Periodic Influx of Interplanetary Dust Particles into the Terrestrial Atmosphere

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(Received 15 March 1954)

ABSTRACT. In this paper a brief account is at first given of some available evidences on the influx of interplanetary dust particles into the terrestrial atmosphere, *viz.*, presence of sodium at high altitudes, appearance of noctilucent clouds, pitting of polished surfaces during high altitude rocket flights, high nickel content in deep sea sediments and periodic occurrence of heavy rainfall in association with meteor showers. These dust particles have sizes of the same order as of those which account for the outer corona of the Sun, but terrestrial evidences suggest a higher concentration in the vicinity of the Earth. Discussing the processes which are responsible for the high concentration of dust particles, it has been suggested that solar corpuscular streams push interplanetary dust particles towards the Earth by repeated impacts. This mechanism is expected to give rise to an accumulation of dust particles near the Earth as well as in the plane of ecliptic.

1. Introduction

It is a recognised fact that interplanetary space contains some dust particles left as debris by disintegrating comets of which, the larger fragments provide visible evidence in the form of meteoric phenomena. According to Fessenkov (1942), most of the dust particles enter the solar system from outside, but a portion of the dust particles, particularly in the asteroid belt is formed as a result of collision of sporadic meteors with the asteroids which cannot retain the particles due to inadequate gravitational attraction. The meteorites which are larger and less abundant than meteors apparently contribute little towards the accumulation of the dust particles; in fact, these are believed to belong to a class different from that of meteors, and have a different rate of fall.

The composition of the meteor showers would naturally be similar to that of the parent comets from which they originate. One class of showers to which the Leonids belong reveals the presence of a number of metallic elements, *viz.*, Calcium, Nickel, Manganese, Magnesium, Chromium, Aluminium, Sodium and Silicon as determined from their spectra. Interplanetary dust particles being closely associated with the production of meteor showers may be presumed to contain most of these elements.

Nothing definite is known about the movements of sporadic meteors. But a characteristic feature of the meteor swarms is their tendency to follow the orbits of their parent comets, and reveal as showers everytime the Earth crosses their orbits.

Interplanetary dust particles have, however, a tendency to accumulate near the plane of the ecliptic, and find their way into the terrestrial atmosphere as a result of accretion. The accumulation of dust particles and influx into the terrestrial atmosphere will obviously be accentuated during the periods when the Earth crosses the orbits of the meteor swarms, particularly when the showers are most numerous, *viz.*, in August, December and January.

2. Extra-terrestrial evidence of the presence of interplanetary dust particles

The idea that the zodiacal light is a visible evidence of the scattering of sun light by particles belonging to the solar system dates back by a century, when Jones (1856) took observations on the phenomenon. Van de Hulst (1947) and Allen (1946, 1947) have put forward the suggestion that the outer corona of the Sun, which shows the Fraunhofer lines but no polarization, originates from a scattering of photospheric radiation by the interplanetary dust particles which extend beyond the ecliptic and give rise to the zodiacal light.

Van de Hulst deduced the space density to be 5×10^{-21} gm/cm³ and suggested that "the thickness of the dust cloud perpendicular to the plane of the ecliptic may be about 0.1 A.U. The total mass of the particles within the orbit of the earth then is 5×10^{18} gm, *i.e.*, 10^{-9} times the mass of the earth". According to him while the largest of the particles have a radius of the order of ·01 to ·03 cm, the same as that of the telescopic meteors, most of the particles have much smaller radii. He pointed out that the visible meteors apparently form a very small fraction of the total number of interplanetary dust particles of sizes between 1 mm and 0·1 mm, which were estimated to be about 10,000 times more numerous. We shall see that the high density of the dust particles is supported by evidence from other sources.

3. Presence of interplanetary dust particles in the upper atmosphere

Noctilucent clouds—The presence of noctilucent clouds at a mean height of 82 km has puzzled many observers and has led to a number of speculations as regards their composition. These clouds look like Cirrus, having a bluish-white to yellowish colour and are frequently seen after the solstices, particularly during the summer months in the northern hemisphere when the visibility is good. Vestine (1934) associated the formation of these clouds with the presence of dust particles. From Vestine's results, Bowen (1953) found that the frequency of the incidence of noctilucent clouds happened to increase at the time of occurrence of well known meteor showers, thus confirming Vestine's ideas.

Sodium in the Upper Atmosphere—The spectroscopic observations of night sky light and twilight have established the presence of atomic sodium in upper atmosphere. The altitude of the layer responsible for the emission of the D-lines of sodium has been found to be 130 km by Cabannes, Dufay and Gauzit (1938), 80 km by Dufay and Tcheng Mao-Lin (1948) and 250 km by Roach and Barbier (1950). According to Bates and Nicolet (1950), the distribution of terrestrial sodium with height can account for the emission of the D-lines from the lower altitudes, but not from the highest altitudes. Thus the emission of D-lines of sodium at the higher altitudes could only be accounted for by the influx of extra-terrestrial sodium into the upper atmosphere. Vegard (1948) has also come to the same conclusion from his observations on the presence of the D-lines of sodium in the spectra of high altitude aurora and upper sections of auroral streamers. Vegard believes that the formation of noctilucent clouds at about 80 km may be due to the influx of extra terrestrial sodium which after chemical combination with atmospheric constituents provide condensation nuclei.

Effect on high flying rockets—In a review giving the results of Rocket and Meteor Research, Whipple (1952) has drawn attention to certain effects on high flying rockets, which could be attributed to nothing else but the influx of micrometeorites in the upper atmosphere. For instance polished surfaces exposed even for a few minutes developed small craters having dimensions of the order of 10 to 100 microns. The density of the dust particles was estimated to be 1 per 10^6 cc from these observations. These particles have also been found to give rise to high frequency noise of the order 60 Kc/s per second by impact on the nose cones of the V—2 rockets (Bohn and Nadig, 1950). The observations on the noise suggested the presence of particles of mass of the order of 10^{-12} gm, radii about 10 microns, and frequency of the order of 1 particle per 10^8 cc. The fall of micrometeorites, as these dust particles are called, would amount to about 1000 tons per day over the Earth.

4. Presence of interplanetary dust particles in the troposphere and their influence on rainfall

Recently Bowen (1953) found from an analysis of the daily rainfall figures of a number of stations for a large number of years that heavy falls of rain tended to occur on certain days of the year almost simultaneously over a large part of the world. He discovered further that the dates when the rainfall peaks manifested themselves, lagged behind those of some of the well known meteor showers, *viz.*, Geminids (13 December), Ursids (22 December) and Quadrantids (3 January) by an interval of about 30 days in each case. In view of the close connection of rainfall activity with meteor showers Bowen has suggested that some of the condensation nuclei are provided by the dust particles associated with the meteor showers. The physical process as pictured by him is as follows. Only particles of sizes smaller than 4 microns in diameter reach the troposphere as the larger sizes are burnt up in the upper atmosphere (Whipple 1950). On reaching down to the 100-km level, these particles slow down considerably and pile up with the result that the density increases almost a million times. Thereafter it takes about 30 to 50 days for these dust particles (of 1 to 4 microns in diameter) to descend to the 40,000 or 50,000-ft level, where they are able to seed some of the larger clouds thereby inducing precipitation. It has, however, to be borne in mind that in this process an essential condition is the presence of proper type of clouds without which no seeding can be successful.

5. Presence of interplanetary dust particles in deep sea sediments

Petterssen and Rotschi (1950) found that the nickel content of deep sea sediments and the rate of sedimentation were too high to originate from terrestrial sources. Therefore, associating the increased sedimentation with the fall of micrometeorites, as the only cause, they estimated the density of the extra terrestrial dust particles as 1 in 10^7cc and the rate of fall of the order of several thousand tons per day over the Earth. It will be seen that the rate of fall as deduced by Van de Hulst and Whipple (*vide* Sections 2 and 3) is of the same order.

6. Origin of high density of interplanetary dust particles and its variations

In view of the evidence available from independent investigations, there seems to be little doubt that the density of the dust particles in interplanetary space is rather high, particularly in the vicinity of the plane of the ecliptic. As already mentioned, the number of telescopic meteors is too small to account for the high number of dust particles. The number of telescopic meteors is derived mostly from the figures for sporadic meteors, but even allowing for the shower meteors, it does not make any appreciable change in the result (Van de Hulst 1947). The question, therefore, arises as to what causes the particles to pile up in this manner in the vicinity of the ecliptic. Of course the periodic meteor swarms (and sporadic meteors) augment the number density of the dust particles at certain times of the year as manifested by the appearance of visible meteors and annual variation of the incidence of heavy rainfall and intensity of the D-line of the night sky spectra etc. But we have to look for a more continuous process to account for the high concentration of interplanetary dust particles as deduced from observations on zodiacal light.

In this connection it may be of interest to consider any possible contribution from the solar corpuscular streams which on arrival at the Earth give rise to auroral display, magnetic and ionospheric disturbances. Some of the solar elements like Hydrogen, Magnesium, Sodium, Calcium etc. are brought by the corpuscular stream into the terrestrial atmosphere. But to account for the incursion of dust particles with the corpuscular stream, it may be suggested that the corpuscular stream pushes forward some amount of interplanetary dust particles towards the Earth. We may try to form an idea of the physical process involved in this mechanism from the property of the corpuscular stream according to the well known ideas of Chapman (1940). The solar corpuscular stream is believed to come out almost radially from limited areas of the Sun through a narrow angle. If the emitting area on the Sun subtends an angle of 1° at its centre, we find that about half way between the Sun and the Earth, the corpuscular stream diverges laterally to the extent of about 2×10^{12} cm (considering that magnetic storms caused by the stream last for a day or so) near the plane of the ecliptic. A moderate magnetic storm requires a minimum of 200 charged corpuscles per cm^3 in the stream at a distance of a few Earth radii. Thus half way between the Sun and the Earth, there may be several thousand such corpuscles (spread laterally to the extent of 10^{12}cm) per cm^3. Repeated impacts of these corpuscles on the dust particles will push the latter towards the ecliptic, increasing the concentration. It may be mentioned that the number of the dust particles is of the order of 1 in 10^8 cm^3. Thus each dust particle driven forward with the solar corpuscular stream will augment the concentration materially. Chapman (1950) pointed out that this corpuscular stream (which contains equal number of positive ions and electrons) gets retarded by the Earth's magnetic field in the vicinity of the Earth with the result that the corpuscles pile up rapidly. As a consequence, the probability of impacts between the solar corpuscles and the dust particles increases, helping in concentrating the dust particles further in the vicinity of the Earth.

The highest velocities of the order 1600 km sec^{-1} of the corpuscles are associated with solar flares. But the persistent streams have much smaller velocities and are believed to be associated with the solar M-regions which are known to be situated in the equatorial regions of the Sun. With the rotation of the Sun, such a stream sweeps round like a fire hose (Chapman 1940) almost in the plane of the ecliptic. Thus the regions near the plane of the ecliptic is expected to contain more of the dust particles with increased concentration towards the ecliptic.

The physical process as postulated above, is expected to give rise to the following variations in the effects ascribed to interplanetary dust particles—

(*i*) Sporadic variations associated with solar flares, showing correlation with intense auroral displays, magnetic storms and radio fade-outs. In the case of zodiacal light such variations have been noticed (Hulburt 1930).

(*ii*) A 27-day periodicity associated with the synodic rotation of the Sun, showing correlation with M-storm activity.

Superposed on the above, there will be annual variations associated with the appearance of the meteor swarms as already discussed.

Certain effects, for instance the emission of the D-lines of sodium, depend upon the presence of certain kinds of elements, the proportion of which is likely to be higher in meteor swarms than in the interplanetary space and may also vary from one meteor shower to another. Therefore the enhancement of a particular effect will depend more upon the appearance of the particular meteor swarm which contains a higher proportion of the element concerned as compared to other swarms.

7. Influence on rainfall

According to Bowen's ideas, interplanetary dust particles induce rainfall by supplying condensation nuclei from above, provided the right kind of clouds are present. This supply is practically inexhaustible and persistent, if we consider the process of accretion of dust particles by Earth replenished by meteor showers and the persistent corpuscular streams from the M-regions of the Sun. We have here an explanation of a puzzling feature connected with the occurrence of heavy falls for several days in succession. If condensation nuclei are considered essential for the formation of large drops and heavy rain, it was not understood from where the fresh supply of condensation nuclei came after the first day's heavy rainfall washed away the existing nuclei. But the constant supply of condensation nuclei by the interplanetary dust particles from above removes the difficulty.

Again rainfall will depend upon the influx of the dust particles containing the right kind of nuclei. Obviously, the meteor showers containing a high proportion of this kind will influence rainfall more than others, and if we can identify the type, it may be helpful in experiments on artificial inducement of rainfall.

While looking for the effects on rainfall due to flares and M-regions, a lag of about 30 days will have to be allowed, as found by Bowen.

8. Acknowledgement

I am thankful to Mr. S. Basu, Director General of Observatories for taking keen interest in this paper.

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MEMOIRS OF THE INDIA METEOROLOGICAL DEPARTMENT

Vol. XXX, Part 1

Rainfall of Madras State with special reference to Tamilnad and Rayalaseema

by

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(pp. 61, diagrams 6)

The above mentioned memoir has recently been issued and is priced at Rs. 3-2-0 or 5 sh. Copies are available for sale with the Manager of Publications, Delhi.

A brief summary of the contents is given below—

The rainfall of the four sub-divisions of Madras State for 77 years (1875-1951) and the district rainfall of Tamilnad and Rayalaseema for 82 years (1870-1951) have been studied. Tables of sub-divisional rainfall and its percentage departures and the percentage departures of rainfall of the districts of Tamilnad and Rayalaseema have been given. The abnormalities have been classified under different categories and the number and frequency of years of slight, moderate and severe drought, the mean deviation (percentage) of the rainfall and the extreme abnormalities have been analysed and discussed. A measure of "Liability to drought" has been introduced and the liability to drought of the four sub-divisions and of the districts of Tamilnad and Rayalaseema have been compared. The chief features of the Northeast Monsoon Rainfall of Tamilnad, specially its distribution and its relation to cyclonic storms and depressions affecting the Tamilnad coast, have been discussed. Association of the Northeast Monsoon Rainfall of Tamilnad with the contemporary Southwest Monsoon Rainfall and of the Northeast Monsoon Rainfall of the other sub-divisions has been examined.