalytic converters and/or filters) lack
•the necessary concentration of larger particle fraction onto which the smaller can condense onto;
•lack the time required to form larger aggregates before leaving the exhaust system;

Source: Majewski WA (2011) Diesel Particulate Filters. Dieselnet Technology Guide. http:www.dieselnet.com/tech/dpf.php

Aerosol | Climate | Health | Tools | Model

Kinetics (5/5)

Aerosol Kinetics – main Modi:

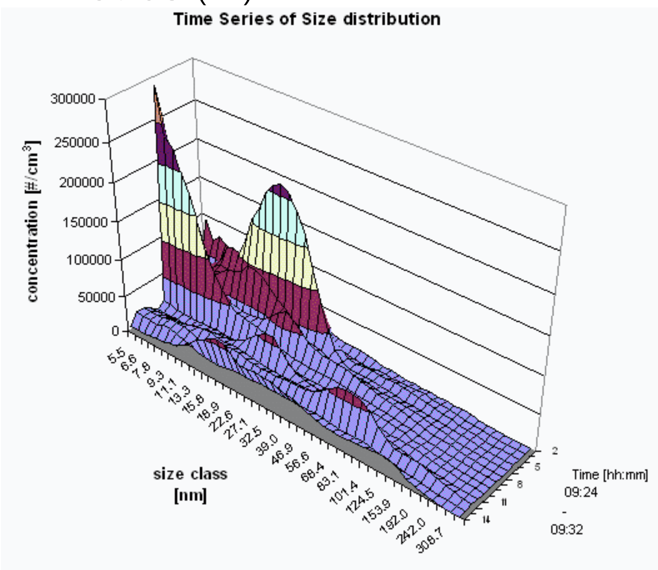
- Formation of Aitken & Accumulation modes

Ambient particle load of highway related vehicle exhaust nanoparticles comprise two types:

- nucleation mode – mainly condensed lubricating oil centred @ 20 nm;
- solid mode – graphitic carbon – centred @ 50-60 nm;

Source: Madl & Heinzlmann, 2006

Harrison et al., 2011



15-01-14 Madl EDGE 55

Here, the high particle load in the nucleation mode becomes strikingly evident – this sample of air is the characteristic cocktail of highway related air-exhaust mixture – especially when trapped in-between sound-absorbing protective-walls or tunnels;

Source: & Heinzlmann, 2006 (personal communication)
Harrison RM, Beddows DCS, Dall'Osto M (2011) PMF Analysis of Wide-Range Particle Size Spectra Collected on a Major Highway. Environ. Sci. Technol., Vol.45, 5522-5528.

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (1a/9)

Mass vs. Number Concentration

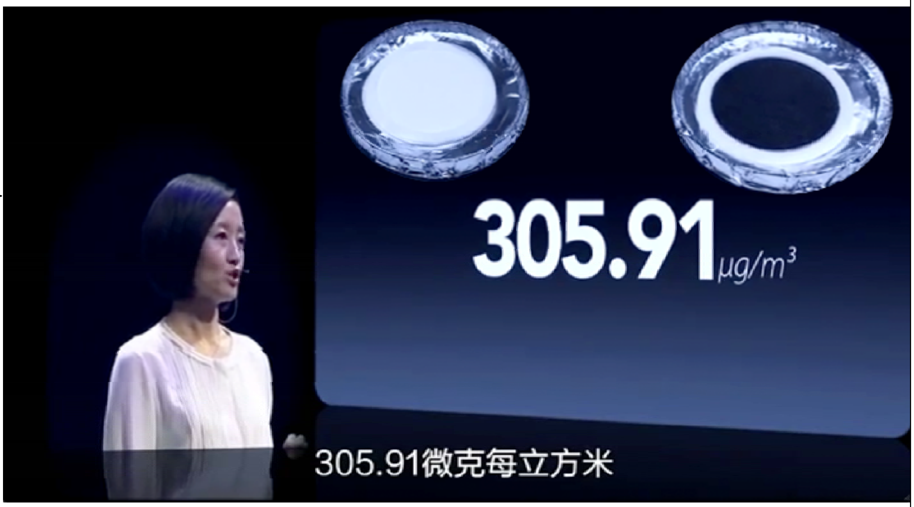
standard tool:
determine mass ….

(北京 **air** over 24h)

(respiratory equivalent or continuous measurement mode?)

WHO $PM_{2.5}$ 24h-standard: 25 µg/m³

Chai, 2015



Under the Dome 穹顶之下 (*QióngDǐng ZhīXià*) is a 2015 self-financed, Chinese documentary film by Chai Jing, a former China Central Television journalist, concerning air pollution in China. It was viewed over 150 million times on Tencent within three days of its release. Chai Jing started making the documentary when her as yet unborn daughter developed a tumour in the womb, which had to be removed very soon after her birth. Chai blames air pollution for the tumour. The film, which combines footage of a lecture with interviews and factory visits, has been compared with Al Gore's *An Inconvenient Truth* in both its style and likely impact. The film openly criticises state-owned energy companies, steel producers and coal factories, as well as showing the inability of the Ministry of Environmental Protection to act against the big polluters. Despite demonstrating the failure of China's regulations on pollution, the Chinese government at first did not censor the film. Instead, the *People's Daily* reposted the film alongside an interview with Chai, while Chen Jining, the recently appointed minister for environmental protection, praised the film, comparing its significance with *Silent Spring*, the 1962 book by US environmentalist Rachel Carson. However, within a week, the Communist Party's publicity department confidentially ordered the film to be removed. An employee of China Business News was suspended for leaking the order.

Particulate matter - Guideline values

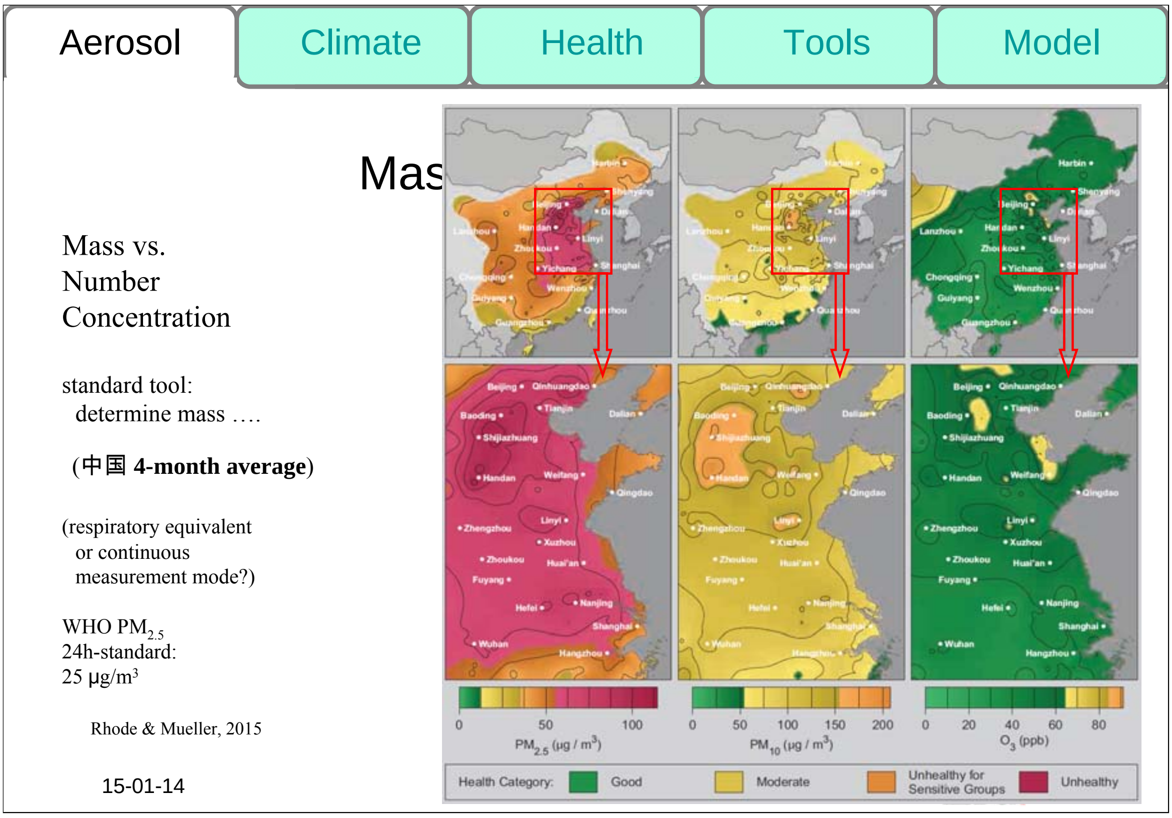
$PM_{2.5}$: 10 µg/m³ annual mean vs. 25 µg/m³ 24-hour mean
PM_{10}: 20 µg/m³ annual mean vs. 50 µg/m³ 24-hour mean

The 2005 AQG set for the first time a guideline value for particulate matter (PM). The aim is to achieve the lowest concentrations possible. As no threshold for PM has been identified below which no damage to health is observed, the recommended value should represent an acceptable and achievable objective to minimize health effects in the context of local constraints, capabilities and public health priorities.

Definition and principle sources: PM affects more people than any other pollutant. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. The particles are identified according to their aerodynamic diameter, as either PM_{10} (particles with an aerodynamic diameter smaller than 10 µm) or $PM_{2.5}$ (aerodynamic diameter smaller than 2.5 µm). The latter are more dangerous since, when inhaled, they may reach the peripheral regions of the bronchioles, and interfere with gas exchange inside the lungs.

Source: http://en.wikipedia.org/wiki/Under_the_Dome_%28film%29
https://www.youtube.com/watch?v=MhIZ50HKIp0

WHO (2008) Air quality and health. Fact sheet N°313.
http://www.who.int/mediacentre/factsheets/fs313/en/print.html



China has recently made available hourly air pollution data from over 1500 sites, including airborne particulate matter (PM), SO_2, NO_2, and O_3. We apply Kriging interpolation to four months of data to derive pollution maps for eastern China. Consistent with prior findings, the greatest pollution occurs in the east, but significant levels are widespread across northern and central China and are not limited to major cities or geologic basins. Sources of pollution are widespread, but are particularly intense in a northeast corridor that extends from near Shanghai to north of Beijing. During our analysis period, 92% of the population of China experienced >120 hours of unhealthy air (US EPA standard), and 38% experienced average concentrations that were unhealthy. China's population-weighted average exposure to $PM_{2.5}$ was 52 µg/m³. The observed air pollution is calculated to contribute to 1.6 million deaths/year in China [0.7–2.2 million deaths/year at 95% confidence], roughly 17% of all deaths in China.

Image: **Average air pollution maps.** Maps of average pollutant concentration for PM2.5, PM10, and O3 for eastern China (top row) and the Beijing to Shanghai corridor (bottom row). Concentrations are shown using color gradients and contour lines; the colors (green, yellow, etc.) represent US EPA qualitative health impacts. Pollution concentrations were computed as described in the text using hourly data and then the hourly concentration fields were averaged over the four month study duration.

Source: Rohde RA, Muller RA (2015) Air Pollution in China: Mapping of Concentrations and Sources, PLOS in press

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (2/9)

Mass vs. Number Concentration

… obviously ….

a large object (e.g. basketball) in comparison to light objects (stack of pin-pong-balls) dominates the balancing act;

…. ergo: mass measurements is not the ultimate *grail*

15-01-14

Challenge: the mass of nano-particles is neglectably small in comparison to an e.g. 10µm particle.

Example: spherical particle of the same unit **density** is proportional to **d³**, Surface Area is proportional to diameter²;

Diameter	rel. Mass	rel. Surface
10 µm	1	1
1 µm	10^{-3} (1 thousandth)	10^{-2}
100 nm	10^{-6} (1 millionth)	10^{-4}
10 nm	10^{-9} (1 billionth)	10^{-6}

1 million 100nm particle of the same mass as a **single** 10µm particle!
Thus, the mass of a single nano-particle is undetectable in PM_{10} measurements (yet this standard is routinely applied in EPA measurements).

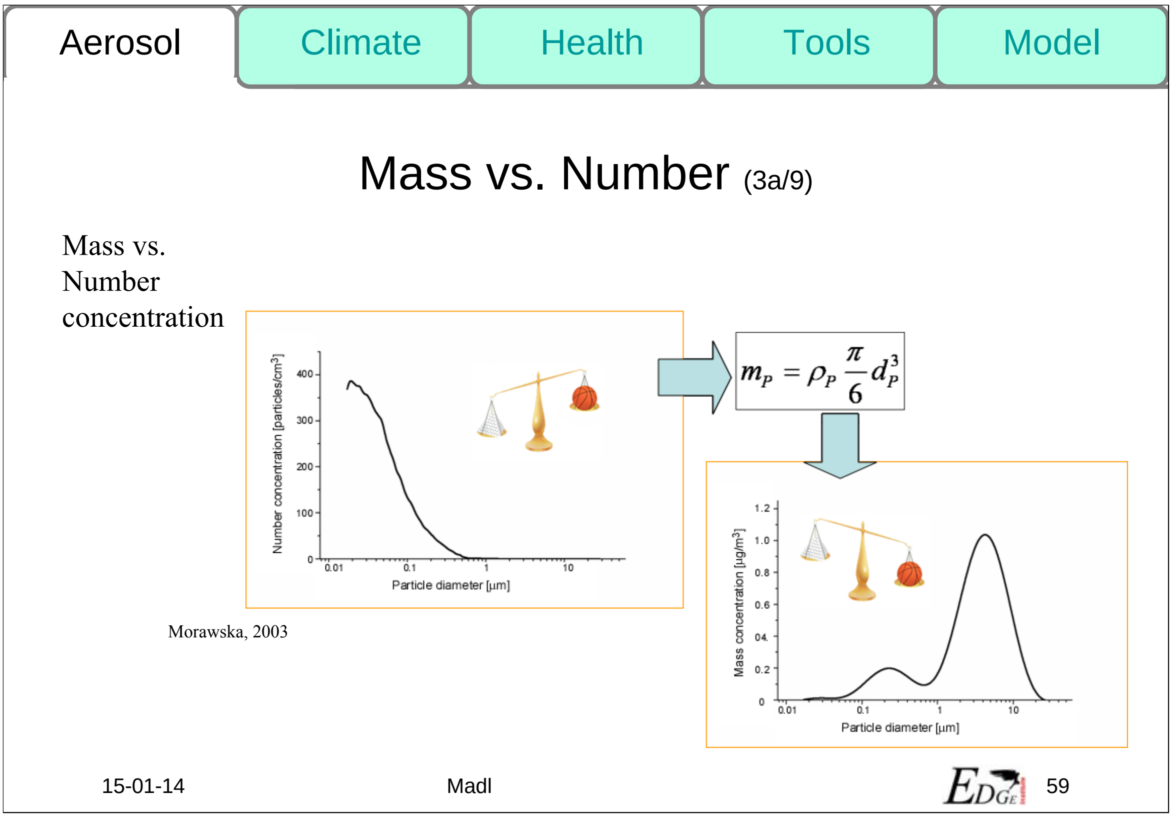
Why do we use this system?

- Gravimetric determination fails under a certain threshold value – EPA's usually measure PM10, PM2.5 and eventually PM1; (PM = Particle Mass); PM totally ignores the numeric abundance of the lighter counterparts;
- Mass is a misleading parameter as number concentration act much more thoroughly than mass;

Example: comparing the mass of 100 table-tennis balls to that of 1 baseball, it becomes obvious that the baseball dominates by mass units, while the table-tennis balls dominate by their number;

Hence the particle in its nucleation mode exerts a far deeper action onto the respiratory organ than a particle cluster in accumulation mode or even in coarse mode;

Source: http://kjmaclean.com/Geometry/3DBasicsRevised.html; http://www.prosportsofficialteamsites.com/



Conversion from particle number concentrations to particle mass. Gravimetric measurements of particle inventory such as PM_{10} fail to account for the huge bulk of even smaller particles in the smallest size range.

Why do we use this system?

- Gravimetric determination fails under a certain threshold value – EPA's usually measure PM10, PM2.5 and eventually PM1; (PM = Particle Mass);
- Mass is a misleading parameter as number concentration act much more thoroughly than mass;

Example: comparing the mass of 100 table-tennis balls to that of 1 baseball, it becomes obvious that the baseball dominates by mass units, while the table-tennis balls dominate by their number; hence the particle in its nucleation mode exerts a far deeper action onto the respiratory organ than a particle cluster in accumulation mode or even in coarse mode;

Scan: Masse wichtigsten Partikelquellen. Bei den Werten handelt es sich um geschätzte Werte; die mögliche Spanne kann für einige Quellen sehr groß sein, z. B. für vulkanische Emissionen schwanken die Schätzwerte je nach Autor zwischen 4 und 10.000 Tonnen/Jahr.

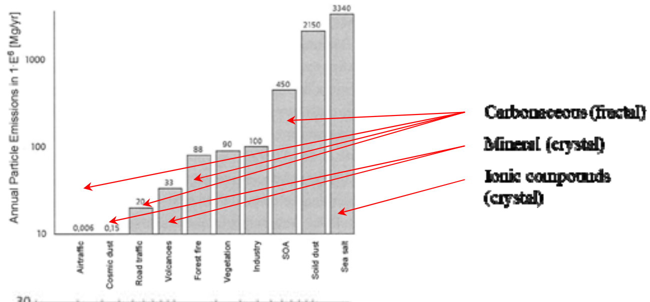
Source: http://explorations.ucsd.edu/indoex/news.cfm
Lecturing script, Morawska, 2003;

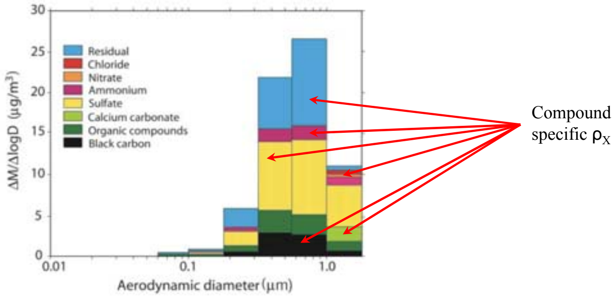
Aerosol | Climate | Health | Tools | Model

Mass vs. Number (3b/9)

Mass vs. Number concentration

In order to achieve accurate conversion from particle number concentration (PN) to mass concentration (PM), the corresponding density must known …. e.g. $\rho_{\text{black carbon}} < \rho_{\text{carbonate}}$





Soentgen & Voelzke, 2006

15-01-14

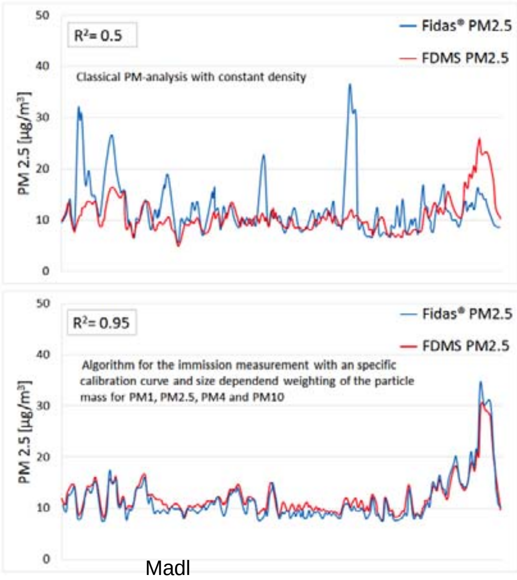
60

Soentgen J., Völzke K. (2006). Staub - Spiegel der Umwelt, in der Reihe “Stoffgeschichten“. oekom verlag, Muenich, FRG

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (3c/9)

Mass vs. Number concentration



Palas, 2017
Ray & Vaughn, 2009

Assigning a weighted density conversion factor (according to DIN EN.481) allows a more accurate conversion from PN to PM

15-01-14 Madl 61

In order to convert the measured values into a mass or mass fraction, the particle size distribution in each value is multiplied by a correlation factor that reflects the different sources (e.g. combustion aerosols, tire wear, pollen) of the environmental aerosol. A mass fraction is obtained by additionally applying the separation curve (e.g. DIN EN 481) to the determined particle size distribution. Multiple separation curves can be used simultaneously for the same size distribution, which enables the simultaneous output of PM10, PM2.5, PM1 (and others).
When considering a spectral representation and given the fact that particle number as well as their size distribution can be measured in 32 or more size classes per decade within the particle size range of 0.18 – 18 µm each channel by itself should be assigned a proper density factor to enable conversion into particle mass.

Source: http://www.palas.de/en/product/fidas
https://www.beuth.de/en/standard/din-en-481/2162612

Alison E. Ray AE, Vaughn DL (2009) Standard Operating Procedure for the Continuous Measurement of Particulate Matter. Sonoma Technology, Inc.

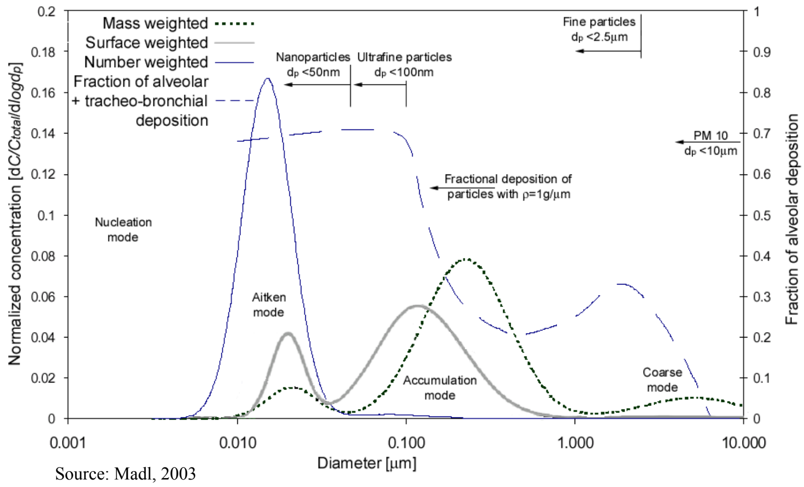
https://www3.epa.gov/ttnamti1/files/ambient/pm25/sop_project/905505_TEOM_SOP_Draft_Final_Sept09.pdf

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (4/9)

Aerosol Kinetics – main Modi:

- Nucleation.
- Aitken
- Accumulation
- Coarse



Source: Madl, 2003

Aerosols modes and their Dynamics: Tropospheric condensation nuclei are typically very small and cover a range from a few nanometers to less than 100 nm. Under favorable abiotic conditions, these aerosols can rapidly agglomerate to larger clusters that characterize the Aitken mode (see Fig). Condensation nuclei are particles directly emitted into the atmosphere or formed there by gas-to-particle conversion. This mode is not always present, but is usually found in the upper troposphere or near combustion sources. Because of their high number concentration, especially near their source, these tiny nano-particles coagulate rapidly with each other and give rise to the Aitken mode. Consequently, nucleation particles have relatively short lifetimes in the atmosphere and eventually agglomerate to larger clusters, which are then grouped into the accumulation mode.[1]

Image: Normalized and weighted distribution curve of diesel exhaust; Mass-, surface-, and number weighted particle-size distributions shown with alveolar deposition fraction.[2]

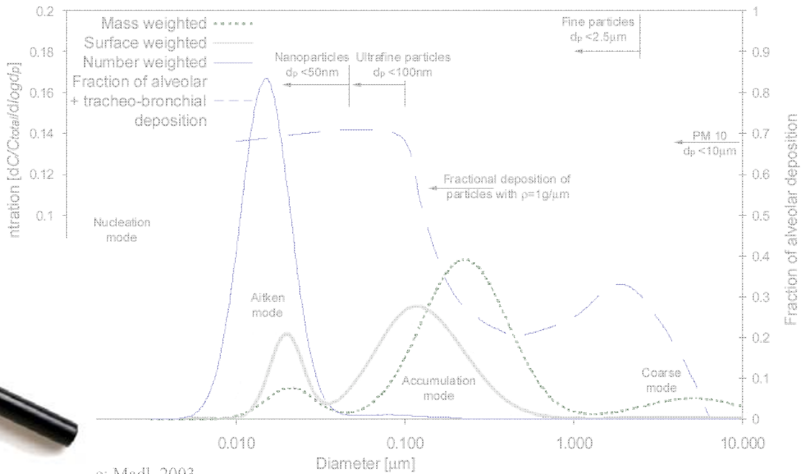
Source: [1] Hinds W.C. (1999). Aerosol Technology – Properties, Behavior and Measurement of Airborne Particles, 2nd ed. John Wiley & Sons – USA.
[2] Madl P. (2003) Instrumental development and application of a thermodenuder. MSc-thesis, Queensland University of Technology, Brisbane & Paris Lodron University of Salzburg. Available online: http://www.ubs.sbg.ac.at/pdf/AC04556571.pdf

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (4/9)

Aerosol Kinetics – main Modi:

- Nucleation.
- Aitken
- Accumulation
- Coarse

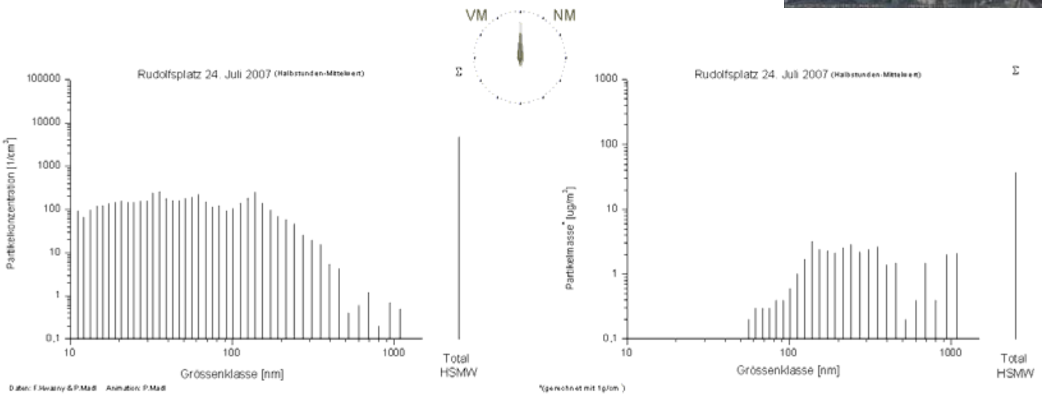


c: Madl, 2003

For details on aerosol physics see scripts from:
Prof. Lidia Morawska: biophysics.sbg.ac.at/transcript/aerosol2.pdf
Prof. Werner Hofmann: biophysics.sbg.ac.at/transcript/aerosol1.pdf

Mass vs. Number (5/9)

Mass vs.
Number
concentration

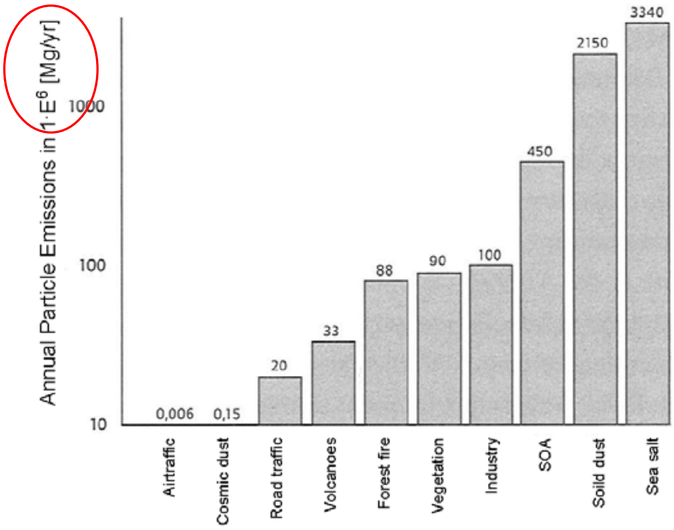


Aerosol | Climate | Health | Tools | Model

Mass vs. Number (6/9)

Composition

…. MASS …. !



Source: Soentgen & Voelzke, 2006

15-01-14 Madl 65

When we combined the satellite measurements with surface measurements, we found that the reduction of sunlight reaching the surface was three times larger than the amount of sunlight reflected back to space," says V. Ramanathan …. Averaged over the entire northern Indian Ocean, the man-made pollutants reflected more solar radiation back to space (than pristine skies), but they absorbed up to twice as much radiation in the atmosphere ….

Together, these features maximize the effects of aerosol pollution," Ramanathan explains. As a result of human industry-automobiles, factories, and burning vegetation-particles build up in the atmosphere where they are blown southward over most of the tropical Indian Ocean. The Indo-Asian haze covered an area larger than that of the United States. Although the INDOEX team found atmospheric particles of natural origin-such as trace amounts of sea salts and desert dust-they also found that 75 percent of the aerosol over the region resulted from human activities-including sulfates, nitrates, black carbon, and fly ash. Most natural aerosols scatter and reflect sunlight back to space, thereby making our planet brighter. However, human-produced black carbon aerosol absorbs more light than it reflects, thereby making our planet darker ….

Scan: Masse wichtigsten Partikelquellen. Bei den Werten handelt es sich um geschätzte Werte; die mögliche Spanne kann für einige Quellen sehr groß sein, z. B. für vulkanische Emissionen schwanken die Schätzwerte je nach Autor zwischen 4 und 10.000 Tonnen/Jahr.

Source: http://explorations.ucsd.edu/indoex/news.cfm
Soentgen J., Völzke K. (2006). Staub - Spiegel der Umwelt, in der Reihe ..Stoffgeschichten". oekom verlag, Muenich, FRG

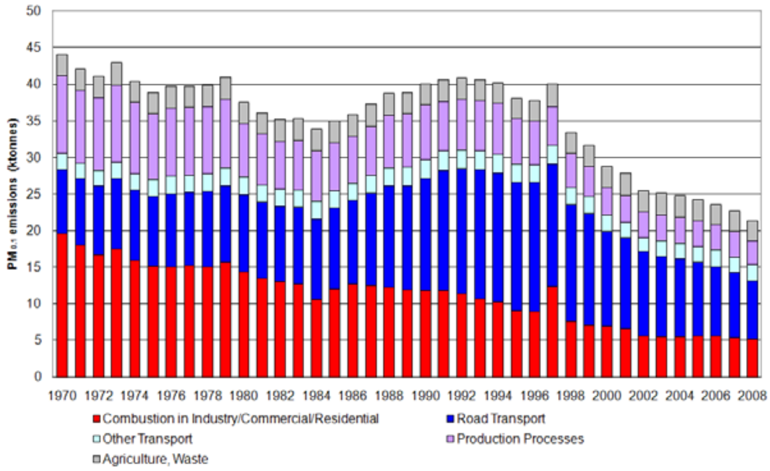
Aerosol | Climate | Health | Tools | Model

Mass vs. Number (7/9)

Composition

- Dominance of Aitken- over suppression of Accumulation-Mode due to ULS content in fuel.

PM_{10}: standard
$PM_{2.5}$: standard
$PM_{1.0}$: rare
$PM_{0.1}$: very rare (!)
….
$PM_{0.1}$ Emissions 1970-2008 (UK)



Source: Harrison , 2010

Source: Harrison RM (2010) Regulatory and Air Quality Implications of Setting Particle Number Standards. Universiity of Brimingham (UK)

Aerosol | Climate | Health | Tools | Model

Mass vs. Number (8/9)

Composition

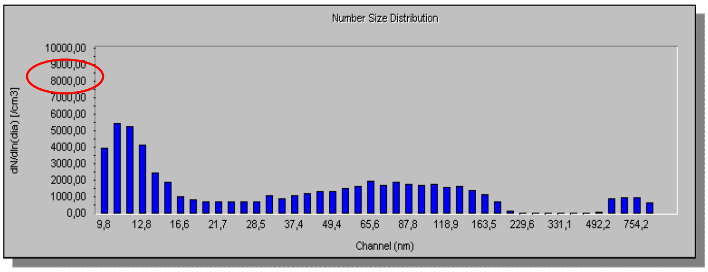
- Dominance of Aitken- over suppression of Accumulation-Mode due to ULS content in fuel.

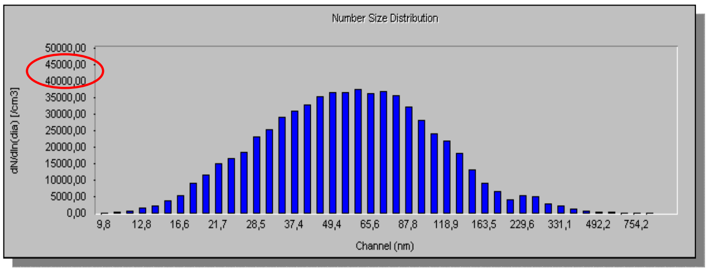
Ultra Low Sulfur Fuel (top)

Low Sulfur Content (bottom)

Source: Grimm, 2004

Jones et al., 2012





Thus: Nanoparticle concentrations @ roadsides have fallen sharply since the introduction of low-sulfur fuel

The sulfur content in fuel acts as a “binder” to glue the smaller fraction onto the agglomerating particle cluster;

Source: Grimm, 2004;
Jones AM, Harrison RM, Fuller G, Barratt B (2012) A Large Reduction in Airborne Particle Number Concentrations at the time of the Introduction of “Sulphur Free” Diesel and the London Low Emission Zone, Atmos. Environ., Vol.50: 129-138.

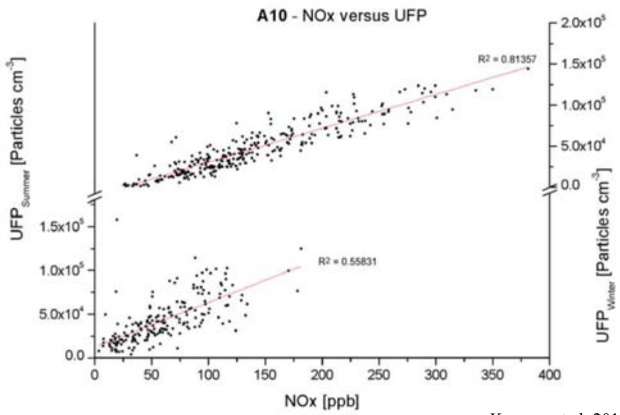
Aerosol | Climate | Health | Tools | Model

Mass vs. Number (9/9)

Composition

- good correlation b/w PM & NO_X (use of NO_X as proxy of UFP-data not available)
- decrease in PM ….
- Boost in NO_X (threshold level 40µg/m^3)
- transmutation from
  gas to solid
  and vice versa

Dieselgate.mp4



Kwasny et al, 2010

This study monitored ultrafine particles (UFP) concurrent with environmental air quality data, investigating whether already existing instrumentation used by environmental authorities can provide reference values for estimating UFP concentrations. Of particular interest was the relation of UFP to PM_{10} (particulate matter) and nitrogen oxides (NO_X, NO_2) in ambient air. Existing PM measurement methods alone did not correspond exactly enough with the actual particle number, but we observed a link between NO_X and NO_2 to UFP concentration. The combined data could act as proxy indicator for authorities in estimating particle number concentrations, but cannot replace UFP monitoring.

Source: Kwasny F, Madl P, Hofmann W (2010). Correlation of Air Quality Data to Ultrafine Particles (UFP) Concentration and Size Distribution in Ambient Air. *Atmosphere*, Vol .1: 3-14;

Video: http://www.arte.tv/guide/de/064729-000-A/die-macht-und-ihr-preis-die-akte-vw

Aerosol | Climate | Health | Tools | Model

Air Quality Standards (1/3)

US-EPA

Primary Standards for:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)
- Ground-level Ozone (O_3)
- Particle Mass (PM)
- Sulfur Dioxide (SO_2)

EPA, 2016

Pollutant		Primary/ Secondary	Averaging Time	Level	Form
Carbon Monoxide (CO)		primary	8 hours	9 ppm	Not to be exceeded more than once per year
			1 hour	35 ppm	
Lead (Pb)		primary and secondary	Rolling 3 month average	0.15 $\mu g/m^3$	Not to be exceeded
Nitrogen Dioxide (NO_2)		primary	1 hour	100 ppb	98th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		primary and secondary	1 year	53 ppb	Annual Mean
Ozone (O_3)		primary and secondary	8 hours	0.070 ppm	Annual fourth-highest daily maximum 8-hour concentration, averaged over 3 years
Particle Pollution (PM)	$PM_{2.5}$	primary	1 year	12.0 $\mu g/m^3$	annual mean, averaged over 3 years
		secondary	1 year	15.0 $\mu g/m^3$	annual mean, averaged over 3 years
		primary and secondary	24 hours	35 $\mu g/m^3$	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24 hours	mass! 150 $\mu g/m^3$	Not to be exceeded more than once per year on average over 3 years
Sulfur Dioxide (SO_2)		primary	1 hour	75 ppb	99th percentile of 1-hour daily maximum concentrations, averaged over 3 years
		secondary	3 hours	0.5 ppm	Not to be exceeded more than once per year

U.S. National (Primary) Ambient Air Quality Standards For detailed information regarding policy and precise statistical and time-based computations to achieve attainment.

The Clean Air Act, which was last amended in 1990, requires EPA to set National Ambient Air Quality Standards (40 CFR part 50) for pollutants considered harmful to public health and the environment. The Clean Air Act identifies two types of national ambient air quality standards.

The EPA has set National Ambient Air Quality Standards for six principal pollutants, which are called "criteria" air pollutants. Periodically, the standards are reviewed and may be revised. The current standards are listed below. Units of measure for the standards are parts per million (ppm) by volume, parts per billion (ppb) by volume, and micrograms per cubic meter of air ($\mu g/m^3$).

Image: **Primary standards** provide public health protection, including protecting the health of "sensitive" populations such as asthmatics, children, and the elderly. **Secondary standards** provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Source: www.epa.gov/criteria-air-pollutants

https://www.epa.gov/criteria-air-pollutants/naaqs-table

Aerosol | Climate | Health | Tools | Model

Air Quality Standards (2/3)

EU-EEA

Primary Standards for:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)
- Ground-level Ozone (O_3)
- Particle Mass (PM)
- Sulfur Dioxide (SO_2)
- Heavy Metals (As, Cd, Ni)
- Hydrocarbons (PAH)

Pollutant	*Concentration*	*Averaging period*	*Legal nature*	*Permitted exceedences each year*
Fine particles ($PM_{2.5}$)	25 µg/m^3 mass!	1 year	01.01.2015	n/a
Sulphur dioxide (SO_2)	350 µg/m^3	1 hour	01.01.2005	24
	125 µg/m^3	24 hours	01.01.2005	3
Nitrogen dioxide (NO_2)	200 µg/m^3	1 hour	01.01.2005	18
	40 µg/m^3	1 year	01.01.2010	n/a
PM_{10}	50 µg/m^3	24 hours	01.01.2005	35
	40 µg/m^3 mass!	1 year	01.01.2005	n/a
Lead (Pb)	0.5 µg/m^3	1 year	01.01.2005	n/a
Carbon monoxide (CO)	10 mg/mv	max. daily 8 hour mean	01.01.2005	n/a
Benzene	5 µg/m^3	1 year	01.01.2010	n/a
Ozone	120 µg/m^3	max. daily 8 hour mean	01.01.2010	25 days avg over 3 years
Arsenic (As)	6 ng/m^3	1 year	01.01.2012 (target)	n/a
Cadmium (Cd)	5 ng/m^3	1 year	01.01.2012 (target)	n/a
Nickel (Ni)	20 ng/m^3	1 year	01.01.2012 (target)	n/a
Polycyclic Aromatic Hydrocarbons (PAHs)	1 ng/m^3 (as conc. of BaP)	1 year	01.01.2012 (target)	n/a

EEA, 2016

Air Quality Standards: At a Member State level, the existing National Emission Ceilings Directive (NEC Directive) imposes emission ceilings (or limits) for emissions of four key air pollutants (nitrogen oxides, sulphur dioxide, non-methane volatile organic compounds and ammonia) that harm human health and the environment.

Image: Humans can be adversely affected by exposure to air pollutants in ambient air. In response, the European Union has developed an extensive body of legislation which establishes health based standards and objectives for a number of pollutants in air. These standards and objectives are summarised in the table below. These apply over differing periods of time because the observed health impacts associated with the various pollutants occur over different exposure times.

Source: http://ec.europa.eu/environment/air/quality/standards.htm

Aerosol | Climate | Health | Tools | Model

Air Quality Standards (3/3)

EU-EEA

Primary Standards for:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)
- Ground-level Ozone (O_3)
- Particle Mass (PM)
- Sulfur Dioxide (SO_2)
- Conversion Factors

Irish EPA, 2016
Finlayson & Pitts, 2000

Conversion factors from relative units to mass-volumes:	
Nitrogen dioxide	1 ppm = 1.91 $\mu g/m^3$
Sulphur dioxide	1 ppm = 2.66 $\mu g/m^3$
Ozone	1 ppm = 2.0 $\mu g/m^3$
Carbon monoxide	1 ppm = 1.16 $\mu g/m^3$
Carbon dioxide	1 ppm = 1.80 $\mu g/m^3$
Benzene	1 ppm = 3.24 $\mu g/m^3$

$$[\mu g/m^3] = 1{\cdot}E^{-6}\ [ppm] \cdot 40.9\ [mol/m^3] \cdot M\ [g/mol]$$

M …. molar mass of molecule

Parts per	Unit	Molecules, atoms, or radicals per cm^3
$1{\cdot}E^6$	1 ppm	$2.46{\cdot}E^{13}$
$1{\cdot}E^9$	1 ppb	$2.46{\cdot}E^{10}$
$1{\cdot}E^{12}$	1 ppt	$2.46{\cdot}E^7$

ppm in units of mass per cubic meter = $40.9{\cdot}M$ [$\mu g/m^3$] @ STP

For gas-phase species, the most commonly used units are parts per million (ppm), parts per hundred million (pphm), parts per billion (ppb), and parts per trillion (ppt). These units express the number of molecules of pollutant found in a million ($1{\cdot}E^6$), a hundred million (10s), a billion (an American billion ($1{\cdot}E^9$), or a trillion ($1{\cdot}E^{12}$) molecules of air, respectively. It should be noted that, although these are commonly used, confusion may arise in that in some European countries a billion means $1{\cdot}E^{12}$ and a trillion means $1{\cdot}E^{15}$. As a result, in some journals when these units are used, they are accompanied by a definition, e.g., ppb (parts in $1{\cdot}E^9$). Care must also be taken to ensure that ppt means parts per trillion and not parts per thousand. The latter unit is often used in isotope studies and is denoted parts per mille, or ‰.[1]

Conversion factors from relative units to mass-volumes - see table above [2]

The unit of measurement for gaseous species is mass per unit volume, usually $1{\cdot}E^{-6}$ g per cubic meter ($\mu g{\cdot}m^{-3}$). Since 1 atm at 25°C contains $4.09{\cdot}1{\cdot}E^{-2}$ $mol{\cdot}L^{-1}$, 1 ppm must contain $(4.09{\cdot}1{\cdot}E^{-2}){\cdot}\ 1{\cdot}E^{-6}$ or $4.09{\cdot}1{\cdot}E^{-8}$ mol L^{-1} or $4.09{\cdot}1{\cdot}E^{-5}$ $mol{\cdot}m^{-3}$. If the molar mass of the pollutant is M_X [g/mol], then 1 ppm in units of mass per m^3 is $4.09{\cdot}1{\cdot}E^{-5} \cdot M_X$ [$g{\cdot}m^{-3}$] or $40.9 \cdot M_X$ [$\mu g{\cdot}m^{-3}$]. For example:

1 ppm O_3 converts to $40.9{\cdot}48{\cdot}1$ ($M_{O3} = 3{\cdot}16 = 48$ [$g{\cdot}mo1^{-1}$] or 1.96 [$\mu g{\cdot}m^{-3}$].

1 ppm SO_2: $40.9{\cdot}64{\cdot}1$ ($M_{SO2} = 32{+}2{\cdot}16 = 64$ [g/mol]) or 2.62 [$\mu g{\cdot}m^{-3}$].

1 ppm CO_2: $40.9{\cdot}44{\cdot}1$ ($M_{CO2}{=}12{+}2{\cdot}16 = 44$ [g/mol]) or 1.80 [$\mu g{\cdot}m^{-3}$].

Source: [1] Finlayson-Pitts BJ, Pitts JN (2000) Chemistry of the Upper and Lower Atmosphere - Theory, Experiments, and Applications. Academic Press, San Diego, California, USA

[2] http://www.epa.ie/air/quality/standards/

Aerosol | Climate | Health | Tools | Model

Air Quality Standards (3/3)

EU-EEA

Primary Standards for:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)
- Ground-level Ozone (O_3)

Conversion factors from relative units to mass-volumes:	
Nitrogen dioxide	1 ppm = 1.91 $\mu g/m^3$
Sulphur dioxide	1 ppm = 2.66 $\mu g/m^3$
Ozone	1 ppm = 2.0 $\mu g/m^3$
Carbon monoxide	1 ppm = 1.16 $\mu g/m^3$
Carbon dioxide	1 ppm = 1.80 $\mu g/m^3$
Benzene	1 ppm = 3.24 $\mu g/m^3$

$$[\mu g/m^3] = 1\cdot E^{-6}\,[ppm] \cdot 40.9\,[mol/m^3] \cdot M\,[g/mol]$$

M …. molar mass of molecule

Parts per	Unit	Molecules, atoms, or radicals per cm^3
$1\cdot E^{6}$	1 ppm	$2.46\cdot E^{13}$
$1\cdot E^{9}$	1 ppb	$2.46\cdot E^{10}$
$1\cdot E^{12}$	1 ppt	$2.46\cdot E^{7}$

ppm in units of mass per cubic meter = $40.9\cdot M$ [$\mu g/m^3$] @ STP

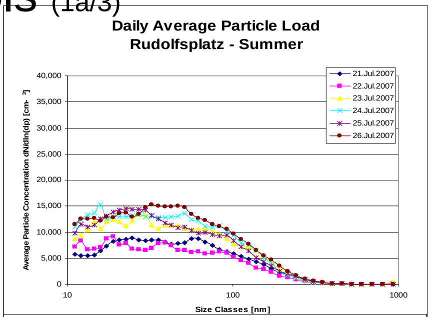
For a more in-depth look into the chemistry behind it, please refer to the lecture scriptby Dr.Markus Haider: http://biophysics.sbg.ac.at/glossary/luftanalytik.pdf

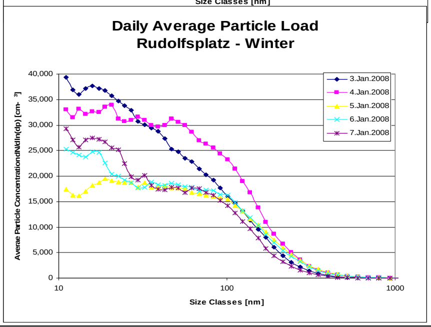
Aerosol | Climate | Health | Tools | Model

Urban Aerosols (1a/3)

Urban Air: SMPS-measurements

Kwasny et al. 2009





This study has shown that there is a significant difference in the size distribution of particles depending on the season. As expected, sites closely located to areas with heavy traffic were highly impacted. The comparison between the slow city traffic to the high speed highway traffic revealed a shift of the particle towards the smaller particle sizes for the highway traffic.

The measurement site 30 km outside of Salzburg (Haunsberg) more closely approached the background concentrations of anthropogenic produced aerosols. Although it did not closely follow the day/night and weekend patterns, the fluctuations and influence of traffic exhaust was still recognizable and was most likely associated with the long-range transport of aerosols (Dorsey et al., 2002).

Although PM_{10} seemed to be correlated with trends in ultrafine particles, it did not provide enough evidence that ultrafine particle behavior can be considered simply as a fraction of PM_{10} (Rosenbohm et al., 2005).

On the other hand, traffic related exhaust pollutants like NO and NO_2 indeed unveiled a close link to the measured ultrafine particle concentrations. Hence, such exhaust chemicals can be used as an indicator for ultrafine particles in close proximity to road traffic conditions (Janhäll et al., 2006).

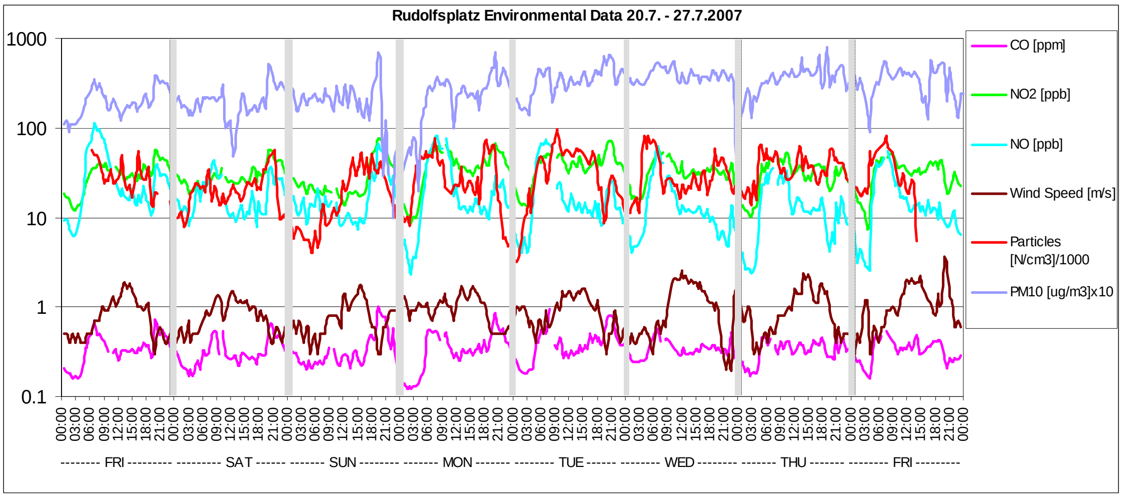
Considering the health effects of the smallest nano-particles observed in this study, the difference in seasonal particle-size composition should play a roll in exposure and health assessments, in particular, as the winter measurements revealed a significantly higher amount in the spectrum of particles which easily penetrate into deeper lung areas.

Source: Kwasny F., Madl P., Hofmann W. (2008). Nanopartikel in Salzburg Stadt und Umland – Sommer- und Wintererhebung. Messkampagne, Land Salzburg (Sbg): In Madl (ed), PhD-Thesis: 270-309;

Aerosol | Climate | Health | Tools | Model

Urban Aerosols (1b/3)

Urban Air: SMPS-measurements



This study has shown that there is a significant difference in the size distribution of particles depending on the season. As expected, sites closely located to areas with heavy traffic were highly impacted. The comparison between the slow city traffic to the high speed highway traffic revealed a shift of the particle towards the smaller particle sizes for the highway traffic.

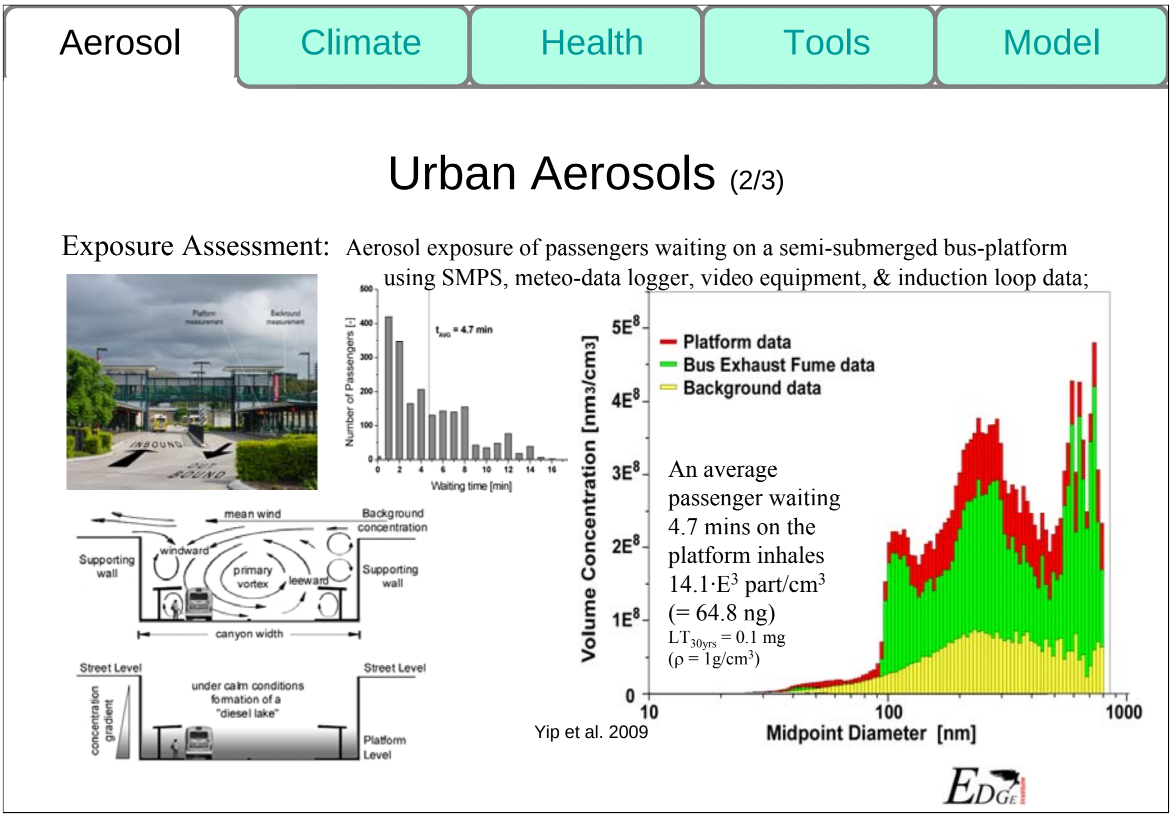
The measurement site 30 km outside of Salzburg (Haunsberg) more closely approached the background concentrations of anthropogenic produced aerosols. Although it did not closely follow the day/night and weekend patterns, the fluctuations and influence of traffic exhaust was still recognizable and was most likely associated with the long-range transport of aerosols (Dorsey et al., 2002).

Although PM_{10} seemed to be correlated with trends in ultrafine particles, it did not provide enough evidence that ultrafine particle behavior can be considered simply as a fraction of PM_{10} (Rosenbohm et al., 2005).

On the other hand, traffic related exhaust pollutants like NO and NO_2 indeed unveiled a close link to the measured ultrafine particle concentrations. Hence, such exhaust chemicals can be used as an indicator for ultrafine particles in close proximity to road traffic conditions (Janhäll et al., 2006).

Considering the health effects of the smallest nano-particles observed in this study, the difference in seasonal particle-size composition should play a roll in exposure and health assessments, in particular, as the winter measurements revealed a significantly higher amount in the spectrum of particles which easily penetrate into deeper lung areas.

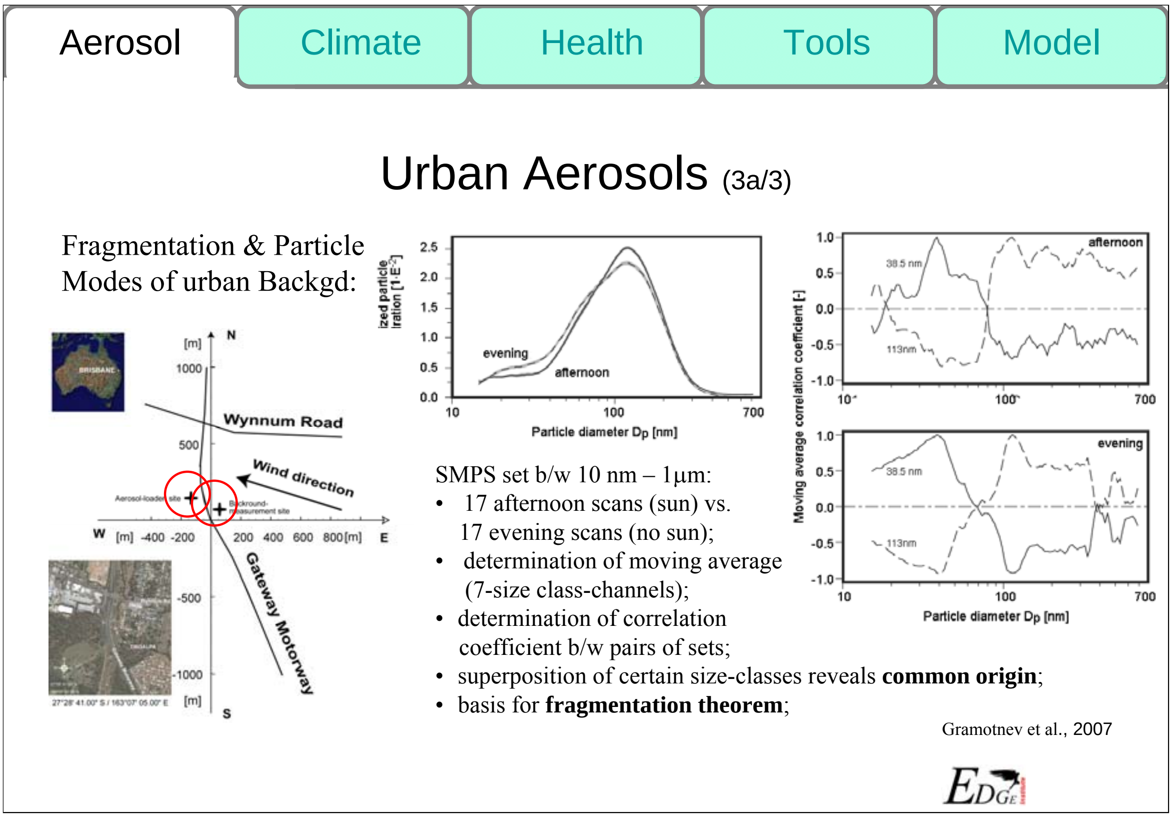
Source: Kwasny F., Madl P., Hofmann W. (2008). Nanopartikel in Salzburg Stadt und Umland – Sommer- und Wintererhebung. Messkampagne, Land Salzburg (Sbg): In Madl (ed), PhD-Thesis: 270-309;



The vehicle number grouped in fuel classes visiting this station on an hourly basis consisted of 78 for diesel powered buses, 15 for compressed natural gas (CNG) buses and an insignificant amount of less than 2 for petrol driven pickup-type service vehicles (Fig.5). Average passenger waiting time was found to be 4.7 min (Fig.6). Particle number exposure for that period resulted to be $14.1 \cdot 10^3$ particles/cm³. Based on a standard density of 1g/cm³ this corresponds to a mass concentration of 1.64 pg·cm⁻³ (compare Fig.8). As some passengers waited longer, so did their exposure to particles increase (Fig.9). Based on the fact that the average passenger spends approximately 5 minutes on the platform, particle number concentration dominates the 10 and 40 to 60% range of bus related exhaust fumes. This changes dramatically when considering the particle mass exposure concentration, where most passengers are exposed to about 50 to 80% of exhaust fumes originating from the buses (Fig.7). As some passengers waited longer, so did their exposure to particles increase (Fig.9). Based on the fact that the average passenger spends approximately 5 minutes on the platform, particle number concentration dominates the 10 and 40 to 60% range of bus related exhaust fumes. This changes dramatically when considering the particle mass exposure concentration, where most passengers are exposed to about 50 to 80% of exhaust fumes originating from the buses (Fig.7).

This study has shown that significant particle exposure concentrations to humans are present at the W'Gabba platform. A significant amount of the particle mass exposure on the platform originates from bus exhaust fumes (56%). Thus, adverse health effects for long-term exposure cannot be excluded. The canyon-like setting, in which the bus station is embedded, prevents the dilution and dispersion of exhaust gases and particles. The authors recommend that major changes should be imposed in the architectural design to improve the exchange of air masses.

Source: Yip M., Madl P., Wiegand A., Hofmann W. (2006) Exposure Assessment of Diesel Bus Emissions-II. In: International Journal of Environmental Research and Public Health, 3(4). Switzerland - EU: Molecular Diversity Preservation International (MDPI), 309-315;



We demonstrate new powerful methods of statistical analysis of atmospheric aerosols on the example of urban background aerosol in the Brisbane area, Australia. It is shown that even in the absence of notable features on the size distribution, it is still possible to identify distinct particles modes and analyze their mutual interactions and transformations. The obtained unique anti-symmetric correlation patterns between particle modes may serve as fingerprints of particular evolutionary processes in the background aerosols. The obtained results suggest that thermal fragmentation of nano-particles may be one of the major physical mechanisms shaping urban background aerosols. In particular, based on the fragmentation theorem, we demonstrate possible existence of substantially different time scales for fragmentation of atmospheric aerosols. The proposed approaches and obtained results may also be important for the analysis of different types of atmospheric aerosols on local, regional and global scales.

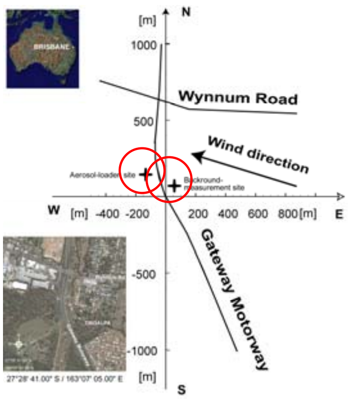
The discussed new statistical approaches open unique opportunities for the detailed analysis of different types of atmospheric aerosols, their possible sources and evolutionary processes. It has been shown that even in the absence of any significant features on the size distribution, it is still possible to identify distinct particles modes and analyze their mutual interactions and transformations. This provides new deep physical insights into the evolutionary processes in atmospheric aerosols. In particular, it has been demonstrated that thermal fragmentation of nano-particles may be one of the major physical mechanisms shaping urban background aerosols. It has been shown that thermal fragmentation of airborne nano-particles is likely to occur on significantly different time scales, leading to a possibility that this mechanism plays a major role in the formation and evolution of atmospheric aerosols not only on the regional, but also on the global scale (though further research in this direction is required).

Source: Gramotnev G, Madl P, Gramotnev DK, Burchill MJ (2007) Urban background aerosols: Negative correlations of particle modes and fragmentation mechanism. Geophysical Research Letters, Vol.34(11):

Aerosol | Climate | Health | Tools | Model

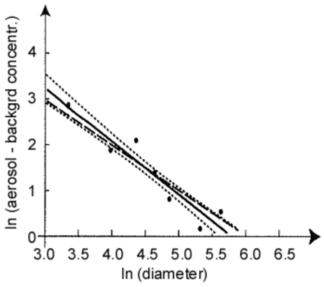
Urban Aerosols (3b/3)

Emission Factors:



SMPS set b/w 10 nm – 1µm:

- background measurement vs. SMPS-measurements
- weekday vs. weekend census, supported by met-data logger & surveillance vehicle frequency (video);
- determination of emission factors of trucks and cars;
  e_{car} = (0.21+/- 0.06)·E[14] [part./km]
  e_{truck} = (25.0+/- 6.0)·E[14] [part./km]
- plucking data into the Caline 4 model (modification of point to line source emission patterns);
- determination of overall emission factors for 2 different vehicle pools present on the motorway;
  $EF_{weekday}$ = 2.80 ·E[14] [particles ·km^{-1} ·vehicle^{-1}]
  $EF_{weekend}$ = 0.23 ·E[14] [particles ·km^{-1} ·vehicle^{-1}]

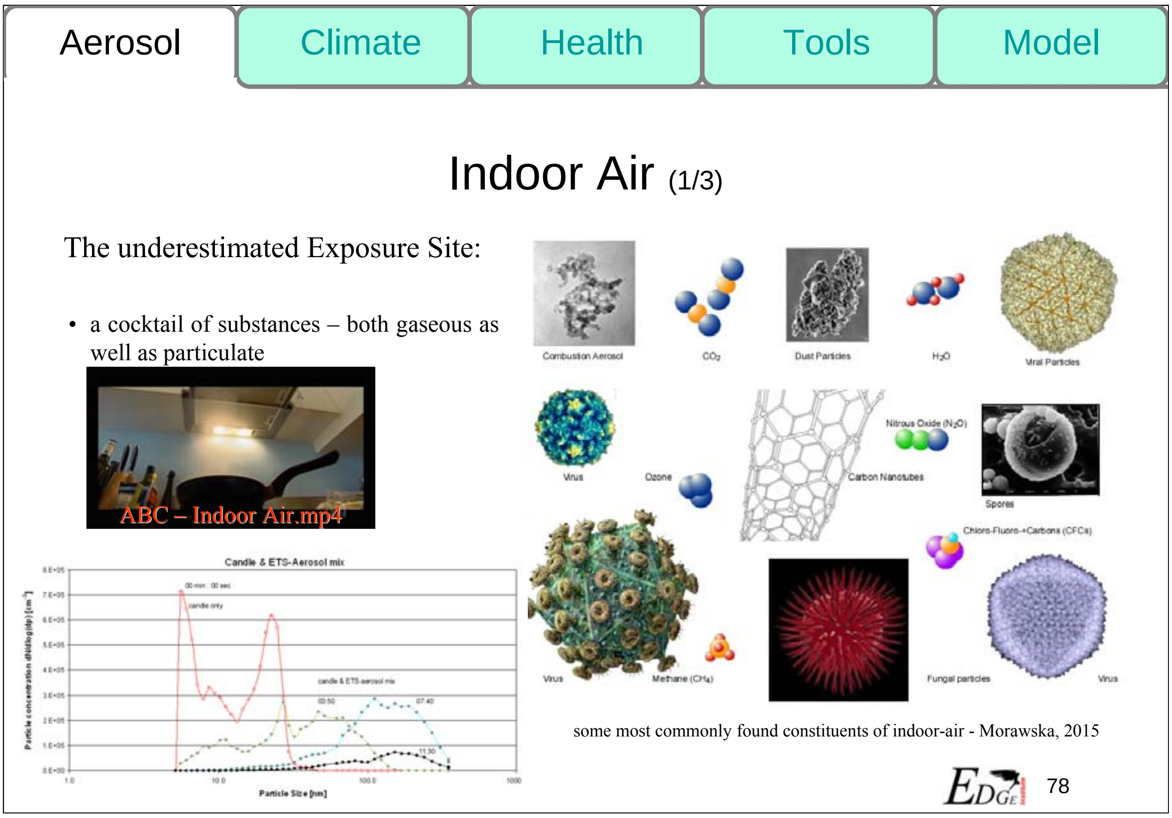


Gramotnev et al., 2004

In this paper, two new methods are developed for the determination of the average emission factors of fine and ultra-fine particles for different groups of vehicles on a busy road. The values of these emission factors for heavy-duty trucks and light-duty cars are calculated, discussed, and compared with the previous results obtained mainly in laboratory conditions.

In this paper, two new methods have been developed for the determination of the average emission factors of fine and ultra-fine particles for two groups of vehicles (heavy-duty trucks and cars) on a busy road. The first method requires experimental measurements of particle concentrations at different traffic conditions (e.g., on a weekday and on a weekend), whereas the second method is applicable when the traffic conditions are not changing. However, the second method requires some knowledge (typical range of variation) of the ratio of the average emission factors for heavy-duty trucks and cars (e.g., from the literature). The values of the emission factors have been determined during the on-road measurements. Both the methods have been shown to yield very similar results, which clearly demonstrates the advantage of the proposed methods compared to the laboratory approaches giving strongly dispersed results.

Source: Gramotnev G, Ristovski ZD, Brown RJ, Madl P. (2004) New Methods of Determination of Average Particle Emission Factors for two Groups of Vehicles an a Busy Road. In: Atmospheric Environment, Volume 38; Issue 16, 2607-2610;



The relationship between indoor and outdoor airborne particles was investigated for 16 residential houses located in a suburban area of Brisbane, Australia. The submicrometer particle numbers were measured using the Scanning Mobility Particle Sizer, the larger particle numbers using the Aerodynamic Particle Sizer and an approximation of $PM_{2.5}$ was also measured using a DustTrak. The measurements were conducted for normal and minimum ventilation conditions using simultaneous and non-simultaneous measurement methods designed for the purpose of the study. Comparison of the ratios of indoor to outdoor particle concentrations revealed that while temporary values of the ratio vary in a broad range from 0.2 to 2.5 for both lower and higher ventilation conditions, average values of the ratios were very close to one regardless of ventilation conditions and of particle size range. The ratios were in the range from 0.78 to 1.07 for submicrometer particles, from 0.95 to 1.0 for supermicrometer particles and from 1.01 to 1.08 for $PM_{2.5}$ fraction. Comparison of the time series of indoor to outdoor particle concentrations shows a clear positive relationship existing for many houses under normal ventilation conditions (estimated to be about and above 2 h^{-1}), but not under minimum ventilation conditions (estimated to be about and below 1 h^{-1}). These results suggest that for normal ventilation conditions, outdoor particle concentrations could be used to predict instantaneous indoor particle concentrations but not for minimum ventilation, unless air exchange rate is known, thus allowing for estimation of the "delay constant".

Scan: candle introduced into a 20L steel chamber, after wchich a 2nd aerosol (ETS) was introduced for 1 min only. Resultingdynamics clearly shows how the scmaller nano-particle spectrum completely adsorbs onto the larger ETS-aerosol.

Source: Morawska L (2015) Indoor Air – Lecturing sript

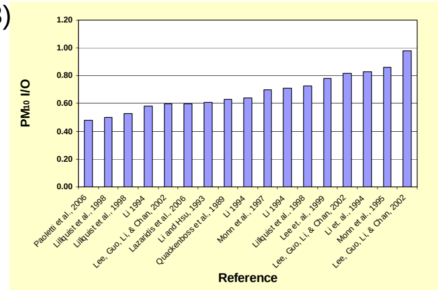
Morawska L., He C., Hitchins J., Gilbert D., and Parappukkaran S. The relationship between indoor and outdoor airborne particles in the residential environment. Atmos Environ 2001: 35: 3463–3473.

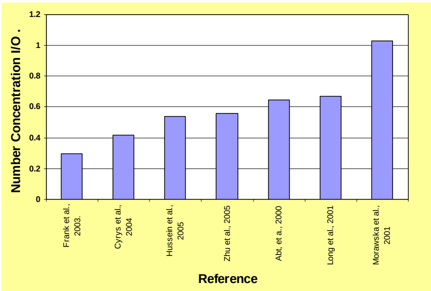
Aerosol | Climate | Health | Tools | Model

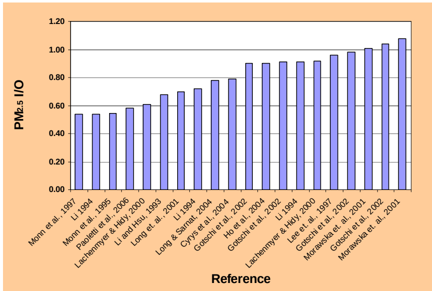
Indoor Air (2/3)

an underestimated situation:

- a cocktail of substances – both gaseous as well as particulate
- Improved housing standards: due to better insulation, indoor concentrations regularly outnumber that of outdoor air!







Morawska, 2015

15-01-14 Madl 79

Source: Morawska L (2015) Indoor Air – Lecturing sript

Aerosol | Climate | Health | Tools | Model

Indoor Air (3/3)

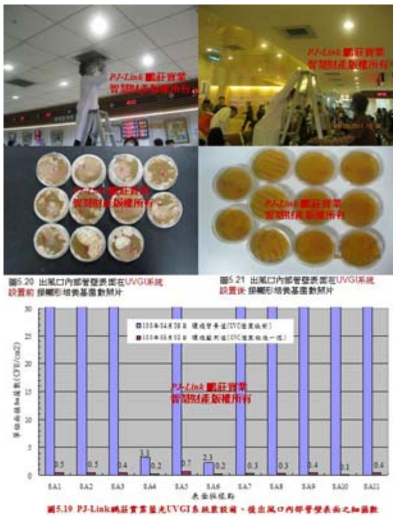
an underestimated situation:

- a cocktail of substances – both gaseous as well as particulate
- Improved housing standards: due to better insulation, indoor concentrations regularly outnumber that of outdoor air!
- Sick Building Syndrome (SBS) ....

.... not to underestimate as we spend most of the time indoors!

Symptoms commonly associated with SBS

- Eyes, nose, and throat irritation
- Headaches
- Fatigue
- Reduced attention span
- Irritability
- Nasal congestion
- Difficulty breathing
- Nosebleeds
- Dry skin
- Nausea



15-01-14 Madl 80

Building-Related Illnesses: This group of illnesses, in contrast to the SBS, consists of well-documented conditions with defined diagnostic criteria and generally recognizable causes. These illnesses typically call for a conventional treatment regimen, since simply exiting the building where the illness was contracted does not readily reverse the symptoms. Several of the bicontaminant-related illnesses (e.g., legionnaires' disease, hypersensitivity pneumonitis, humidifier fever) fall into this group, as do allergies to animal dander, dust mites, and cockroaches. Some toxic inhalants might be classified in this group, such as carbon monoxide. In many cases, however, when the concentrations of CO, NO_2, and many VOCs result in less discernible or definable conditions, the responses may be mistaken for or considered to be SBS, thus complicating the assessment of the situation. It should be noted that many inhalants, such as NO_2 and trichloroethylene (a VOC common to the indoor air arising from chlorinated water or dry-cleaned clothes), have been shown in animal toxicology studies to suppress immune defenses and allow opportunistic pathogens to proliferate in the lung. The involvement of immunologic suppression is a particularly controversial yet important attribute of indoor pollution because of ist insidious nature and implications for all building-related illnesses. This is further complicated in that complex indoor environments comprising of chemicals and biologicals may also lead to in unexpected interactions that are virtually unstudied and thus are not appreciated in the assessment of indoor pollution.

Image: CFUs cultivted after exposure to an air-conditioning systems

http://kk14282.hi178.com/T2002ShowAnceData?y_SketchName=Sketch1-2_Hi178&y_HrefId=41053&y_KindId=53564

Source: Costa DL (2001) Air Pollution, Ch. 28. In: Klaassen CD (ed) Casarett and Doull's Toxicology. Basic Science of Poisons. 6th ed. MacGrawHill, New York, USA;

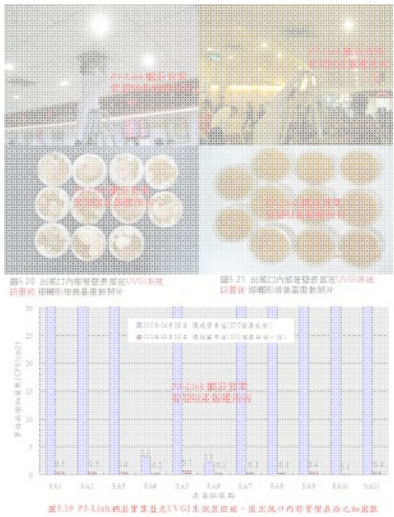
Aerosol | Climate | Health | Tools | Model

Indoor Air (3/3)

an underestimated situation:

- a cocktail of substances – both gaseous as well as particulate
- Improved housing standards: due to better insulation, indoor concentrations regularly outnumber that of outdoor air!
- Sick Building Syndrome (SBS) ....

Symptoms commonly associated with SBS
- Eyes, nose, and throat irritation
- Headaches
- Fatigue
- Reduced attention span
- Irritability
- Nasal congestion
- Difficulty breathing
- Nosebleeds
- Dry skin
- Nausea



For details see lecture on Indoor Air by
Prof, Lidia Morawska:
Prof. W. Riepe: biophysics.sbg.ac.at/transcript/indoair.pdf

.... Continue with part 2 (Climate) ....