GEOFISICA INTERNACIONAL

REVISTA DE LA UNION GEOFISICA MEXICANA, AUSPICIADA POR EL INSTITUTO DE GEOFISICA DE LA UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO

Vol. 26 México, D. F., 1o. de julio de 1987 Núm. 3

THE IMPACT OF DESERTIFICATION ON THE ATMOSPHERE

K. Ya. KONDRATYEV*
A. A. GRIGORYEV*
V. F. ZHVALEV*
(Received: March 18, 1985)
(Accepted: August 4, 1986)

RESUMEN

Se examinan los datos de observación de las tormentas de polvo en los desiertos y de las propiedades físicas del polvo (con énfasis en los resultados de programas complejos de observación efectuados en la URSS). Se han considerado en detalle las observaciones de satélites de dichas tormentas y sus consecuencias. Se discute también el impacto de tales tormentas en el régimen radiativo de la atmósfera sobre el ambiente en general.

ABSTRACT

Survey of observational data on desert dust storms and physical properties of dust (with emphasis on results from complex observational programs accomplished in the USSR) has been given. Satellite observations of dust storms and their consequences have been considered in detail. The impact of dust storms on the radiative regime of the atmosphere and on the environment in general has been discussed.

* *Institute for Lake Research. Laboratory of Remote Sensing. Leningrad, USSR.*

INTRODUCTION

The increased economic value of the use of deserts' natural resources determines the growing urgency of extensive environmental studies on desert conditions. The impact of desertification on atmospheric properties, mainly manifested through the dust loading of the atmosphere (especially during dust storms), leads to strong variability and special features of the atmosphere over deserts. This factor, together with surface albedo transformation during desertification, suggests that there is an unavoidable effect of desertification processes on the formation of weather and of regional climates.

An important aspect of the problem is the role of the desert surface-atmosphere system as a component of the global climatic system "atmosphere-ocean-continents-cryosphere-biosphere" determined by the transport of the anomalous properties of the atmosphere of deserts to other regions of the globe. As far as the factors of climate formation and changes are concerned, the following aspects of this problem have to be mentioned (Borisenkov, 1982; Budyko, 1980; Kondratyev, 1980, 1982; Monin, 1982): *i)* internal variability of the climatic system determined, first of all, by the atmosphere-ocean and then cloud-radiation interactions; *ii)* natural and anthropogenic impacts on climate due to changed gaseous and aerosol composition of the atmosphere (the content of optically active components of the atmosphere) as well as surface properties. Volcanic eruptions leading to a hundred-fold increase of the stratospheric aerosol content, as well as dust storms in deserts leading to a strong increase of the tropospheric dust loading and to a radical change in its radiative regime (Kondratyev and Zhvalev, 1981; Kondratyev *et al.*, 1983; Kondratyev and Moskalenko, 1983) are most powerful natural effects.

PROPAGATION OF AEROSOLS AND THEIR BASIC PROPERTIES

Satellite data processing has made it possible for the first time to assess real frequency of occurrence and unexpectedly substantial areal distribution of dust storms over the globe (Grigoryev and Kondratyev, 1981; Kondratyev *et al.*, 1979; Kondratyev *et al.*, 1983; Kondratyev, 1983; Grigoryev and Kondratyev, 1980; Grigoryev *et al.*, 1976). This can be exemplified by the Saharan dust outbreaks to the USA eastern coastline, as well as by the transport of loess aerosols from the deserts of Central Asia to the Pacific area and to the central Arctic.

Field studies started in 1970 in Kara-Kum under the Complex Atmospheric Energetics Experiment (CAENEX) program, studies of the Saharan aerosol layer during

GATE, of the central Asia aerosols under the Global Atmospheric Aerosol Radiation Experiment (GAAREX) program have created the basis for realistic estimation of the role of atmospheric aerosols in the formation of atmospheric general circulation and climate (Kondratyev and Zhvalev, 1981; Borisenkov, 1982; Kondratyev *et al.*, 1976; Kondratyev, 1980; Kondratyev *et al.*, 1983; Kondratyev, 1983; Kondratyev and Korzov, 1981).

One of the most important results obtained during CAENEX and GAAREX periods consisted in discovery of a significant contribution by aerosols as a solar radiation absorber. It has turned out that the aerosol absorption of the shortwave solar radiation is sometimes comparable with absorption by gaseous components (water vapour, carbon dioxide, ozone). Analysis of aircraft spectral measurement data and of aerosol sampling has led to the conclusion that in the Kara-Kum desert conditions the aerosol absorption is determined mainly by hematite - a small admixture responsible for reddish coloration of aerosols (this situation is typical, apparently, of the Martian atmosphere, too (Kondratyev and Moskalenko, 1983). Since most of the existing theoretical models of climate neglect the presence of aerosol as an absorbing component, it has become necessary to further develop the respective models, with due regard to this factor. First steps have recently been made toward further sophistication of climate models. An important climate-forming role of the amount and optical properties of aerosols from the point of view of their effect on the albedo of the surface-atmosphere system also claims serious attention (Kondratyev, 1980; 1982; 1983).

Special features of the atmosphere over deserts (high surface albedo, low liquid water content of the atmosphere, and dominant clear sky) determine a well known paradox: despite a high level of insolation, deserts are often zones of negative radiation budget of both the surface and surface-atmosphere system. From analysis of satellite data (Kondratyev, 1983), the latter refers particularly to the Sahara, where a vast zone of negative radiation budget of the system is formed. On the other hand, complex studies carried out within the programs CAENEX and GAAREX have shown that the dust-laden atmosphere of deserts turns out to be a powerful heat accumulator due to solar radiation absorption by dust (Kondratyev and Zhvalev, 1981). Since the effect of aerosols on atmospheric energetics over deserts is still inadequately studied, field experiments must be continued.

The atmosphere over deserts creates favourable conditions for accomplishment of sub-satellite observations to develop techniques for remote sensing of various parameters of natural formations. It was the desert Usturt Plateau over which the first complex sub-satellite experiment "Space-Aircraft-Earth" (Kondratyev, 1972) was carried out in 1970, which made it possible for the first time to perform atmospheric correction of brightness spectra of natural formations, recorded on board Soyuz-7, based only on observational data. Possibilities of using deserts as key calibration areas have so far been outlined and require further development. Of great interest is, for instance, calibration of space-borne optical instruments against the brightness of deserts (Kondratyev, 1972; 1983).

OBSERVATIONS OF DUST STORMS FROM SPACE

Still poorly studied undesirable processes of desertification have recently been observed, including those of anthropogenic origin. Observations of desertification processes have become more adequate only with the development of remote sensing from space. Dust outbreaks are one of the important indicators of the processes of desertification.

With the help of images from space a relationship has been found between processes on the dust producing surface and a dust cloud in the atmosphere. The survey from space has made it possible to reveal basic regions of formation and motion of large-scale dust clouds (Grigoryev and Kondratyev, 1981; Grigoryev and Lipatov, 1974; Kondratyev *et al.*, 1979). Many of them appear in central parts of semi-deserts or deserts in particular, in the Sahara, in the Gobi, and in Takla-Makan. Of special interest is formation of dust storms in the regions with intensive desertification (and degradation of the existing ecosystems) under the influence of natural and, to a greater extent, anthropogenic factors.

Analysis of data of the observations from space has shown that the extent of atmospheric dust formations in the regions subject to desertification, can reach hundreds and sometimes thousands of kilometers. Such are, for instance, dust clouds often formed south-west of Lower Volga, in Sal Steppes (Grigoryev *et al.*, 1976). During the development of a dust storm the dust here can easily be lifted from a large area. The anthropogenic factor - broken, loose soil after ploughing, bare soil because of overgrazing - favours much this phenomenon. The generated dust clouds are extended for about several hundred kilometers and their area reaches 100 000 km^2.

During the last decade powerful dust outbreaks are constantly recorded in the

Sahara-Sahel region. An extended development of dust outbreaks from north-western Africa was only discovered in the 70's and later on (Grigoryev and Kondratyev, 1980; 1981; McLeod, 1970; Rapp and Hellden, 1979). Dust clouds formed in Sahel (mainly of anthropogenic origin) are combined with dust formations in the atmosphere, originating in the Sahara (of natural origin). As seen from satellite images, depending on meteorological conditions, they sometimes reach the West Europe coastline, and in other cases the coasts of Central, South, and North America. Most powerful dust formations (of combined natural-anthropogenic origin) were detected from space over Africa and the Atlantic ocean. This area reached sometimes hundreds of thousands square kilometers and larger (Grigoryev and Kondratyev, 1981; Kondratyev *et al.*, 1979).

In satellite images the atmospheric dust loading of anthropogenic origin cannot be distinguished from dust clouds of natural origin. Usually one has to judge about the type of dust pollution based on data on the dust storm origin. Observations from space permit the centers of anthropogenically induced dust storms of various nature and sizes to be determined. One can fix in satellite images even small local dust storms, which give birth to dust fluxes extending for several tens of kilometers. Such centers of local dust storms were found out, for instance, in Mohave desert (Grigoryev and Kondratyev, 1980). Six local dust fluxes in the atmosphere detected from Landsat-1 in January 1975 served as their indicators. As ground-based observations showed, they had resulted from destruction of vegetation cover and soil surface caused by building of new unpaved roads, disorderly car driving outside roads, building of new populated areas, hydrotechnical improvement of the soil, agricultural activity.

Observations from space revealed many local patches of desertification of the territory - the sources of dust loading of the atmosphere. Circular patches of desertification from 0.5 to 6 km in diameter are observed especially in Central Asia (Kara-Kum desert) and in Kazakhstan (deserts and semi-deserts in the Caspian lowland). They have appeared (and still appear) as a result of degradation of the soil-vegetation cover most often around wells, stands and watering places for cattle. As images from space show, several hundreds of such desertification patches have been formed in the Caspian lowland, between the Volga and Ural deltas; in some regions the merging of local desertification patches has led to the formation of zones of entirely degraded soil-vegetation cover. Such zones have appeared, for instance, in the deserts of North Afghanistan, near the USSR frontier, in the deserts of Egipt, near the

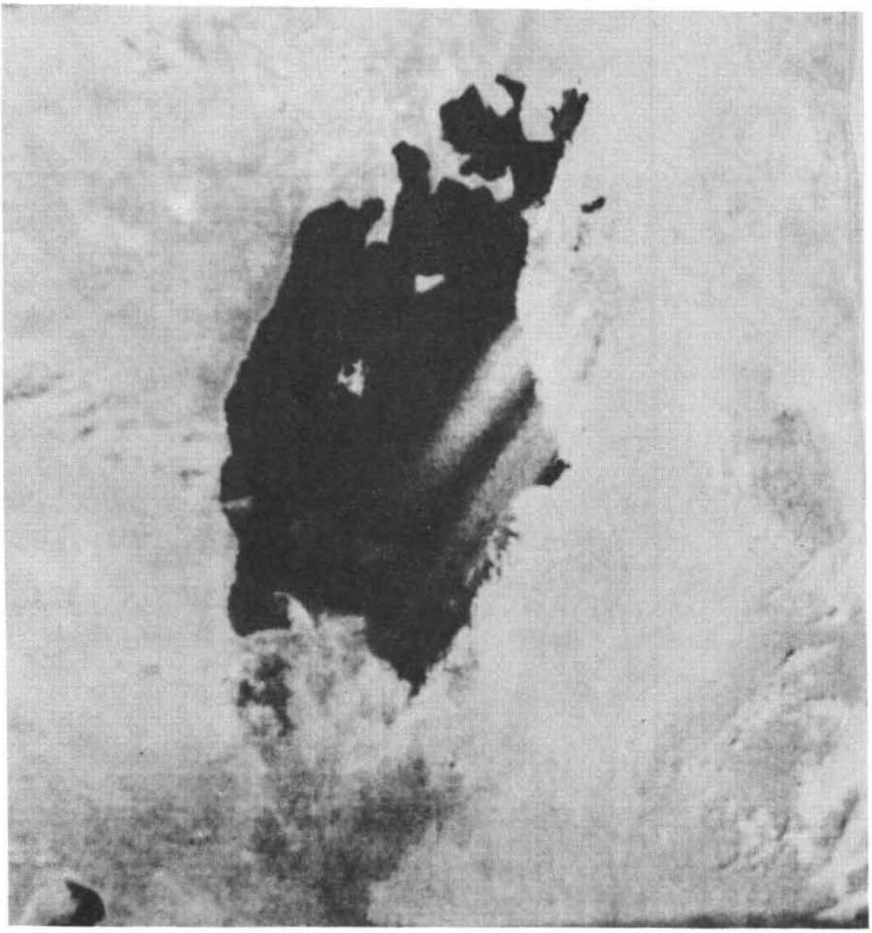
Israel frontier (Otterman *et al.,* 1976), in Sahel, in Africa, in the band of desert-savanna transition (Mainguet *et al.,* 1979; McLeod, 1974; Rapp and Hellden, 1979). The zones of entire desertification are characterized by higher (as compared with adjacent regions) surface albedo and are clearly identified from brighter images. Such surfaces are potential sources of dust storms. Especially are they typical of Sahal.

Dust loading of the atmosphere also happens in areas with intensive desertification processes caused by indirect human impact. Such dust loadings are formed, in particular, along the north-east coasts of the Caspian and Aral Seas (Grigoryev and Lipatov, 1974; 1982; 1977; Grigoryev *et al.,* 1976), being in the first case (Caspian Sea) of the mixed natural-anthropogenic origin, and in the second case (Aral Sea) of purely anthropogenic origin. The center of powerful dust outbreaks near the Aral Sea appeared quite recently. In the spring of 1975 a dust lifting and its transport 200-300 km off was discovered here for the first time from satellite images (Fig. 1) (Grigoryev and Lipatov, 1977). The development of intensive dust outbreaks in this region (not observed earlier) was not occasional. Their appearance had been caused by a newly formed surface on the north-east coast of the Aral Sea. A new coastline band formed due to drying-up of the sea has become a center of dust storm formation. Dust storms, as is seen from images, originate not everywhere but only on the north-east and, partially, east coast of the Aral Sea. It is here that the sea has become shallow. It is of interest that though the dried-up band appeared in 1961, the development of powerful dust outbreaks in this region had not been observed till 1975. Most likely, it was connected with the fact that only in 1975 did this band reach its critical state (size). It became 20-25 km wide and in many places it dried up. In these conditions the dried-up, loose soil almost (or entirely) without vegetation could have been subjected to the process of saltation (Kondratyev *et al.,* 1983).

The dried-up band is, on the whole, a terraced plain (with traces of successive lowering of the sea level), mainly of finegrained quick sand subject to saltation and injection to the atmosphere. Apart from sand, the dry crust of salt-marshes on the band can also be a source of dust.

During the last 8 years the center of dust outbreaks on the north-east coast of the Aral Sea has grown 1.5 times. The length of dust flows (streams) has grown, respectively, by a factor of 1.5 (from 180 km in 1975) (Kondratyev and Moskalenko, 1983).

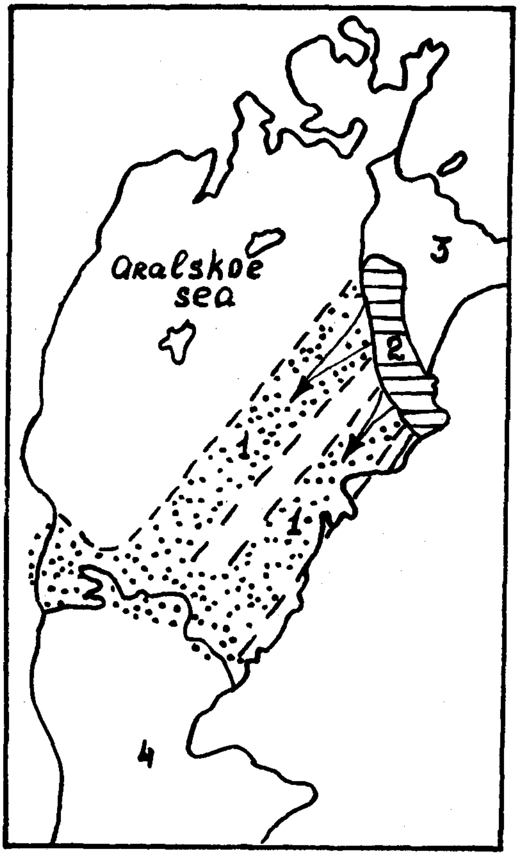
Note that the formation of powerful dust outbreaks on the dried-up band (as in-



1 A

Fig. 1 a) A dust outbreak from the coastal region of the Aral Sea. May 22, 1975. Meteor-satellite. $\lambda = 0.8\text{-}1.1 \mu m$.

dicators of intensive desertification processes) is, to a great extent, caused by meteorological conditions. Dust storms near the Aral Sea appear, provided one of the two characteristic processes has developed (Grigoryev and Lipatov, 1983). In the first case the dust is lifted when a storm zone passes over the dried-up band, which



1B

b) A schematic map of the distribution of a powerful dust outbreak.
1- dust flows; 2 - the center of the dust outbreak; 3 - the Syr-Darya delta; 4 - the Amu-Darya delta.

is caused by a well developed anticyclone centered over South Ural Mountains, the south of West Siberia, west or north Kazakhstan, and by a cyclonic formation over the south-west Central Asia. In the second case the wind is intensified and the dust is lifted with invasion of cold air masses, following the cold fronts, which are often connected with the motion of south-Caspian and Murgab cyclones. Cold air masses are transported with the anticyclone which moves from the arctic regions. It is clear that proper meteorological conditions are required for the dust to be lifted from desertified areas. Without these conditions powerful dust storms do not happen

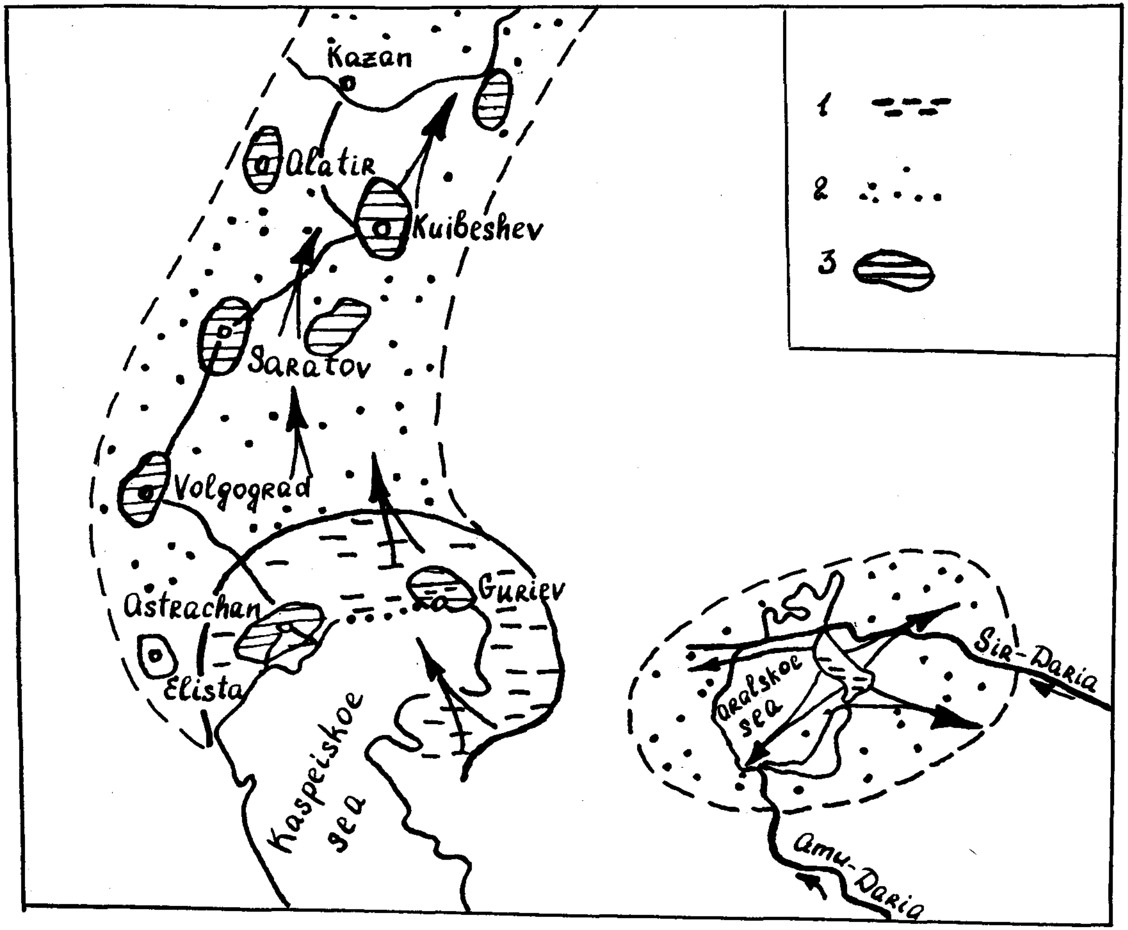


Fig. 2. A scheme of the dust transfer areas (small-grained soil, salts) in the region of Pre-Aral, North Pre-Caspian region, and Povolzhye (composed from analysis of satellite imagery).
1 - the region of the origin of dust outbreaks, 2 - the regions of sedimented dust, harmful for crops at large concentrations, 3 - the regions of sedimented salts damaging the electrical transmission lines around the cities.

even in large territories with intensive processes of desertification. So, for instance, in the territory of north Afghanistan subject to intensive desertification no powerful dust lifting to the atmosphere have been observed so far, judging by images from space.

COMPOSITION OF DUST

The composition of the atmospheric dust during powerful dust outbreaks depends on the properties of surface in the zone of its origin. Sources of dust can be loesses (on plighed soils of Ukraine), loess-like loamy soil (in the region of intensively developed pastures in the Sal Steppes), broken sands (in Sahel). The anthropogenically induced dust outbreaks in Sahel from the region of ancient sedimentation of the Niger river are rich in fragments of diatomei and are light-coloured. In this they differ greatly from dust outbreaks from the depths of the Sahara. The latter contain iron oxide compounds and are brown-reddish.

In some regions atmospheric dust formations contain an increased amount of salts. Extended salt-marshes and dried-up coastlines can be sources of such dust storms. In the USSR dust formations of such a type appear, as has been mentioned above, on the coasts of the Caspian and Aral Seas. Salts (chlorides and sulphates) are transported from the region of the Aral Sea and fall out in the delta of Amu-Darya and partially the delta and valley of Syr-Darya, salting the soil and damaging the blossoming plants and crops (Grigoryev and Kondratyev, 1981). They also fall out on the Usturt plateau, several hundred kilometers off the center of dust outbreaks on the Aral coast, damaging the vegetation growth of the pastures located there.

Studies carried out by the scientists of the Kara-Kalpak branch of the Uzbekistan Academy of Sciences on the eastern Usturt have revealed that a host of plants is discovered, with salt and depressed, at a distance of 25-30 km from the Aral coast. An unusually depressed state of some plants on the western Usturt has recently been noted by geobotanists in the Institute of Deserts of the Turkmenistan Academy of Sciences in Ashkhabad. This phenomenon can be understood, since satellite images show that the salt-containing dust moves from the Aral Sea area at a distance of about 500 km. It can move farther westward, but already in the form of a weak dust flow. That is why it is not seen in satellite images. There is no exact information so far about the effects of salt outbreaks from the Aral coast.

More certain evidence about some effects of the atmospheric transport of the salt-containing dust has been obtained from dust storms appearing on the north-east coast of the Caspian Sea (Grigoryev and Lipatov, 1982). Here the source of dust outbreaks to the atmosphere is mainly salt-marshes on the lowered coast of the sea. The salt-containing dust is most often transported across the Caspian Sea at a distance of 200-250 km, in the direction of the Volga delta. Further dust transport could only have been supposed, based on the estimates of the trajectories of dust flow motion and with due regard to that the dust can move farther, northward, but in a less concentrated state. This assumption has been verified by unexpected surface events. In the vast zone of Povolzhye - from Astrakhan to Kazan - near some large cities, disconnections of electrical transmission lines have been observed (Fig. 2). They have been caused by salts sedimented from the atmosphere onto the insulators of the supports of the electrical transmission lines, usually concentrated around large cities. These disconnections usually occurred with strong south-easterly winds as well as with rainfall and drizzle.

Probably, salt particles served as condensation nuclei and, together with clouds formed within air masses from the Caspian Sea, moved over Povolzhye and fell out together with precipitation. These events occurred in several regions of Povolzhye (Fig. 2). The falling-out of salts in this region can badly affect both wild and cultured plants (and, hence, agriculture).

DUST CONTENT

Quantitative estimates of dust masses lifted to the atmosphere during dust storms from the regions subject to desertification are still scarce. In the USSR such estimates were obtained for a large dust cloud formed over the Sal Steppes on 13 June 1976 and recorded in Meteor images (Grigoryev *et al.*, 1976). The total mass of the dust suspended in the atmosphere in the region of dust storm was estimated at 1.4 million metric tons. On the whole, during 9 hours of the development of dust storm from wind-driven dust of the anthropogenic origin (as a result of ploughing and overgrazing), about 5 million tons of soil were lifted to the atmosphere. Similar estimates obtained for dust outbreaks from the Aral coast have shown that about 50 million tons of dust are annually transported from there (Kondratyev *et al.*, 1979; Grigoryev and Lipatov, 1977).

Exact quantitative estimates can be obtained only with direct aerosol measurements, as it was done during the complex experiments under the GAAREX program and during the GARP Atlantic Tropical Experiment (GATE). Complex observations of the atmospheric aerosol component near the surface and of the wind characteristics carried out under the GAAREX program in the Kara-Kum desert (Kondratyev and Zhvalev, 1981), have made it possible, in particular, to study the dependence of concentration of various aerosol particles on wind speed. At wind speeds exceeding 3-7 m/s an increased concentration of particles is observed with increasing wind speed.

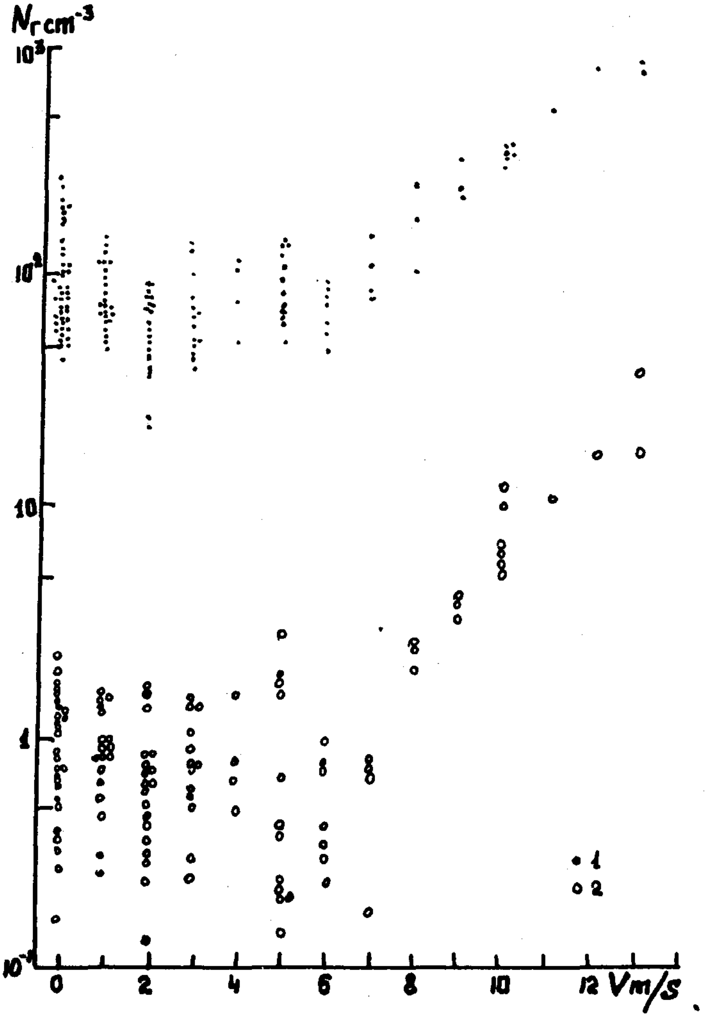


Fig. 3. The concentration of N_r particles vs. wind velocity. 1 - r= 0.13-0.18μm; 2 - r= 9-19μm.

Aircraft aerosol measurements made it possible to estimate concentrations of particles at different altitudes in an aerosol cloud during powerful dust outbreaks. So, for instance, during the GATE measurements in the Saharan Aerosol Layer (SAL) during strong dust outbreaks have shown that the layer of dust outbreak is distributed in the atmosphere at altitudes from 500 m up to 5 000 m, having a non-uniform stratiform structure. Gigantic aerosol particles (with a radius of ~ 10 μm) are concentrated near the lower boundary of the SAL. But a major portion of aerosols is concentrated in the 3-5 km layer. Concentrations of particles with radii 0.8-1.0 μm in the zone of SAL are about 20 times greater as compared to adjacent regions. During dust storms in the region of Kara-Kum desert the concentrations of particles with r ~ 0.2 μm reaching 10-11 cm^{-3} were observed near the surface (Fig. 3). The same values of particles'concentrations were observed from data of aircraft measurements in a dust outbreak from the dried-up band of the Aral Sea.

Thus, in the regions subject to desertification the content of dust aerosol in the atmosphere increases substantially.

IMPACT OF DUST AEROSOLS ON RADIATION TRANSFER AND CLIMATE

The aerosol dust component is manifested first of all as a climate-forming factor, affecting the radiative regime of the atmosphere. Results of complex observations (GAAREX-77) (Kondratyev and Zhvalev, 1981) of atmospheric radiation budget components and of aerosol concentrations (Fig. 4) are convincing evidence for this conclusion. A powerful dust outbreak observed in the experiment area in October 1977 (aerosol concentrations jumped to 10 cm^{-3}) reduced the direct solar radiation coming to the surface at noon practically to zero. Other components of the radiation budget were also much transformed. It is interesting that a day before the dust storm the diurnal change of direct solar radiation has been strongly transformed due to variations in the aerosol component in the upper atmosphere (October 6, 1977).

Dust outbreaks originating from desertified territories change substantially the values and the diurnal change of the atmospheric radiation budget components. In this connection, here are data which characterize the total effect of dust outbreaks on the radiation budget of the atmosphere. Figure 5 shows most typical (from GAAREX experiments) vertical profiles of the short- and longwave components of radiative heat convergence in conditions of a clear cloudless atmosphere (a) and during a powerful dust outbreak in the 0.5-1.5 km layer (b). As is seen, a most substantial feature is that in the presence of a dust outbreak in the atmosphere a substantially increased heating is observed in the dust layer due to aerosol absorption of solar radiation. At the same time, a strong cooling of the layer is observed due to the longwave radiation, which leads to that in this case the dust layer brought forth total cooling of the atmosphere in the dust layer.

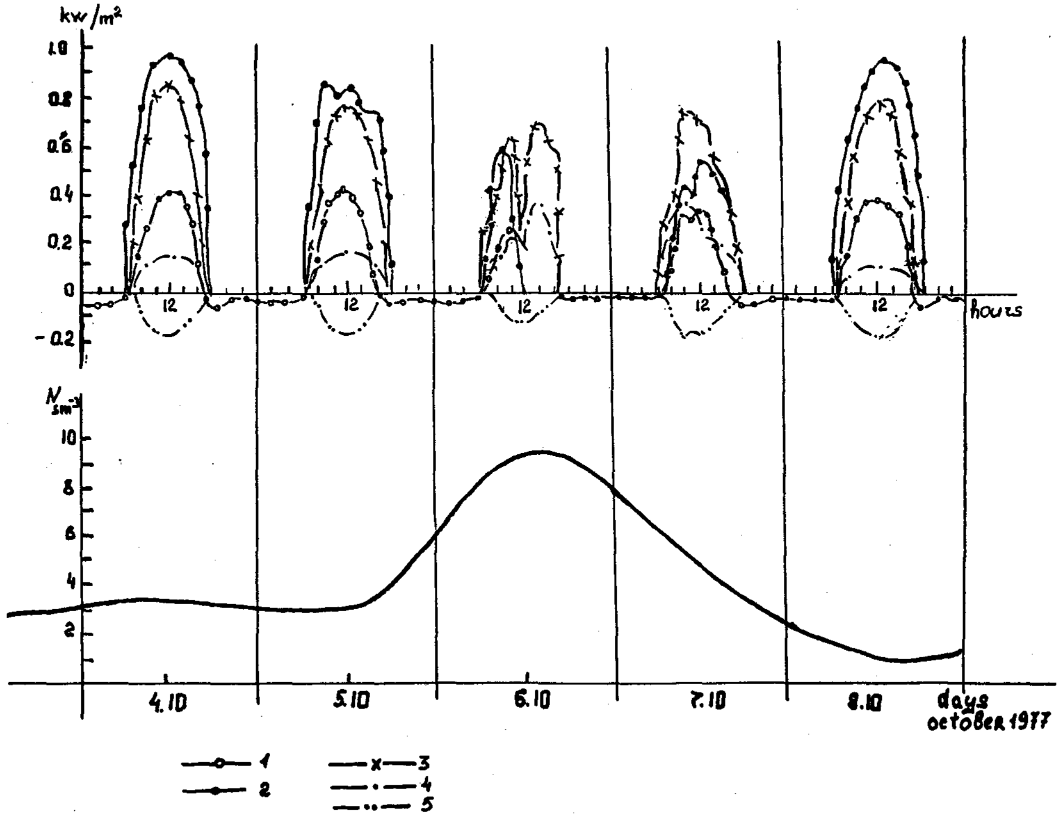


Fig. 4. The diurnal change of the radiation budget (1), the day-time change of direct (2), global (3), scattered (4), and reflected (5) radiation, and changes in aerosol concentrations (N).

Continuous recording of radiative characteristics of the atmosphere over a desert during the GAAREX observational period (Kondratyev and Zhvalev, 1981) have made it possible to asses the contribution by dust storms to the diurnal change of the atmospheric radiation budget and its components. Results shown in Table 1 can serve as an example. A powerful dust storm was observed in the atmosphere on October 6, 1977, and on September 27 the atmosphere has been maximum transparent. It is seen that a powerful dust outbreak almost halves the absolute diurnal sum of the total radiative budget of the atmosphere.

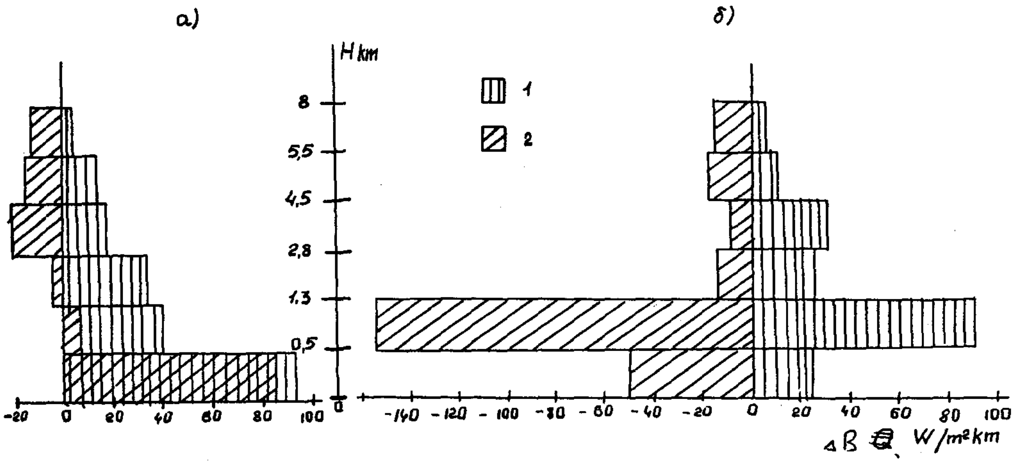


Fig. 5. Vertical profiles of the shortwave (1) and longwave (2) components of the radiative heat flux divergence, B, in different atmospheric conditions. A) Cloudless atmosphere, high transparency. B) Dust outbreak.

Table 1

Diurnal totals of the atmospheric radiation budget, B_d, and of its shortwave, B_s, and longwave, B_L, components during the GAAREX-77 Experiment.

Date	B_s joule/(cm^2 day)	B_L joule/(cm^2 day)	B_d joule/(cm^2 day)
27.09	1732.9	–938.7	–794.2
28.09	1511.5	–807.2	–704.3
29.09	1502.7	–848.5	–654.2
3.10	1492.8	–846.2	–646.6
4.10	1493.1	–867.5	–625.6
5.10	1440.2	–776.2	–664.0
6.10	1041.8	–659.5	–382.3
7.10	1328.9		
8.10	1450.0	–844.4	–605.6
9.10	1469.2	–769.0	–799.3

As has been mentioned above, the desertification processes incease the surface albedo. But a large number of cloudless days in desert regions during a year lead in these conditions to both substantially reduced day-time absorbed shortwave radiation and substantial longwave cooling of the surface at night. Thus, a serious change occurs in the radiative regime of the surface-atmosphere system. Particularly drastic are these effects in the zone of the anthropogenically caused desertification, along the Aral Sea coast. The territory covered earlier with water and now dried-up has an albedo larger by a factor of 7 as compared to that observed earlier. The difference between heat capacity of the water which had covered the now dried-up territory and that of sand changed drastically the diurnal temperature regime of the surface and, hence, the atmosphere.

CONCLUSION

Data from various complex programs of field observations (CAENEX, GAAREX, GATE Radiation Sub-program, etc.) have made it possible to draw a number of important conclusions about the impact of desertification processes on the atmosphere and climate of respective regions. However, to solve the problem of numerical modelling of climate to quantitatively estimate its changes caused by desertification, field observational programs must be continued and theoretical models of climate have to be advanced.

BIBLIOGRAPHY

Aerosol and Climate (Ed. by K. Ya. Kondratyev and V. F. Zhvalev). First Global GARP Experiment, Vol. 1. Leningrad, Gidrometeoizdat, 1981, 166 pp.; Vol. 2. Polar aerosol, extended cloudiness and radiation (Ed. by K. Ya. Kondratyev and V. I. Binenko). Leningrad, Gidrometeoizdat, 1981, 150 pp. (in Russian).

BORISENKOV, E. P., 1982. Climate and Man's Activity. Moscow, Nauka Press, 133 pp. (in Russian).

BUDYKO, M. I., 1980. Climate in the Past and in the Future. Leningrad, Gidrometeoizdat, 351 pp.

Environmental Studies From Manned Orbital Stations. Ed. by K. Ya. Kondratyev. Leningrad, Gidrometeoizdat, 1972, 400 pp. (in Russian).

GRIGORYEV, A. A. and V. B. LIPATOV, 1974. Dust Storms as Studied from Space. Leningrad, Gidrometeoizdat, 31 pp. (in Russian).

GRIGORYEV, A. A., L. S. IVLEV and V. B. LIPATOV, 1976. Analysis of Meteor-4 satellite TV picture of dust storm in the Precaspian region. *COSPAR Space Res., 16, Akademie-Verlag,* Berlin, 29-34.

GRIGORYEV, A. A. and V. B. LIPATOV, 1977. Dust storms in the coastal regions of the Aral Sea from space imagery. Annual remote sensing of Earth resources Conference (Ed. F. Shahrokhi). Vol. 6, Univ. od Tennessee.

GRIGORYEV, A. A. and K. Ya. KONDRATYEV, 1980. Atmospheric dust observed from space. Part I. Analysis of pictures. *WMO Bull., 29,* N 4, 250.

GRIGORYEV, A. A. and K. Ya. KONDRATYEV, 1981. Atmospheric dust observed from Space. Part II. Quantitative assessment of dust content. *WMO Bull., 30,* N 1, 1-9.

GRIGORYEV, A. A. and K. Ya. KONDRATYEV, 1981. Dust Storms on the Earth and Mars. Moscow, Znanie Press, 64 pp. (in Russian).

GRIGORYEV, A. A. and V. B. LIPATOV, 1982. Dust storms over the northern Caspian Sea as observed from space. *In:* Remote Sensing Techniques for Geologo-geographical Studies of the Earth. Leningrad, USSR *Geogr. Soc. Press, 18-28* (in Russian).

GRIGORYEV, A. A. and V. B. LIPATOV, 1983. Propagation of dust loading near the Aral Sea as observed from space IZV. AN SSSR. Ser. Geography, N 3 (in Russian).

KONDRATYEV, K. Ya., O. B. VASILYEV and L. S. IVLEV, 1976. Global Aerosol Radiation Experiment. Obninsk, Inform. Center, 29 pp. (in Russian).

KONDRATYEV, K. Ya., A. A. GRIGORYEV, Yu. I. RABINOVICH and E. M. SHULGINA, 1979. Meteorological Sounding of the Surface From Space. Leningrad, Gidrometeoizdat, 248 pp. (in Russian).

KONDRATYEV, K. Ya., 1980. Radiative Factors of the Present-Day Global Climate Changes. Leningrad, Gidrometeoizdat, 279 pp. (in Russian).

KONDRATYEV, K. Ya., 1982. World Climate Research Programme: the present state, perspectives, and the role of observations from space. - Progress in Sci. and Techn., Meteorology and Climatology, Vol. 8, Moscow, VINITI, 274 pp. (in Russian).

KONDRATYEV, K. Ya., 1982. The Impact of CO_2 on Climate. Gidrometeoizdat, Ser. Meteorology. Obninsk, VNIGMI-MCD, issue 8, 38 pp. (in Russian).

KONDRATYEV, K. Ya., N. I. MOSKALENKO and D. V. POZDNYAKOV, 1983. Atmospheric Aerosol. Leningrad, Gidrometeoizdat, 224 pp. (in Russian).

KONDRATYEV, K. Ya., 1983. Earth's Radiation Budget, Aerosols and Cloudiness. - Progress in Sci. and Techn., Meteorology and Climatology, Vol. 10. Moscow, VINITI, 315 pp. (in Russian).

KONDRATYEV, K. Ya. and N. I. MOSKALENKO, 1983. Key Problems of Studies of the Planets of the Solar System (the greenhouse effect of planetary atmospheres). Progress in Sci. and Techn., Studies in Space, Vol. 19. Moscow, VINITI, 162 pp. (in Russian).

MAINGUET, M., L. CANON-COSSUS et M. C. CHEMIC, 1979. Dégradation dans les régions centrales de la République du Niger. Travaux de l'Institut de Géographie de Reims, n.39-40, 61-73.

McLEOD, N. H., 1974. The use of ERTS imagery and other space data for rehabilitation and development programs in West Africa. Preprint presented at the COSPAR Seminar on Space Applications of Direct Interest to Developing Countries. San Jose des Campos, Brasil, 11 pp.

MONIN, A. S., 1982. Introduction to the Theory of Climate. Leningrad, Gidrometeoizdat, 246 pp. (in Russian).

OTTERMAN, J., L. S. WALTER and T. J. SCHMUGGE, 1976. Observations from the ERTS imagery of overgrazing and cultivation impact of the Earth's surface. *COSPAR Space Research, 16, Akademie-Verlag,* Berlin, 41-49.

Radiative Studies in the Atmosphere. Ed. by K. Ya. Kondratyev and V. I. Korzov. Trudy GGO, 1981, issue 448, 156 pp. (in Russian).

RAPP, A. and U. HELLDEN, 1979. Research on environmental monitoring methods for land-use planning in African drylands. Lund, 124 pp.