

PHYSICS OF AEROSOLS AND THEIR EFFECT ON CLIMATE

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Summary

Classes of atmospheric aerosols and their main sources, distributions of tropospheric aerosol by size and mass, their physico-chemical composition and principal optical properties in various spectral bands are described. Stratospheric aerosols in “quiet” and “disturbed” periods after the major volcanic eruptions, their interactions with clouds and of underlying surface radiative properties affecting the ground surface air radiative temperature, direct and indirect aerosol effects on climate are discussed.

1. Introduction

Atmospheric aerosols play an important role in many atmospheric processes. They may be divided into stratospheric and tropospheric due to their position and origin. Their various classes are distinguished by their dimensions and physico-chemical composition together with their effects on the atmospheric radiation in various spectral bands. They present an active climate forming factor, but in different directions due to the large diversity of their concentrations and properties.

Aerosols present an important but very variable component of atmospheric composition. Their concentrations change considerably in space and time together with large variation in their chemical composition and radiative properties. According to the latter, aerosols can scatter and absorb visual and infrared solar radiation, and absorb (and emit also) the thermal radiation from the Earth surface and the atmosphere. Aerosols take an active part in cloud formation and evolution, thus producing a big indirect effect on all the radiation fields. Cloud liquid water drops and ice crystal particles absorb, emit and scatter radiation in different spectral bands very efficiently. The effects of aerosol content increase may lead to radiative cooling and warming of the Earth surface and of the lower atmosphere in different areas and time periods.

Most of atmospheric aerosols are of natural origin such as mineral dust from soil or sea salt particles. But the man-made share of aerosol sources is increasing due to expanding areas of extensive agriculture, cattle grazing, and deforestation which leads to uplift of soil particles in the air. Sulfur containing compounds, present in fossil fuels lead to their oxidation to sulfate particles during industrial burning of these fuels; the content of such particles is estimated to exceed several fold its natural background in the atmosphere over the industrialized regions.

2. Atmospheric aerosol sources and sinks

Source		Flux (Tg yr ⁻¹)	Global mean column burden (mg m ⁻²)	Mass extinction coefficient (hydrated) (m ² g ⁻¹)	Global mean optical depth
Natural					
Primary	Soil dust (mineral aerosol)	1500	32.2	0.7	0.023
	Sea salt	1300	7.0	0.4	0.003
	Volcanic dust	33	0.7	2.0	0.001
	Biological debris	50	1.1	2.0	0.002
Secondary	Sulfates from natural precursors as (NH ₄) ₂ SO ₄	102	2.8	5.1	0.014
	Organic matter from biogenic VOC	55	2.1	5.1	0.011
	Nitrates from NO _x	22	0.5	2.0	0.001
Anthropogenic					
Primary	Industrial dust etc.	100	2.1	2.0	0.004
	Soot (elemental carbon) from fossil fuels	8	0.2	10.0	0.002
	Soot from biomass combustion	5	0.1	10.0	0.001
Secondary	Sulfates from SO ₂ as (NH ₄) ₂ SO ₄	140	3.8	5.1	0.019
	Biomass burning	80	3.4	5.1	0.017
	Nitrates from NO _x	36	0.8	2.0	0.002

From Climate change 1995 (1996). *The science of climate change* /Eds. Houghton J.T., Meira Filho L.G., Callander B.A., Harris N., Kattenberg A., and Maskell K. - Cambridge University Press, UK, 572p.

Table 1. Source strength, atmospheric burden, extinction efficiency and optical depth due to various types of aerosol particles

Table 1 presents the current knowledge of the main aerosol sources, their intensities,

mass burden in the atmosphere together with some estimations of their optical properties. Table 1 shows that the most intensive sources and maximum atmospheric burden are mineral (soil dust) and sea salt aerosols of natural origin while there are relatively few which are active optically. The aerosol anthropogenic sources are moderate compared to natural ones. By source intensity and in mass burden the most important among them are sulfates, such as ammonium sulfate $(\text{NH}_4)_2\text{SO}_4$ in solid state and sulfuric acid H_2SO_4 water solution in droplets. Sulfate aerosols are produced in comparable quantities also by natural sources. The least mass have anthropogenically produced soot aerosols, but they have the maximum mass extinction (solar radiation flux reduction) coefficient. Not each biomass burning can be considered as being caused by humans; considerable input of soot is delivered by forest fires of natural origin.

Stratospheric sulfate aerosols in “quiet” state of the layer are produced “in situ” by photochemical oxidation of SO_2 and OCS (carbonyl sulfide) gases, transported there from the Earth surface. But after large explosive volcanic eruptions, throwing into the stratosphere not only volcanic ash but large masses of sulfur containing gases, the stratospheric aerosol content may increase by several orders of magnitude. The adjustment time of these aerosols in the lower stratosphere does not exceed 1-3 years.

Considerable masses of tropospheric aerosols originate in the air by condensation of vapors and organic gases of biospheric origin on various condensation nuclei or clusters of molecules. By coagulation the small particles become bigger in the troposphere; often they become coated by liquid water and enter into the clouds, serving as cloud condensation nuclei. The Earth surface is the major aerosol source, either as emitting aerosol precursor gases or as direct source of windblown dust and sea salt particles. The latter remain in the lower atmosphere after evaporation of sea water bubbles broken by wind current at the sea surface. Big deserts, such as the Sahara and Asian deserts (Gobi, Kara-Kum etc.) are producing aerosols mostly by dust storms. The big masses of dust are transformed by winds over the oceans at long distances and are registered by space, airborne and ground-based instruments.

Anthropogenic sulfate aerosols in the troposphere now surpass in quantity the natural ones and present the climatic impact as discussed below. In some regions adjacent to highly industrialized areas, the sulfate containing “acid rains” are seriously damaging the surface waters and vegetation. Tropospheric aerosols settled into this layer surpass stratospheric ones and are captured by cloud particles and by falling rain drops and snow flakes and removed from the atmosphere. Some and lesser amount of aerosols are settling on the ground by gravitation and captured by vegetation (dry deposition). This removal of aerosols may be the dominated one in dry zones and also over oceans, where the above mentioned sea water bubbles are washing out aerosols from the lowest air layer adjacent to oceanic surface. The chemical composition of precipitation reflects predominantly that of captured aerosols and together with windblown particles cause regional and sometime semi-global transport of chemicals over large distances. In the known “Arctic haze” phenomenon, the particles produced by combustion in the middle latitudes are transported to Arctic areas during the winter in the lower and middle troposphere.

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Biographical Sketch

I.L. Karol was born on 27 July 1927 in Leningrad, USSR. In 1944 he entered the Hydrodynamics Dept. of Leningrad State University, Mathematics and Mechanics Faculty, graduating in 1949. He passed postgraduate studies from 1949 to 1952, when he received a scientific degree of Candidate in Maths & Physics. After three years of lecturing in mathematics at the Ural University in Sverdlovsk, in 1956 he entered the Institute of applied Geophysics USSR Academy of Sciences in Moscow as a senior scientist. In 1959 he was transferred to Institute of Experimental Meteorology of USSR Hydrometeorological Service in Obninsk, near Moscow, where he was nominated as chief of laboratory in 1970. Since 1972 he has been with Main Geophysical Observatory of USSR Hydrometeorological Service in Leningrad (now St. Petersburg) after receiving the USSR scientific degree of Doctor of Math & Physics, presenting in 1970 his theses, which was published in 1972 as a book by Gidrometeoizdat Publishing House "Radioactive isotopes and global transport in the atmosphere". This book was translated into English and published in 1974. Since 1953 I.L. Karol has published 10 scientific monographs and more than 140

papers individually or with co-authors. The original papers are dealing with modeling of global atmospheric composition and climate changes due to natural and anthropogenic causes. During several periods he served as a member of various international commissions and committees of the International Association of Meteorology and Atmospheric Physics, of the World Meteorological Organization, of the World Climate Research Program Joint Scientific Committee. Since 1974 he has been the USSR (now Russian) co-leader of the joint project: "Composition of the atmosphere and climate changes" of the US-Russian Cooperation in Environmental Protection. He was the author or co-author of numerous scientific reports, which he presented at international and national scientific meetings throughout his scientific career.

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