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MINERAL AEROSOLS – ORIGIN AND IMPACT

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ABSTRACT

In the last years, atmospheric aerosols have received considerable attention because of their impact on the radiative energy balance of Earth’s atmosphere and their role in cloud condensing nuclei. The heterogeneous chemistry, which involves reactions between gas-phase molecules and solid-phase aerosols, influences on aerosol’s physical properties, modifying its optical properties and altering the chemical composition of the atmosphere. For example, during the Antarctic winter, polar stratospheric clouds catalyse the conversion of chlorine reservoir molecules, such as HCl and $ClONO_2$, into photochemically active chlorine molecules, in this case Cl_2 (Sokolik, Toon, 1986a).

The aim of the paper is to show that aerosols particles are ubiquitous particles and play an important role in the deterioration of historical buildings. Deterioration of these kinds of buildings is caused mainly by SO_2 and PM emissions; sulphate aerosols, at least in Europe, are no longer a serious problem. However, NO_x emissions are still at high levels and nitric-nitrous acids destroy the external stone walls of Cultural Heritage.

INTRODUCTION

There are a lot of particulate matters in the troposphere, including sea salt, sulphate, ice, soot, organic substances and mineral dust; of these, the heterogeneous chemistry of sea salt aerosols has received considerable attention because of their potential to generate highly reactive halogen species in the marine boundary layer

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(Finlayson-Pitts and Hemminger 2000). Recent, modelling studies suggest that mineral aerosols also impact on tropospheric cycles of chemical elements (Dentener et al. 1996). A small numbers of papers have investigated the heterogeneous chemistry of mineral aerosols.

There are some mechanisms in the formation of aerosols (Posfai, Molnar, 2000):

1. **The nucleation (ultrafine) mode** contains particles with diameters less than 0.01μm. These particles result from the condensation of gaseous precursors; gas-to-particle conversion of low volatility gases (e.g. sulphuric acid vapour in troposphere), highly oxidized organics compounds (continental regions), higher oxidation states of iodine (costal marine regions) leads to new particle formation in atmosphere. This nucleation process is not understood at the molecular level (role of ions, specific chemicals being important). The rate of this process is very highly dependent on the chemical nature of the atmosphere and on the amount of pre-existing aerosol surface area.

2. **Accumulation (fine) mode** contains particles in the 0.1 – 1.0 μm size range. These particles arise and grow from coagulation of smaller particles and from condensation/uptake of low volatility/soluble gases. There are also direct emissions of particles of this size to the atmosphere and the (re)formation of particles when cloud droplets evaporate. In urban air or arid regions, this can be the primary source of these particles. In different regions (e.g. urban air, arid and marine regions), this can be the primary source of these particles.

3. **Coarse mode**: these largest particles arise from mechanical forces or from disintegration of Earth'surface, e.g. bubble breaking at the surface of natural waters and dust formation by wind action. These types of particle involve strong forces in the atmosphere.

Chemically speaking many species makes a quantitative description of the atmospheric aerosols. Usually, the aerosols types are divided into: sulphate/nitrate particles, organic particles and mineral dust particles, soot particles, sea salt particles (Reid, Sayer, 2002). Aerosols are produced either by direct emission into the atmosphere (primary production) or by physico-chemical processes within the atmosphere (secondary production). Primary aerosols consist of mineral dust or sea particles, which further reacting or condensing onto existing aerosols to produce secondary aerosols. The classes of primary and secondary sources are presented in the table 1. Natural sources of atmospheric aerosol are substantial larger than the anthropogenic sources. The anthropogenic sources are concentrated around the urban places.

The aerosols in the atmosphere are divided (Posfai and Molnar, 2000):

1. primary aerosols: fume (aerosols from condensation of vapours), mineral dust, mists (from liquids or vapours condensation), smoke (from incomplete combustion of fuels - gas, solid or liquid).

2. secondary aerosols: products of chemical reactions (nitrate, sulphate, oxyhydrocarbons), low volatile compounds (alkenes) which condense to become particles.

Tab. 1. Classes of primary and secondary aerosols (Reid, Sayer, 2002)

	Natural	Dimension
Primary	Soil dust mineral	Mainly coarse
	Sea salt	Coarse
	Volcanic dust	Coarse
	Biological debris	Coarse
Secondary	Sulphate from biogenic gases	Fine
	Sulphates from volcanic SO_2	Fine
	Organic matter from biogenic VOC's	Fine
	Nitrates fom NO_x	Fine and coarse
	Anthrogenic	Dimension
Primary	Industrial dust	Fine and coarse
	Soot	Mainly fine
Secondary	Sulphate from SO_2	Fine
	Biomass burning	Fine
	Nitrates from NO_x	Mainly coarse
	Organics from anthropogenic VOC's	Fine

Coarse particles are > 1 μm in diameter, Fine particles < 1 μm in diameter, VOC = volatile organic compounds, NO_x = NO, NO_2.

Posfai and Molnar, 2000 evidenced that large amounts of ***natural primary aerosol*** particles are emitted on the continents, particularly in arid and semiarid areas. The chemical composition of mineral dust particles are determined by the composition of Earth's crust. Since human activities are increasing like extension, the dust production is modified. The disintegration of bulk plant produce primary aerosol. The data in the table 2 give an indicator of the mass of particles produced by surface disintegration.

Combustion processes produce primary aerosols particles that consist mostly of carbon and organic compounds. Fossil fuels contain residual mineral materials, including clays, sulphides, carbonates and various other materials that are also emitted in particulate from fly ash particles in the coarse size range. The condensation of metallic and non-metallic oxides (including SiO_2) produces fine particles. Soot particles are emitted by mobile sources, particularly by Diesel engines, producing aerosols population.

Tab. 2. Estimates of the annual mass production of aerosol particles from surface disintegration (after Posfai, Molnar, 2000)

Ocean surface	1.000 Tg yr^{-1} 1.000 – 2.000 Tg yr^{-1}
Crustal surface	3.000 Tg yr^{-1}

Source of aerosols can be divided in four classes (Reid, Sayer, 2002):

a) aerosols from water: cluster, cloud particles, rain droplets;

b) marine source: saline water from the oceans with metal halides, sulphates and organic compounds, biogenic compounds from algal;

c) naturals sources: desert sands, rock weathering, soil erosion, and volcanoes (alumino-silicates, ores, clays, organic matter and soot);

d) anthropogenic source: chemical emissions, fossil fuel combustion and heavy industry (soot, fuels, heavy metals).

MINERAL DUST AEROSOLS

Aerosols are systems in which exists a condensed phase of a solid or liquid dispersed in a gaseous phase and that has dimensions that fall into the colloidal range. There are two sub-classes of aerosols depending on whether the dispersed phase is a liquid or a solid. Where the dispersed phase is a liquid, the system is commonly referred to as a “mist” or a “fog”. For solid aerosols, one may commonly refer to a “dust” or “smoke”. Each class of aerosol has its own characteristics of formation and stabilization. In some situations, aerosols formed through dispersion processes are termed “dusts”, while those arising from condensation processes are called “smokes”.

Alternatively, other researchers prefer to label as dusts aerosols a particle which has relatively rapid sedimentation rates in air, while smokes would be smaller particles. Regardless of the terminology employed, it is clear that solid aerosols constitute a very important component of many modern processes.

The majority of industrial aerosols are produced by processes of dispersion in which small particles are formed from greater solid particles. Mining dusts and some exhausts from internal combustion engines fall into this general category of mineral aerosol formation. Because of the practical importance and potentially impact of solid aerosols produced by dispersion processes, they have received a great attention in terms of how their production can be eliminated or reduced from the atmosphere.

A mineral dust aerosol is defined as *a mixed phase or suspension of mineral particles dispersed in a gaseous medium* (similar with a liquid aerosol). Atmospheric examples of the former include smoke and mineral dust (fog, cloud and mist are examples for the latter). Particle diameters range from 10 nm to 100 µm. In troposphere there are many particles less then 1 μm in a volume air, while the particles larger than 1 μ much more rare (less than 1 cm^{-3}) (Posfai and Molnar, 2000). The consequences of atmospheric aerosols are the blueness of the sky and the redness of a sunset or sunrise. Solid aerosols produced by condensation processes are often of more theoretical interest because it is easier to control their nucleation and growth rate, particle size and size distribution, and rate of disappearance. They can therefore be used more readily to study the various theories of aerosol formation and destruction.

In the atmosphere there is a continuous material exchange between condensed and gas-phase materials; vapours condense to form liquid particles, which further evaporate depending on the ambient conditions. The condensation or nucleation takes place either homogeneously or heterogeneously on existing aerosols particles (nuclei).

The human-made aerosols are mainly sulphates, nitrates, organic carbon, and soil dust (fig. 1). Sources include fossil fuel burning and agricultural activities (Finlayson-Pitts, Hemminger, 2000). Black (elemental) carbon ("soot"), a product of incomplete combustion, can be seen in the exhaust of diesel-engine, and also is produced by biofuels and outdoor biomass burning. Black carbon aerosols are not well measured, but their climate forcing is estimated from multi-spectral measurements of total aerosol absorption. The estimated forcing effect of soot includes the reduction of the reflectance of snow and ice.

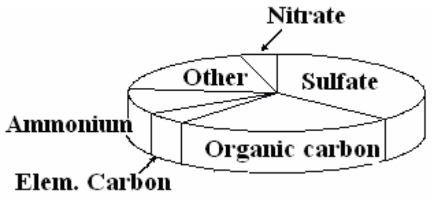


Fig. 1. Distribution of tropospheric aerosols (organic carbon can be dominant fraction, aprox. 90% over continental regions)

Organic compounds are emitted in the atmosphere through pollutant industries and biogenic sources (Olariu, Arsene, 2002). Although initially volatile, the organic compounds are chemically converted into non-volatile/soluble species through gas-phase chemistry. Mineral dust is the most important aerosol in the atmosphere, because large amounts of mineral dust are formed from the storms over desertic regions (e.g. Africa, Asia, North America). The winds can transport the clouds of mineral dust over large areas, from Africa to Europe or from Asia to America; in these clouds, the dust particles are dominant over the other aerosol types. Dust mineral are extremely important in nucleation processes, as sites for heterogeneous chemistry (fig. 2). Particles are formed from a large numbers of minerals, e.g. alumina, silica, iron oxide, carbonates, coated with sulphates, organic species as small particles in the atmosphere. Mineral dust and soot particles always act like solid core for the gases from the atmosphere. This will lead to a thin liquid shell of sulphate/nitrate/organics that may make the particles to react like a liquid.

Mineral particles are transported into the lower atmosphere by winds blowing through arid regions, while clay aerosols can remain suspended in the atmosphere for several months because of their relatively small diameters (fig. 3). There are some papers which confirm that these particles catalyze the formation of HONO, which is a major source of hydroxyl radicals (the dominant oxidizer in the atmosphere) (Hinrichs, 2004).

Soot particles are very small particles which contain elemental carbon resulted from combustion of fossil fuels and biomass burning (agricultural burning, domestic biomass burning, forest fires etc.). Large amounts of soot particles are taken up by larger sulphate/organic/dust particles. Sea salt are formed when bubble are broken at the surface of the oceans, seas or other bodies of water. Large amounts of these particles are formed in this way, so they frequently dominate the surface area or mass in the marine layer. Because the sulphur oxidation (the non-sea-salt particles) occurs in water droplets, mineral aerosols will also contain sulphate, similar to sulphate concentrations found in sea water.

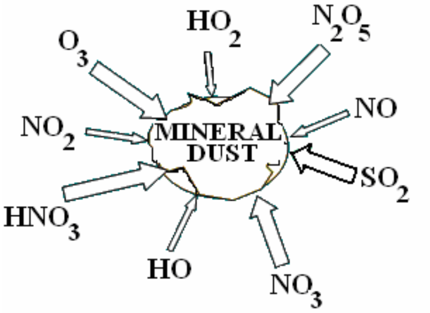


Fig. 2. The adsorbed molecules onto mineral dust

The flux of mineral dust into the troposphere varies greatly with location and season. It has been estimated that average annual emission of mineral dust into the atmosphere is approx. 1000-3000 Tg (Grassian, 2002) and from these up to 50% of the global mineral aerosol emissions result from human activities, such as agriculture or industry. Also, it has been estimated that annually 360-500 Tg of mineral dust is deposited into the oceans, with approx. 50% of the total deposition occurring in the North Atlantic Ocean (Zhang, Carmichael, 1999). The frequency and intensity of dust events, and ultimately the mineral aerosol loading in the atmosphere, are expected to increase as long as improper land-use practices are driven by economic circumstances. By the year 2100, mineral aerosol production is anticipated to increase by 10% from its current level (Dentener et al., 1996). Mineral dust aerosol plays an important role in the coupled global processes of chemistry, climate, biogeochemical cycles, and health. Because mineral dust may undergo processing as it is transported in the atmosphere its impact on global processes may change over the course of its "life history".

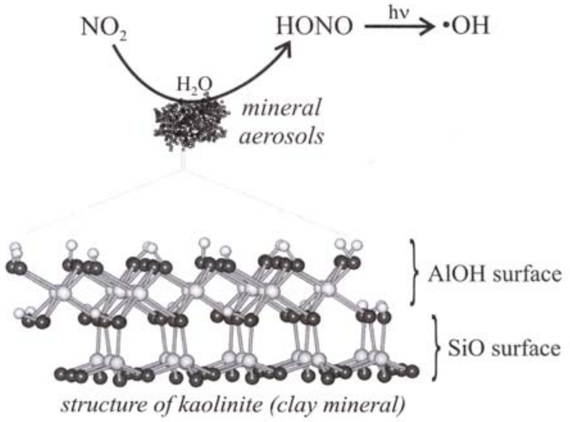


Fig. 3. Influence of crystalline structure of minerals on nitrous acid formation (Hinrichs, 2004).

Mineral aerosols can alter the Earth temperature through direct and indirect climate forcing. Deposited mineral dust containing metals can be a major source of iron or other heavy metals on the Earth. Mineral dust aerosols can change the chemistry balance of the troposphere through surface absorption. In the same time, mineral dust aerosols are responsible for human health if these particles are associated with bacteria or other microbes (fig. 4). Air pollutants can cause adverse health effects, loss of visibility through light scattering and have the potential to cause other environmental damages. The effects of atmospheric aerosols depend on their size and chemical composition. Water soluble components comprise most of the aerosol fraction. The two major inorganic water soluble compounds which play a key role in aerosol properties are sulfate and nitrate. Non-sea salt sulfate is often the most dominant secondary inorganic aerosol component in the atmosphere. Sulfate particles are formed by oxidation of sulfur dioxide (SO_2) either in the gas phase or in water droplets (Arsene, Olariu, 2003).

Until now the researches believed that mineral aerosols were relatively inert in the atmosphere. Strong evidences indicate that mineral aerosols have a significant tropospheric influence. Dentener et al., 1996 found that nitrate adsorbed on mineral dust is account for over 40% of total nitrate (adsorbed + gaseous HNO_3). This means a strong correlation between nitrate and mineral dust, suggesting further heterogeneous nitrification reactions. Additional results suggest that mineral aerosols may decrease ozone concentrations by 10% (Dentener et al. 1996). This decrease results from direct removal of O_3 by mineral surfaces and from interactions with N_2O_5 and HO_2 radical.

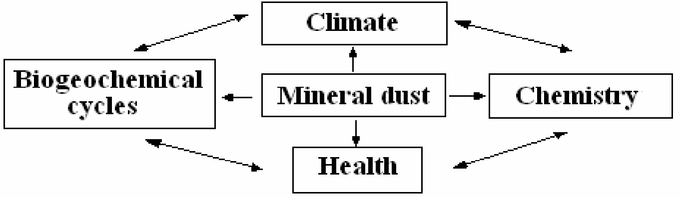


Fig. 4. Influence of mineral dust on other sciences

The heterogeneous chemistry of mineral aerosols is complicated by chemical composition. Most sources produce dust containing one or more of the following minerals: silica, carbonates, clays, gypsum, and hematite (Sokolik, Toon, 1996a). Majority of experiments have focused on mineral oxides such as SiO_2, Al_2O_3, and CaO, while the other compounds have less attention and a few studies have expanded the laboratory investigations on carbonates and clay minerals. Mediterranean field measurements on mineral dust originating from the Saharan desert found that aerosol compositions consist of up to 30% calcite. Aluminium silicates comprise a significant portion of mineral dust generated in Asia.

Most of the SO_2 emissions globally result from fossil fuel burning. For this reason, most of the aerosol produced from the oxidation of SO_2 is considered to be anthropogenic (Finlayson-Pitts, Hemminger, 2000). In an increasing number of cases, nitrate is the most abundant component in fine particles anthropogenic (Finlayson-Pitts, Hemminger, 2000). Nitrate may exist in the accumulation mode (mainly as ammonium nitrate), but may also exist in coarse particles due to deposition of nitric acid (HNO_3) on alkaline mineral or salt particles (Sokolik, Toon, 1996b). Sulfur and nitrogen containing aerosols are of interest to atmospheric studies due to their influence on radiative transfer and cloud formation, and hence on global climate (Hinrichs, 2004). Several authors reported the radiative and cloud formation effect of sulfate aerosol. However, until recently nitrate has not been considered in assessments of the radiative effects of aerosols. Van Dorland et al., 1997 (after Houghton et al., 2001) suggested that radiative forcing due to ammonium nitrate is about one tenth of the sulfate forcing. However, the importance of aerosol nitrate could increase substantially over the next century. Observations and model results show that in regions of elevated NO_x and NH_3 emissions, such as Europe, and parts of North America, NH_4NO_3 aerosol concentrations may be quite high and actually exceed those of sulfate.

AEROSOLS CHEMISTRY

Aerosol nitrate is formed from the reaction of nitric acid with aerosol species from the atmosphere: ammonia, sea salt or mineral dust. Reaction of nitric acid with the mineral dust yields to a stable product, like $Ca(NO_3)_2$, which is found in the coarse aerosols fraction.

Cologne Cathedral is a monument from world Cultural Heritage, with amazing dimensions. One of the campaign to which the author has been participate was focused on pollutant effects of wet and dry deposition of gases in particular NO_x. Since emission of SO_2 is a solved problem in Germany, the NO_x emissions are still high, especially in big cities. The conversion of NO_2 from the atmosphere beside water on the surface of cultural heritage buildings can lead to nitrous or nitric acid formation on the stone or other materials. These acids may destruct the buildings wall through a simple reaction of calcium carbonate with nitric acid forming calcium nitrate. Besides air pollution, many parameters influence the damage of the Cologne Cathedral' walls. Atmospheric corrosion involves chemical, physical and biological parameters (Chiari, 2000). Wall' materials behave differently and can be sensitive to pollution in general or sensitive to a particular pollutant. In the present multi-pollutant situation several different options, i.e. change of SO_2, HNO_3 and/or PM10, can be used in order to reach a situation that is acceptable and where the effects of corrosion attack can be managed. The impact of reactive nitrogen species on the destruction of stone surfaces of Cologne Cathedral is presented here in some pictures which were realized during the campaign.

One of the natural destruction of nitric acid in the atmosphere (although there is little literature describing experimental study) is the reaction with mineral surface forming nitrate and water (sand particles, old buildings walls). Some papers show that the alkalinity of $CaCO_3$ increases the uptake of gaseous acids such as HNO_3 (g) and the reaction similar with reaction (1) is happening in the atmosphere (Schaap, 2003):

$$CaCO_3(s) + 2HNO_3(g) \rightarrow Ca(NO_3)_2(s) + CO_2(g) + H_2O(g) \qquad (1)$$

The author specified that water which is adsorbed to the surface increases the uptake process for this reaction. There are same evidences for a possible reaction:

$$CaCO_3(s) + HNO_3(g) \rightarrow Ca^{2+}(aq) + HCO_3^{-}(aq) + NO_3^{-}(aq) \qquad (2)$$

Goodman et al. 2000 (after Schaap, 2003) found that surface adsorbed water increase the uptake coefficients: increasing the RH from 0% to 20%, the uptake coefficient is enhancing by an order of magnitude. The surface adsorbed water plays a critical role: the $CaCO_3$ particles exposure to HNO_3 at 20% RH shows a marked change in surface morphology. It is well known that surface adsorbed water enhances the ion mobility of the product like $Ca(NO_3)_2$, with subsequently exposing fresh areas of $CaCO_3$ for further reactions due to the hydrophilic nature of calcium nitrate over calcite. Using a Knudsen cell reactor, Hanisch and Crowley, 2001 have studied the uptake of HNO_3 onto dolomite, $CaMg(CO_3)_2$ and kaolinite $Al_2Si_2O_5(OH)_4$ and they founded a significant uptake coefficient for both measurements ($\gamma=1.4\cdot10^{-1}$). A considerable attention has received the sulphate and sea salt aerosols (Finlayson-Pitts, Pitts 1997).

Ro et al. 2002 (after Schaap, 2003) have founded significant levels of Al_2O_3 in atmospheric aerosols. In addition, they considered that surface hydroxyl groups will play a critical role in the heterogeneous uptake of NO_2 forming $OH\cdots NO_2$ adducts types. Same authors have identified that gas-phase nitrous acid, HONO is important in hydrolysis of NO_2:

$$2NO_2(g) + H_2O(l) \xrightarrow{kaolinite} HONO(g) + HNO_3(g) \qquad (3)$$

The products of the above heterogeneous reactions are formation of surface adsorbed nitrate and nitrite. This provides a mechanism for the long-range transport of nitrogen oxide species in the atmosphere.

As we know the primary responsible acids for the acidification of the atmosphere are sulphuric and nitric acids (H_2SO_4 and HNO_3), which are produced by the oxidation of sulphur and nitrogen oxides. Chemistry of aerosols plays an important role in atmospheric processes.

The NO_3 radical has been of interest to chemists since its existence was first postulated by Hautefeuille and Chappuis (1881). The discovery of the night-time presence of NO_3 radical in the stratosphere and troposphere has necessitated the study of the role that it plays in the atmosphere. NO_3 radical is one of the several atmospheric oxidizing agents, the other important species being OH radical and O_3. In the atmosphere by far the most important source for NO_3 radical is the relatively slow reaction between NO_2 and O_3:

$$NO_2 + O_3 \to NO_3 + O_2, \qquad k_1 = 3{,}2\cdot10^{-17}\,cm^3\cdot molec^{-1}s^{-1} \qquad (4)$$

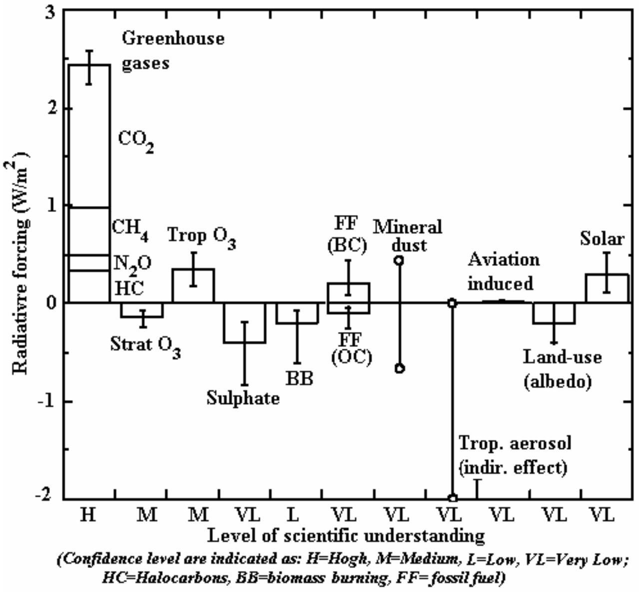
Consequently, the atmospheric oxidation potential of NO_3 radical is limited by the available O_3 and it is, moreover, related to the abundance of NO_2. OH radical is present at high concentrations during daylight and has very low concentrations at night; NO_3 is maximum at night but minimum during the day; and O_3 is present all the time.

Although the concentration of atmospheric NO_3 radical is always much lower than that of O_3, the NO_3 radical reacts with most substances sufficiently faster than O_3 do. So, the rate of NO_3 radical removal in the atmosphere is greater than that of ozone. The presence of NO_3 radical can increase the effective rate of atmospheric oxidation by ozone. So, the presence of nitrate radical increases the oxidizing potential of the atmosphere.

Many papers show that the yield of nitric acid from NO_3 or N_2O_5 is the same with that from the OH oxidation of NO_2 in certain regions of the Northern Hemisphere. This process leads to the efficient removal of NO_x from the atmosphere.

Atmospheric aerosols, especially mineral aerosol, may affect local and global climate through the absorption and scattering of solar radiation. When aerosol particles absorb and scatter radiation themselves, the resulting radiative forcing is named “direct”, whereas if the particles influence the optical properties of clouds, then the radiative forcing is "indirect." Positive radiative forcing values, measured in $W \cdot m^{-2}$, result in a warming effect on the Earth's surface, and conversely, negative forcing has a cooling effect. Researchers have a very low level of scientific understanding about the effect that mineral aerosol particles have on the radiative budget of the atmosphere. For example, it has been estimates the net radiative forcing by volcanic aerosol to range from –0.60 to +0.40 $W\ m^{-2}$ (fig. 5). The figure shows a global estimation of radiative forcing, in $W.m^{-2}$ due to the modification in aerosols concentrations (Schaap M., 2003). Sulphate is the most studied aerosol component and has a cooling effect on atmosphere with an estimated forcing of –0.4 W/m^2. Carbonaceous aerosols from fuel burning has a forcing effect which arrive at + 0.2 W/m^2, which mean a warming effect on atmosphere.

For carbonaceous aerosol resulting from biomass burning the net effect is negative (-0.1 W/m^2). This mineral dust exerts a negative forcing by scattering and absorption of short wave radiation and a positive radiative forcing by absorption of long wave radiation. Many uncertainties still remain in the estimation of the forcing of mineral dust. The studies suggested that the short wave negative effect is larger that the positive long wave forcing. Most significant thing is that not only the sign of radiative forcing is known, but also the range from negative to positive values is interesting. That means it is completely uncertain whether mineral dust causes global warming or global cooling. The radiative impact of mineral dust in the atmosphere is quite unclear due to the incomplete understanding concerning the diverse nature, the transport and removal processes, and the chemical and physical properties of the particles. The experiments are focused on modelling analyses of mineral dust optical properties that will significantly enhance our understanding of the impact of mineral dust aerosol on global climate through direct radiative forcing. In particular, the researches will explore how atmospheric aging (through chemical and physical processing) may alter the optical properties of the mineral dust and hence how it changes the impact that dust has on climate. Typical abundance of ions, minerals or organic species is presented in the table 2 (Reid, Sayer, 2002). Varying hygroscopic properties lead to the movement of an aerosol particle, even to the stratosphere.



(Confidence level are indicated as: H=Hogh, M=Medium, L=Low, VL=Very Low; HC=Halocarbons, BB=biomass burning, FF=fossil fuel)

Fig. 5. Global estimation of radiative forcing, in W.m^{-2} due to the modification in aerosols concentrations

Tab. 2. Composition of tropospheric aerosols (µg / m^3 air) (Reid, Sayer, 2002)

Species	Marine	Continental
	Cations	
Na^+	2.91	0.08
K^+	0.11	0.12
NH_4^+	0.16	0.16
Ca^{2+}	0.17	0.30
Mg^{2+}	0.40	0.25
	Anions	
SO_4^{2-}	2.58	4.90
NO_3^-	0.05	1.35
Cl^-	4.63	0.14
Br^-	0.015	< 0.01
Methanesulfonic acid	0.12	-
	Mineral components	
Fe_2O_3	0.07	0.37
SiO_2	-	1.25
Al_2O_3	-	0.39
CaO	-	0.18

Organic components		
Neutral aliphatics	0.16	0.53
Neutral aromatics	0.20	0.26
Neutral polar	0.10	0.35
Organic acids	0.23	0.7
Organic bases	0.03	0.2
Unidentified	0.8	2.1

Some aspects of impact of mineral aerosols with the walls of old buildings are presented in plate I. Here, there are some images of the external walls of Cologne Cathedral, Germany

CONCLUSIONS

Our understanding of atmospheric pollution and its effects on the environment has increased over the last decade. The future of aerosol science is challenging. Important issues such as the relations between aerosols and climate, and aerosols and health need to be quantified better. At this moment large gaps in knowledge exist, which prevent to assess these relations with large confidence. For large regions in the world the aerosol load, not to mention its chemical composition, is unknown. Formation routes (e.g. sulphate and secondary organic aerosol) or emission strengths (e.g. soil dust) are associated with large uncertainties. The (optical) properties of these aerosols, being a mixture of components, are poorly known, which severely disturb the assessment of aerosol impacts on the radiation balance. These gaps in knowledge need to be closed.

Some conclusions must be presented:

1. Aerosol concentration is highly variable in space and time. Concentrations are usually highest near the ground and near sources.
2. The values of aerosols concentrations may range from 2 orders of magnitude in much polluted regions to several lower in very clean air.
3. Radii range from ~ 10^{-7} cm for the small ions to more than 10 μm (10^{-3} cm) for the largest salt and dust particles.
4. The largest particles are only able to remain airborne for a limited time.
5. Interactions of trace gases e.g. HNO_3 with dust potentially affect the photochemical oxidant cycle, causing O_3 decreases up to 10% near the dust source regions.
6. Mineral aerosol can influence trace gas budget due to uptake of HNO_3 and repartitioning of nitrate to the particle phase.
7. The long-range transport of adsorbed nitrates on mineral aerosols has the potential to interact with the wall of the buildings.

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