Abstract Volume
9th Swiss Geoscience Meeting

Zurich, 11th – 13th November 2011

12. Natural or man-made mineral dust and its influence on humans, environment and climate

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Geosciences
Platform of the Swiss Academy of Sciences

ETH
Eidgenössische Technische Hochschule Zürich
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12. Natural or man-made mineral dust and its influence on humans, environment and climate

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Swiss Society of Mineralogy and Petrology (SSMP)
Commission on Atmospheric Chemistry and Physics (ACP)

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12.1
Dust analysis in human lungs

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Every day, we inhale airborne dust from different sources. Natural dust sources are erosion, sandstorms, volcanic eruptions, sea spray or pollen. Forest and bush fires also contribute to the dust load as well as human activities like industry, traffic, construction and agriculture. Many people are exposed to high dust levels at their workplaces e.g. in mines, industry and construction.
Dust particles have various shapes, therefore the parameter used to describe and compare particles is the aerodynamical diameter. Particles with a diameter smaller than 8 µm are deposited in the lung. For fibrous material this means that fibers with a diameter smaller than 3 µm and as long as 100 µm can reach the alveoli. Clearance of particles/fibers mainly depends on the biopersistence of the material. So many materials get accumulated and cause health problems like silicosis (quartz), asbestosis, and hard metal (W, Ti, Ta, Nb, Mo) disease. Improvement of workplaces has led to reduced amount of inhaled dust. Silicosis has practically disappeared in Switzerland. Asbestos related diseases have a long latency period and are still diagnosed even so the use of asbestos has been banned in 1989 in Switzerland.

Workplace related dust induced lung diseases in Switzerland are insured by SUVA (Swiss Accident Insurance Fund). SUVA requires a work place investigation as well as a dust analysis on lung tissue for most insurance cases. The 'Staublungenlabor der SILAG' provides the analysis of dust separated from lung tissue or from bronchoalveolar lavage liquid (BAL).

At the 'Staublungenlabor der SILAG', the standard procedure comprises two different approaches to separate the dust from the lung tissue. One half of the sample is digested in sodium hypochlorite (Javelle) and the solution filtered on 1.2 µm Millipore filter. These filters are investigated by light microscopy to count the ferruginous bodies (see figure 1; Rüttner et al. 1991). The second half of the sample is dried and then ashed in an oxygen plasma at low temperatures. The remaining ash is dispersed in water and filtrated on 0.2 µm Nuclepore filter (Romer 1993). These filters are coated with carbon and placed on Cu-grids for TEM analysis. During TEM analysis fibers are counted, analysed by EDS, and if necessary identified by electron diffraction. The standard procedure allows the detection of fibers as short as 1 µm. Particle analysis consists of qualitative EDS spectra for approximately 100 particles.

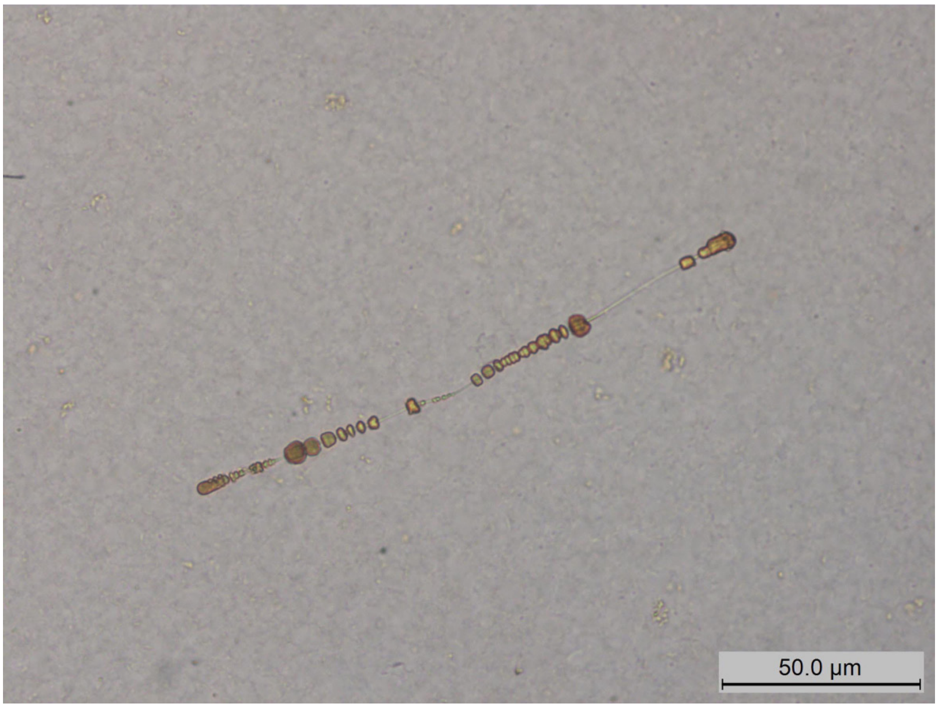

Figure 1. Ferruginous body: asbestos fiber coated by ferro-protein, isolated from lung tissue. Photographed by B. K. Kuhn.

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12.2
Characterization of two different biomass pellets and their combustion products

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In this study, two different biomass pellets (DIN+ wood pellet and a new grass pellet "Miscanthus") and their combustion products (bottom ash and fly ash) were investigated by Atomic Absorption Spectroscopy (AAS), Scanning Electron Microscopy (SEM) and Electron Microprobe Analysis (EMPA). Also, an attempt was made to characterize combustion derived particles by using SEM images and EDX spectra. Figure 1 shows a comparison of the particle types found for the two pellet types.

The fuels were combusted with a heating ramp (20°C to 820°C @ 20°C/min) using a glass tube reactor, and the particles were collected by an Electrical Low Pressure Impactor (ELPI) on twelve stages depending on their aerodynamic diameter. The results were compared with literature data. The main focus was put on the alkali, alkaline earth and silicon contents as these compounds lead to the formation of corrosive deposits in biomass power plants and hazardous primary and secondary particulate matter in the atmosphere.

The results reveal relatively higher potassium and calcium contents in the Miscanthus fuel and its combustion products (see figure 2 for bottom ash composition), whereas the silicon contents are almost the same for both fuel types. The unexpected high silicon and calcium content in the wood pellet is inferred to derive from contamination, probably from the pellet production process. Grains of calcite and quartz were observed in both pellet types by electron microscopy. In the grass pellet potassium and silicon were also found inside the cells (figure 3). In the bottom ash of the Miscanthus pellet, mineral phases from the melilite-group, quartz, calcite and sillimanite have been detected with X-ray diffraction. In the bottom ash of the DIN+ wood pellet, only quartz and calcite were detected.

In addition to the composition of the pellets and their combustion products, useful insights were gained on the suitability of sampling substrate materials for collecting the particles for further SEM analysis. Properties such as applicability with the ELPI, stability, purity and handling in the SEM and EMPA were taken in account while six different sampling substrate materials were used.

The main problem on the method of particle sampling and characterization for biomass combustion products was found to be the relatively large amount of organic condensates that appear to cover almost all of the ultra-fine particles on the sampling substrate and started to melt and evaporate during SEM measurements.

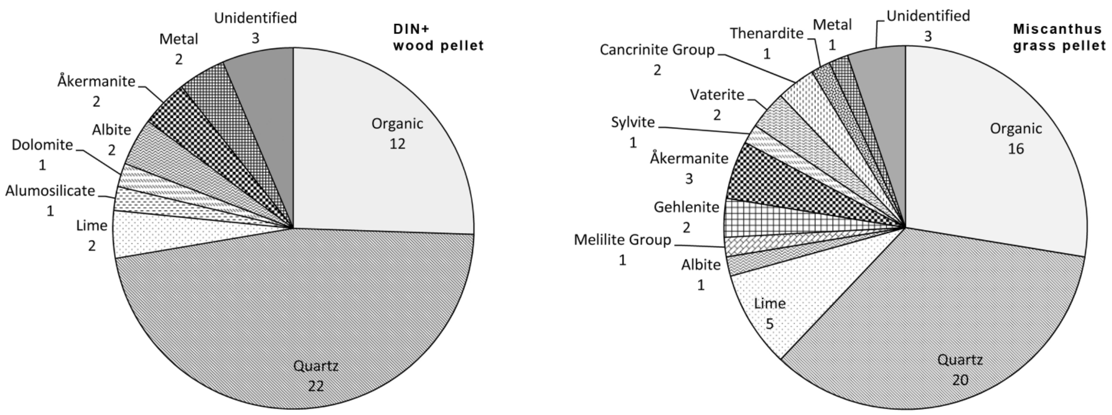

Figure 1: Distribution of particles formed during the combustion of the DIN+ wood pellet (left) and the Miscanthus grass pellet (right). Data obtained by Scanning Electron Microscopy (SEM) and EDX-Analysis.

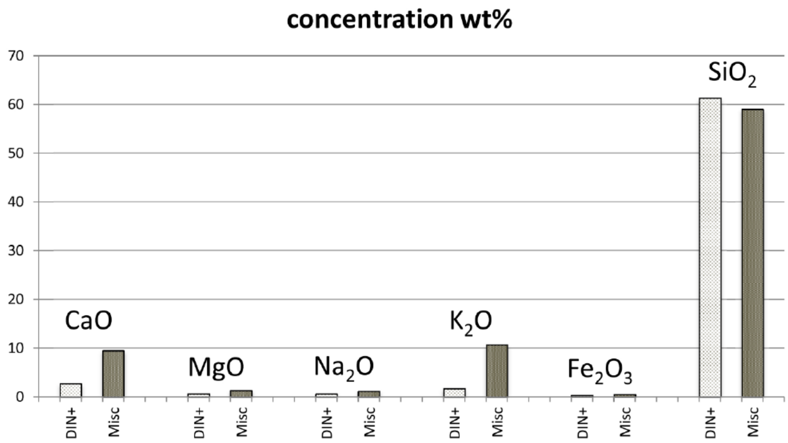

Figure 2: concentration of selected oxide components from the bottom ashes of the DIN+ wood pellet (light grey columns) and the Miscanthus grass pellet (dark grey columns) obtained by Atomic Absorption Spectroscopy (AAS).

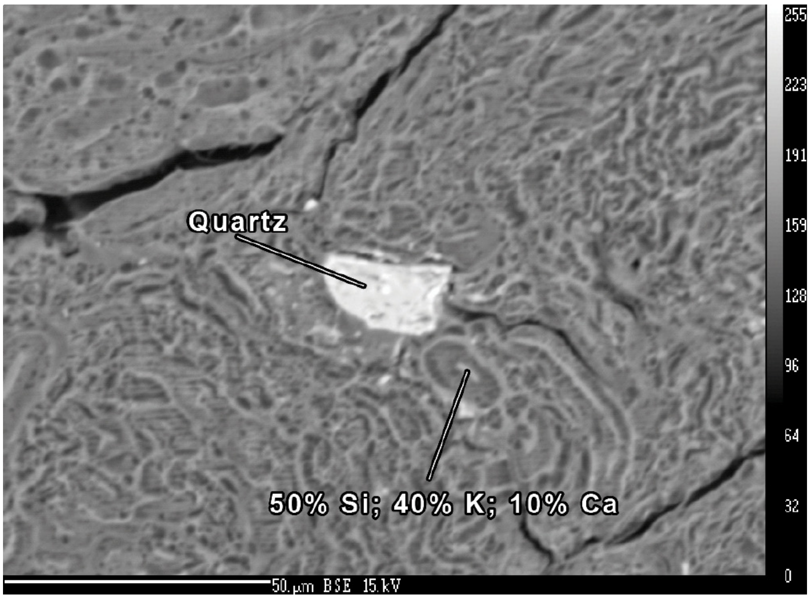

Figure 3: Scanning electron image of a section through a Miscanthus grass pellet. The quartz grain is probably a contamination from the pellet production process or grass harvest. Spectra indicate 50 wt% silicon, 40 wt% potassium and 10 wt% calcium (roughly) inside the grass cells (probably biogenic).

12.3

Validation of a Lagrangian dust transport model with data from the FENNEC/LADUNEX field campaign

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Mineral dust aerosol is a key player in the Earth system. Strong winds over the world's major deserts mobilise and subsequently lift mineral dust high into the atmosphere. Due to the harshness and inaccessibility of desert regions, the exact processes of mobilisation and lifting, and layer formation are still unclear. One major unknown in the dust cycle is the dust source or emission strength. Despite better quantification being key for global models, the assessment of impacts on clouds, radiation and biogeochemical cycles, estimates in the literature from global and regional models span a wide range. Here, we validate the state-of-the-art Lagrangian particle dispersion model FLEXPART which has been made capable of simulating dust mobilisation and settling with airborne and ground-based mineral aerosol and turbulence measurements from the FENNEC/LADUNEX field campaign which was carried out over the western Sahara during June 2011. For selected case studies we compare in-situ data from the aircraft airborne and spaceborne LIDAR measurements and the FLEXPART model simulations. In combination, this will provide the data basis for the application of a dust inversion algorithm to povide a first step towards a new dust emission function from the inversion of airborne measurements of aerosol distribution and mass using the Lagrangian model.

12.4

Analysis of re-suspended ash from the Eyjafjallajökull

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The 2010 eruption of the Eyjafjalla volcano had a great impact on international air traffic and illustrated the potential risks of active volcanism. It also showed the need for more investigations on the properties of airborne ash particles emitted by explosive vents. The explosive reaction between the magma and the ice from the glacier produced an extreme plume of ash up to 20 km in height in the atmosphere. The large particle fraction was deposited around the volcano and smaller sizes have been transported mainly southwards over Europe. The present study is focussed on particle re-suspension by wind conditions after the eruptions. It aims to examine the airborne particles and to develop automated analysis techniques.

Ambient air samples of airborne re-suspended ash were collected in winter 2010/11 with a passive sampler of the Sigma-2 type positioned 12 km south of the eruption zone. The first examination has been performed manually to ascertain the properties of the sample. Using an optical microscope under transmitted, polarized and cross-polarized light and an electron microprobe with BSE and EDX-analysis around 200 particles were characterized. Subsequently, the data were processed with an image analysis program. This procedure allowed for a categorization of the individual particles as glass, mineral, composite or agglutinated particles as well as to obtain chemical information about individual particles. To gain a statistically relevant overview about the composition of the sample and to minimize the analytic work, a larger area of the same sample, including the area studied manually, was examined using automatic single-particle SEM analysis (EDAX Genesis program), which resulted in characterisation of approximately 1600 particles. The results of both methods were compared against each other to evaluate the advantages and disadvantages of the different approaches and to develop the combined analytical approach further.

The examined particles range from 2.5 µm to 80 µm in size (equivalence diameters). The size distribution shows the typical character of ambient aerosol, i.e. increasing size with decreasing number of particles. The main fraction is contributed by particles larger than 10 µm. Only about 10 % (surface area) of the particles consist of glassy material; the main part is crystalline. With a surface-area fraction of 63 %, feldspar is the dominating mineral (plagioclase 43 %, K-feldspar 20 %), followed by pyroxene (18 %) and quartz (12 %). In minor quantities (1% or less) olivine, ilmenite and titanite can be found. The sample is also contaminated with salt of oceanic and/or volcanic origin.

To obtain optimal results a combination of automated and manual analysis is required. Only an automated method allows for an examination of a large number of particles, but the manual control is necessary to obtain more detailed information about the composition and the crystallinity of the particles.

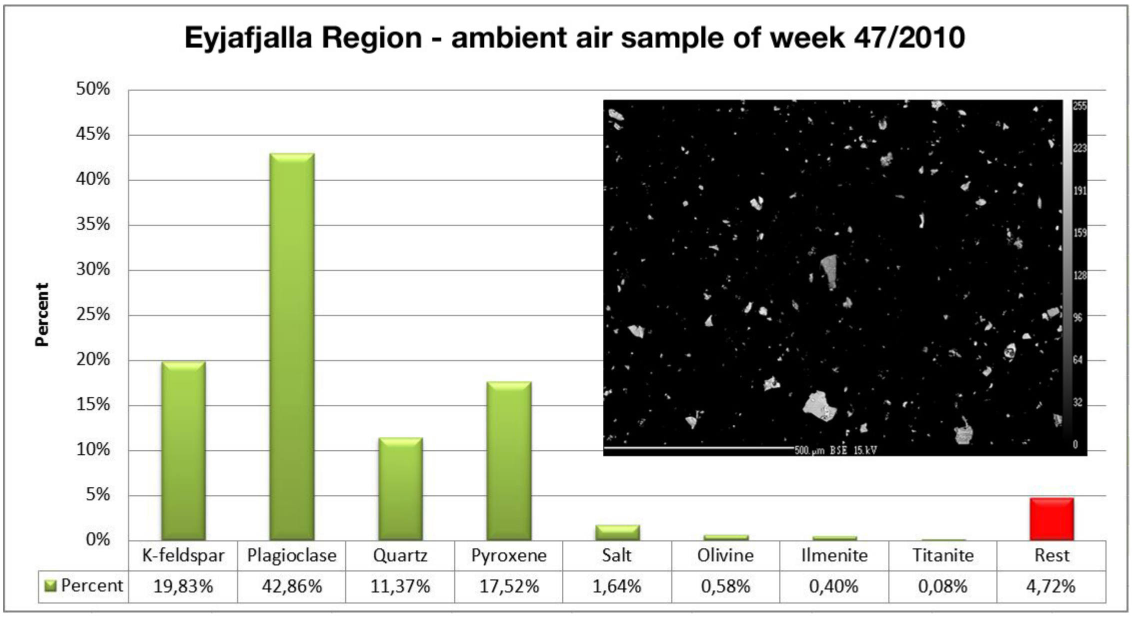

Figure 1. BSE image and the distribution of the surface area of the minerals in percent.

12.5

The role of mineral dust particles and their surface properties for clouds

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Mineral dust particles are among the most abundant particle types in the atmosphere. They can serve as catalysts for chemical reactions in the atmosphere but also for phase transitions such as the formation of ice crystals in clouds. Once ice crystals start to form within a cloud it changes its radiative properties because they scatter light differently than cloud droplets. But ice crystals also often initiate precipitation and therefore reduce cloud lifetime. All these processes are important in the climate system and changes in the number of ice forming particles (ice nuclei) or their properties (temperatures at which they activate) can ultimately influence the global climate. But our knowledge of the underlying fundamental processes is still incomplete and especially the chemical and physical properties that govern the ice nucleation ability of a particle are still unknown. Classical Nucleation Theory may be applied for these processes and the important particle properties can be summarized here in the parameter called contact angel. It becomes even more complex when the variability of the particle surface is considered. It is a subject of current research how this variability can be parameterized with probability density functions of the contact angle.

Another degree of complexity results from the fact that different mechanism for ice nucleation in clouds exist. These are deposition nucleation, immersion freezing, condensation freezing, and contact freezing. Their relative importance is also a subject of current research. It is however unquestioned that the relative fraction of the different modes depends on the thermodynamic conditions within a cloud.

In our lab we investigate these different ice nucleation mechanisms with individual experiments for the different mechanisms using mineral dust aerosols (Ladino et al. 2011; Lüönd et al. 2010). In this paper, our recent results on the ice nucleation properties of mineral dust particles for immersion freezing, and contact freezing are presented and compared. The results demonstrate how different particle types differ in their ice nucleation ability as a function of temperature but also particle size. We also investigated the frozen fraction of droplets as a function of residence time. These measurements are compared with different model calculations, which are based on theoretical assumptions about the surface properties of the dust particles.

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12.6

Tire-wear particles and their effects on human A549 lung cells

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In the recent time there has been a lot of discussion on the real properties of tire-wear particles, especially concerning their size and characteristic features but also with respect to their effects on health. In this study, three different tire-wear samples from the tire-test rig of the BASt in Bergisch-Gladbach (Germany) as well as one pure tire sample were analysed to specify parameters, such as, size distribution, chemical composition, particle structure, and optical behaviour. In a further step, the impact of tire-wear and tire particles on human lung cells, from the commonly used lung cell line A549, were investigated. An important goal was to develop standard treatment procedures, which lead to representative results and minimize the influence of preparation agents. The automated optical microscope analysis delivered information concerning the size and the grey value of the particles. In contrast to previous estimates, the pure tire sample contained both opaque and transparent particles. This result is not in agreement with the usual counting methods, for which so far only the opaque particles were regarded as tire material whereas the transparent particles were assumed to originate from the pavement only. Still, the transparent particles could result from pavement material, which stuck to the tires before they were shredded and ground for the experimental work. For the real tire-wear particles the size distributions were distinct for the different samples, but only one sample showed the often described bimodal size distribution with modes at approximately 7 µm and 20 µm. All samples contained particles smaller than 10 µm and opaque as well as transparent particles.

The experiments have shown that the lung cells, which were exposed for up to 8 h to the various samples at concentrations between 5 and 50 µg/cm², did not show any increase in NF-κB-DNA binding activity. An exception is one sample, for which an 8 h exposure to 50 µg/cm² sample material, led to a stronger increase in NF-κB-DNA binding activity measured by EMSA. Activation of the transcription factor NF-κB is closely linked to inflammatory processes.
Cytotoxicity tests revealed an increased cytotoxic potential for all the samples from the tire-test rig but not for the pure tire material. The extent of cytotoxicity, as measured by the MTT test, varies with concentration but is not always increasing with higher concentrations (Fig. 1). Whereas in most cases cytotoxicity is only slight, one sample induces cytotoxicity up to about 50%.

The preliminary results of this study indicate that there is a certain amount of particles smaller than 10 µm present, which is able to penetrate into the deeper part of the human lung and may cause health impacts.
The results from the cytotoxicity tests point to a negative impact on cells and health in general. However, additional tests are needed to corroborate the first conclusions. This study has so far also shown that there are significant differences between the samples from different tire types. Also the effects of pure material are distinct. This may either be due to structural differences or the cytotoxic effect resulting from the pavement material, which is present in small amounts and is abraded to a different extent by the different tire types. This question and the influence of size or chemical composition of the tire particles on the cells will be in the subject of further investigations.

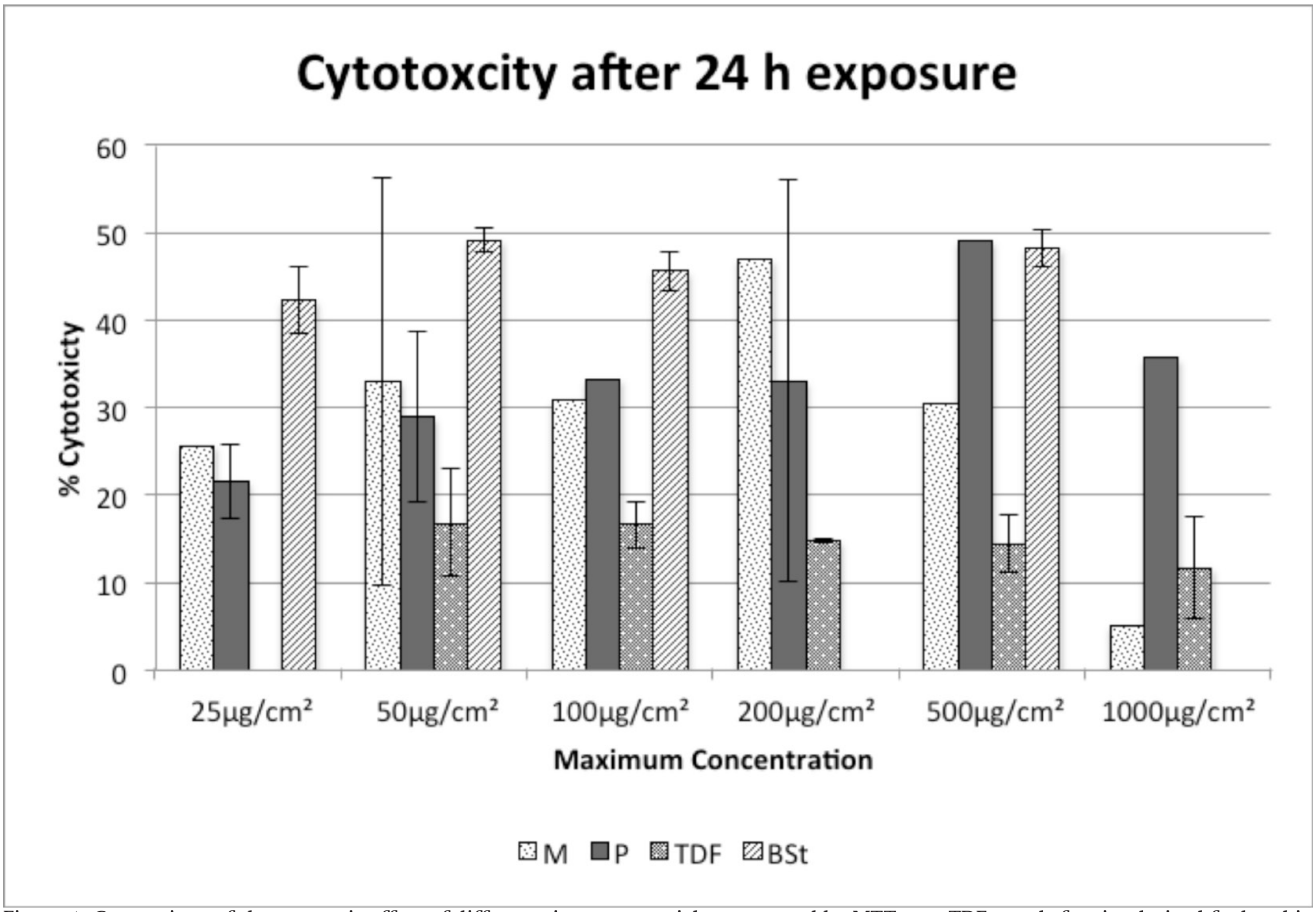

Figure 1. Comparison of the cytotoxic effect of different tire-wear particles measured by MTT test. TDF stands for tire-derived fuel and is the only analysed pure tire-particle sample. M, P and BSt are real tire-wear particles. The cytotoxicity was measured in A549 lung cells in six-well plates with 400 000 cells in each well. All the samples were measured in duplicate. Camptothecin and Actinomycin D were used as positive controls.

P 12.1

A 1000-year record of Sahara dust from an Alpine ice core

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Saharan dust transport towards Central Europe is a common phenomenon, where mineral dust, mainly emitted from the Sahel and Saharan desert, is then transported northwards. Evidences of these events can be found in Alpine glaciers, where dust containing "red rain" or "yellow snow" is deposited.
The time duration of these phenomena, involving emission, transport and deposition, is of the order of magnitude of days. The atmospheric path can be quite variable, via direct or diverted transport (Sodemann et al. 2006). Most of the events generally occur in spring-summer (Collaud Coen et al. 2004).

Several studies show that at longer time scales dust emission at the source regions is controlled by the reduced rainfall in the previous years, leading to a slow adjustment of the vegetation (Engelstaedter & Tegen 2006).
We hypothesize that the interannual variability of Saharan dust deposition over the Alps depends on the drought conditions over Sahel and/or Sahara which seem to be related to the North Atlantic Oscillation.

For this purpose we investigate a highly resolved millennial record of mineral dust obtained from the Colle Gnifetti ice core, Swiss-Italian Alps.
Mean dust concentrations of the most recent 20 years are exceptional in the context of the last 1,000 years. This is consistent with direct and satellite-based observations of a widespread increase in dustiness and dust storm frequencies in Northern Africa over the last decades, also probably related to a
human-induced desertification over Sahel (Moulin & Chiapello 2006).

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P12.2

Sediments size characteristic of Sistan plain and Hamoon lakes as an important source of dust production in the world and adverse health effects of air pollution

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Since east of Iran have annual rainfall less than 100 mm, dust storms were occurred mainly from dried akes, wetlands and playas. Types of playa, area, location, morphological characteristics and the vegetation pattern, hydrology, climate and winds are important factors that control the dust storm. In this research 12 surface sediments collected from Sistan plain, Hamoon and Hirmand lakes. Each sample contains 64 subsamples belongs to 1600 m2. Granulometry, mineralogy (XRD) and calcimetry analysis have been done in Geological survey of Iran. Frequency and cumulative curves for each sample were drowned. Results show that the types of sediments are sandy mud and mud. It's sorting sediments are bad to very bad. Grain size of sediments are between 4 micron to 2 mm. Kurtosis of sediments are leptokurtic to very platykurtic. Sediments are coarse skewed to strongly coarse skewed. A few gravel exist in the sediments. Carbonate minerals are 28 percents contain 25% calcite and 3% dolomite. Mineralogy of sediment contains Quartz, Calcite, Feldspar, Dolomite and Clay minerals respectively contain Chlorite, Montmorillonite, Illite and Kaolinite. Due to very strong wind system(120-days winds of Sistan and dray lake with low topography, soft and disconnected fine grain sediments this area is the most important source for producing dust in Iran and even South of Asia. Common health effects are respiratory tract, cardiovascular system, nervous system, cancer. Respiratory tract are cough, nose, throat and eye irritation, shortness of breath, exacerbation of allergic symptoms.

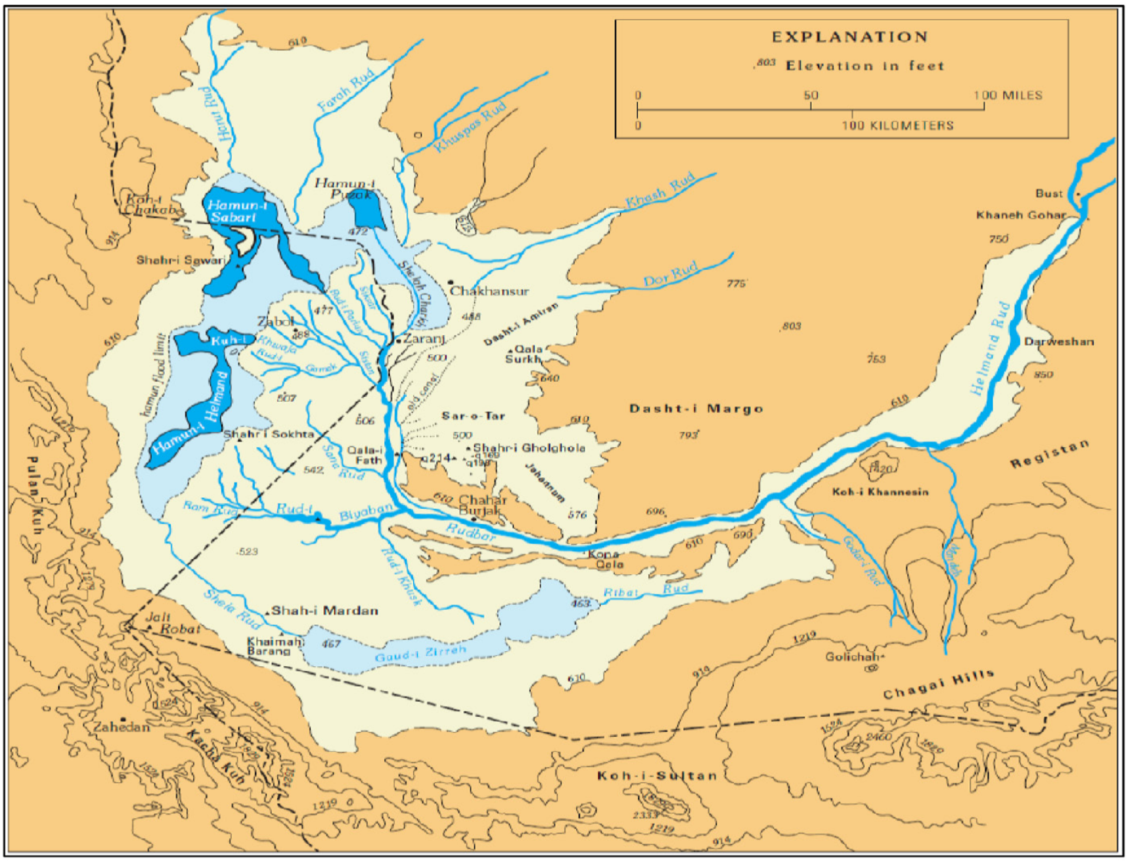

Figure 1: Geological map of Southern Helmand basin and along Helmand River and Puzak Saberi and Helmand Whitney, 2006)

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P 12.3

Does long-range transported African Dust affect cloud droplet size distributions in a Tropical Montane Cloud Forest in Puerto Rico?

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Long-range transport of dust on a global scale as well as the impact of dust on global climate has recently received special attention. Dust particles influence the Earth's radiative budget (a) directly by scattering and absorbing solar radiation, and (b) indirectly by affecting cloud formation and, consequently, cloud albedo. However, the underlying processes are poorly understood. We are particularly interested in how the dust hygroscopicity changes due to its aging during transport. In this study, we present preliminary results for droplet size spectra and derived variables such as liquid water content of clouds measured during an intensive sampling campaign of the "Puerto Rico African Dust And Clouds Study" (PRADACS), a project focusing on the impact of African Dust on clouds and precipitation in a tropical montane cloud forest. The cloud measurements were carried out in a tropical montane cloud forest on the Pico del Este at 1051 m amsl in July 2011. We used a forward scattering spectrometer probe (DMT Fog Monitor FM-100, Droplet Measurement Technologies, Boulder, CO, USA) which measures droplet size distributions in 40 size bins ranging from 2-50 µm. In a three days case study, we compared cloud data of three different days classified as (1) heavily dust-laden, (2) lightly dust-laden, and (3) dust-free, by using backward trajectories and aerosol data collected in the framework of PRADACS. We will discuss how long-range transported dust changes the cloud droplet size distributions. Preliminary results indicate that liquid water content, median volume diameter and effective diameter calculated for the measured size distributions are lowest for the heavily dust-laden day (1) and increase for the lightly dust-laden air mass (2). These parameters are highest for the dust-free day (3).