by Brian R. Marker

Mineral dust: An overview

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It has been estimated that the 1990s global annual mineral dust emissions were of the order of 1490± 160 Tg yr $^{-1}$. Mineral dust comes from a wide variety of sources through both natural processes such as wind erosion and volcanic activity, and many human activities. It has varied significant impacts on the environment, economies and society but also brings some benefits. Climate change and activities of growing human populations are affecting the nature and frequency of dust emissions and the levels of impacts. Urbanisation is leading to increased risks of exposure for some people. Health effects of exposure are well recognised and widely regulated but wider effects of dust are often accepted as a fact of life. Information on impacts and appropriate responses is often not readily accessible or intelligible to the general public or to administrators leading to failures to take steps to reduce impacts and exposure. There is a need to provide clear information for non-specialists. Improved monitoring and modelling of emissions, and evaluation of costs and benefits are also needed. Research requires collaboration between geologists, geomorphologists, economists, atmospheric scientists, microbiologists, medical practitioners, soil and agricultural scientists and ecologists.

Introduction

It has been estimated that the 1990s global annual mineral dust emissions were of the order of 1490±160 Tg yr $^{-1}$ (Zender et al, 2003). These come from a wide variety of sources through both natural processes and human activities. Dust has varied significant impacts on the environment, economies and society. Health effects of exposure are well recognised and widely regulated. But the wider effects of dust are often accepted as a fact of life, at least until extreme events occur.

Information on dust and the levels of impacts is often not readily accessible or intelligible to the general public or to administrators leading to failures to take steps to reduce impacts and exposure. There is a need to communicate knowledge more effectively because climate change is altering the scale and the nature of impacts and growing urbanisation is increasing exposure of populations to effects. A Dust Working Group has been convened by the IUGS Commission on Geoscience for Environmental Management to help to improve awareness of dust issues (www.iugs-gem/dust). This contribution reviews some of the impacts of dust from geological sources.

The nature of dust

Dust is defined as having particle sizes between 1-75 mµ (British Standards Institution, 1994) but smaller particles, which are readily inhaled deep into the lungs, also have major implications for health.

Dust reflects its origins depending on whether there is a single homogenous or varied source, or multiple sources. Mixtures are often complex. Constituent particles may be inorganic, organic or even include micro-organisms. Constituents may be toxic, corrosive, radioactive or pathogenic. But a major proportion of dust comes either directly or indirectly from geological sources. The physical, chemical and biological characteristics of constituent particles are important but so are physical, chemical and biological changes during and after entrainment. Physical processes within dust clouds, as well as the behaviour of and changes to particles in aerosols are relatively poorly known but have a major influence on weather. Work is needed on how particles with different masses, densities and electrical charges behave differentially within aerosols.

A key concept in considering impacts of emissions is the pollution linkage between the source, the route by which it reaches a given destination (pathway), and the organisms or environments that are affected (receptors).

Principal sources of dust

Soil erosion

Exposed rocks and soils in dry situations are eroded by the wind and wind borne particles giving rise to aerosols containing very fine to silt grade particles which may account for 50±20% of the total atmospheric dust mass (Tegen et al., 1996). Vulnerable surfaces are: natural exposures; ground cleared of vegetation by wild- and controlled fires or for agriculture, construction work and mineral extraction; unpaved roads; and mine tips and lagoons. Off-road traffic also throws up dust and, in desert areas, damages delicate stabilising crusts increasing the rate of erosion. Soil erosion occurs year round in arid areas, in dry seasons elsewhere (e.g. savannas) and sporadically in more humid areas and, so, is closely related to local climate and weather (Cooke and Doornkamp, 1994).

Coarse material may be quickly incorporated into soils, or migrate as dunes, but finer material is entrained in the atmosphere (Figure 1) and can be carried for long distances. For example, dust from North Africa is carried northwards into Europe (Prodi and Frea, 1979) and west across the Atlantic into the Caribbean and mainland Americas (Monteil, 2008). Aerosols from central Asia are carried eastwards across China, Japan and the Pacific Islands (Duce et al., 1979).

Volcanic ash

Some volcanic eruptions, particularly andesitic events associated

Figure 1. Dust storm in Texas, 1935, during a period of major drought and soil loss (Photograph from US National Oceanic and Atmospheric Administration).

with subduction zones, produce large quantities of ash. Pyroclastic flows are mainly deposited on and near the slopes of the volcano but dry ash is remobilised by the wind (Figure 2). Volcanic plumes also carry ash high in the troposphere and into the stratosphere to be distributed inter-continentally or globally by high level winds. Recent examples have been the 2010 eruptions of Eyjafjallajõkull in Iceland (Harrison, 2010) and Puyehue-Cordon Caulle in Chile (Rose, 2011).

Industrial emissions

Industrial emissions include a range of particulates, including potentially harmful elements and compounds that may be carried far from the source before being deposited. For instance, much research has been done on "acid rain" originating in parts of North America and deposited in northern Europe (Selinus, 1996). Significant emissions also arise from minerals operations (Figure 3) including: dust from drilling and blasting; vehicle loads and haulage roads, processing plant, tips and tailings ponds (AEA Technology, 2011).

Transport

Road and off-road vehicles give rise to particulates (Figure 4) including pollutants that may be deposited nearby (Hitchens et al., 2000) or become entrained at various levels in the atmosphere, especially from aircraft (Brasseur et al., 1998).

Construction and demolition

Exposed soil and stored construction materials can be eroded by the wind. Dust is also generated during demolition and this can sometimes contain harmful minerals, such as asbestos, and elements, such as lead, if precautions are not taken to remove these carefully (Brown, 1987; Farfel et al., 2003).

Accidents, fires, warfare and terrorism

Emissions can also arise from accidental or deliberate fires and explosions. For instance, major forest and peat fires in Kalimantan have affected large areas of South-east Asia with smoke (Siew Chin Liew et al., 1998). Explosions in modern warfare mobilise dust. "Fall out" from atmospheric nuclear tests was a major concern in the 1950's and 1960's. More recently, major radioactive contamination at long distances was caused by the Chernobyl event of 1985 (Aarkrog, 1988) and regionally at Fukushima (Makhijani, 2011). Large amounts of dust raised by terrorist attacks on the World Trade Centre in New York in 2001 affected many people in the vicinity (Claudio, 2001).

Impacts of mineral dust

Whatever the source, the impacts of dust, when deposited, inhaled or ingested, depends on its physical, chemical and biological properties, quantity and composition. Much dust has local effects but once entrained, some dust may remain in suspension for very long periods, and cause regional and even global impacts. Because dust is diverse impacts are varied ranging from nuisance to serious harm. Also certain types of development are more sensitive to dust, for instance hospitals, schools and precision industrial processes and certain "receptors" such as the elderly, ill and children are more seriously affected.

Health

Effects of dust on people and livestock are varied. For instance, certain particulates cause irritation to lung tissues and can lead to serious medical syndromes (e.g. asbestos fibres leading to asbestosis and mesothelioma; silicate particles to silicosis; and coal dust associated with pneumoconiosis) and radioactive particles damage cells and genetic material. Some particulates are chemically corrosive or toxic, for instance sulphur and fluoride rich volcanic emissions. Dust may also contain particles of a wide variety of potentially harmful elements (e.g. lead, copper, zinc, arsenic). Dust may also include

Figure 2. Dry volcanic dust remobilised by wind, Montserrat (photograph courtesy of Dr Laurance Donnelly).

Figure 3. Dust emissions from a working quarry (photograph courtesy of Dr Hugh Datson).

Figure 4. Road traffic dust, Naukluft-Namib National Park, Namibia.

pollen and spores responsible for some allergic reactions and respiratory problems. Active or dormant pathogens can be transported within a plume or attached to particles for long distances (CRPESPH, 2007).

Effects on vegetation

Wind erosion causes loss of topsoil and therefore loss of fertility and contributes to desertification. Deposition of large quantities may smother or damage natural vegetation or crops. But dust can also add nutrients to soils when minerals are released by weathering thus improving fertility (Lal, 1998). Similarly pollution plumes from industry or from volcanic eruptions can be deposited on vegetation causing harm to plants (Selinus op cit.; Grattan and Pyatt, 1994).

Transport

Dense dust clouds reduce visibility on roads and can cause accidents (Hall, 1967). Dust at higher levels in the atmosphere can cause abrasion damage to jet engines and can potentially cause aircraft engines to cut out and crash. Volcanic ash, in particular, causes re-routing of aircraft or cancellations of departures with consequent costs to airlines, airports and losses of tourist income (Casadevoll, 1994).

Water environments

Dust falling into water can affect supply, eco-systems and fisheries by changing water quality and composition, killing organisms and reducing biodiversity (Budianta, 2011; Selinus, op cit).

Weather and climate

Dust can affect weather and climate. A radiative transfer model embedded in a general circulation model has indicated that dust from disturbed soils causes a decrease of net surface radiation forcing of about $1Wm^{-2}$ accompanied by increased atmospheric heating (Tegen et al., op cit).

Major volcanic events may have impacts at the local regional and global levels. For instance, the eruption of Tambora caused cool conditions leading to crop failures and starvation as far away as Europe (Oppenheimer, 2003). Persistent major dust clouds could, depending on the circumstances, either reflect solar energy reducing surface temperatures or absorb heat and cause a rise (Slingo et al, 2006). Long term interruption of insolation could lead to disruption of the food chain and extinction of vulnerable species.

Precipitation depends on the formation of droplets of water that reach sufficient size to fall as rain, snow or ice (Min et al., 2009). Droplets form around dust or smaller particles leading to the general impression that dust is always good for promoting rainfall. However, recent research indicates that some desert dust may suppress rainfall (Rosenfeld et al., 2001). Increased or decreased precipitation has major implications for both people and ecosystems especially in areas bordering on drought conditions.

Climate warming is currently causing changes in amounts and distribution of rainfall and the behaviour of winds and vegetation cover and, therefore the potential for erosion, entrainment and deposition of dust. There is current concern about an increase in drought episodes, accompanied by increased soil erosion, as far apart as the Sahel, parts of Australia, the eastern USA and the Mediterranean (Le Houérou, 1996).

Taking action

Monitoring and modelling

Direct monitoring of the levels and compositions of dust emissions is widely undertaken in factories and processing plant (Hall et al., 1994) and close to mining and quarrying operations (AEA Technology, op cit; Hearl and Hewett, 1993). Until recently it has been challenging to discriminate between particles from different sources even in these relatively constrained settings,. At the regional scale, direct monitoring is even more challenging because of the practical difficulties in securing sufficient numbers of representative samples from different levels within the atmosphere and weather systems. While the dispersal of dust clouds can be now be monitored using remote sensing techniques (Ackerman, 1997; Kaufmann et al., 2001; Liu et al., 2008) it is still difficult to investigate the three dimensional structure of, and variations within, dust clouds with precision. Interpretation of data depends on reasonably accurate modelling of the structure and behaviour of dust clouds. Current models are fairly effective but often tend to overestimate dust fluxes (Hua La and Yaping Shaob, 2001; Heinold et al., 2009). More work to improve techniques and models at both the local and regional levels is needed.

Mitigation

Dust from industrial sources, construction and transport can be fairly readily reduced by: improvements to location, design and use of plant and machinery, containment of dust forming processes and, if possible, dampening or strengthening exposed surfaces (AEA Technology, op cit). These can be controlled through planning (ODPM, 2004) and environmental permitting procedures (e.g. Department of Sustainable Development, 2002) and occupational health and safety regulations (e.g. US Department of Labor, undated).

In the agricultural sector, the situation can be more of a challenge, especially at times of drought, but much can be done to reduce erosion by good land management and adjustment of farming practices. This depends on high quality guidance on good practices for cropping, avoiding leaving soils exposed at certain seasons (e.g. McTainsh and Tews, 2011). But in extreme cases such as volcanic ash emissions or dense wind erosion dust clouds it is only possible to reduce risks by avoiding the worst of the emissions. This requires administrative awareness, safe locations, public awareness and careful management of transport based on good, easily understandable advice, education and training.

Conclusions

There are significant costs in terms of health of people and ecosystems and wealth of communities but dust also brings some benefits. With increasing populations, the pressures of human activity in clearing and managing land for agriculture, off-road transport, and expansion of extractive, manufacturing and energy producing industries are intensifying particularly in developing countries. These, and climatic variations, will modify the nature and frequency of dust emissions and the levels of impacts. However climatic trends are influencing weather patterns, causing changes in amounts and distribution of rainfall and the behaviour of winds and, therefore the potential for erosion, entrainment and deposition of dust, and changes to vegetation cover. There is current concern about an increase in drought episodes, accompanied by increased soil erosion, as far apart as the Sahel, parts of Australia and the eastern USA. However dust also has important positive environmental functions.

Research requires collaboration between geologists, geomorphologists, economists, atmospheric scientists, microbiologists, medical practitioners, soil and agricultural scientists and ecologists. Also clear information for the public is required. The IUGS-GEM Dust Working Group is focussing on stimulating cooperation and preparation of public information.

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