Atmospheric Aerosol Particles Observed in High Altitude Himalayas

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Abstract

In East Nepal, aerosol observations were carried out at Lhajung (4420 m) from August to October 1975, at Shorong Base Camp (4900 m) from June to September 1976, and in Middle-West Nepal, at Muktinath (3700 m) in November 1976. From the physical appearance and chemical tests of individual particles under an electron microscope, it was concluded that particles mostly contained sulfate during the monsoon season in East Nepal. Besides, the composition of particles in East Nepal can be considered to be the same as that during the post-monsoon season based on growth characteristics of particles with relative humidity. The average number concentration of particles with radius larger than 0.05 μm collected at Shorong Base Camp was 72 cm⁻³. Though few observations were made in Middle-West Nepal, the types and composition of particles in this area during the post-monsoon season are similar to those in East Nepal. Aerosol particles similar to combustion products were observed in the village of Muktinath.

1. Introduction

Studies of atmospheric aerosol particles are important from the viewpoints of cloud physics, atmospheric optics and air pollution. The information required is not only the concentration and size distribution of aerosol particles, but also the chemical composition of individual particles. Various investigations of concentration and size distribution of aerosol particles have been carried out in the troposphere and stratosphere. The chemical composition of individual particles, however, especially submicron particles, has been studied to a lesser extent.

It is important to study the nature of aerosol particles in the Nepal Himalayas, since the Nepal Himalayas are far from industrial areas, and thus the characteristics of aerosol particles in this area can be considered as the background of aerosol over the continent. The climates of this region are influenced by the monsoon, as the details have been described by Inoue (1976). It is interesting to study the influences of the monsoon on the nature of aerosol particles in the Nepal Himalayas. In the high altitude Himalayas where glaciers exist, studies of atmospheric aerosol particles are also important for problems relating to the precipitation process in the accumulation area of glaciers. Besides, atmospheric aerosol particles fallen or transported to a glacier surface are accumulated during the melting process as particulate matter on the surface, by which the albedo of a glacier can be changed, as discussed by Higuchi and Nagoshi (1977).

Observations of aerosol particles were carried out at three places during the different periods as follows: at Lhajung (4420 m) in Khumbu from August to October 1975, at Shorong Base Camp (B.C.) (4900 m) from June to September 1976, and at Muktinath (3700 m) in Middle-West Nepal in November 1976. [The locations of these three places are shown in the maps in Higuchi's paper (1978).] This report contains the preliminary results on the physical appearance, the size distribution and the chemical nature of the aerosol particles obtained by observations under an electron microscope, and the growth of particles as a function of the relative humidity obtained with an optical microscope.

2. Procedure of sampling and observation

For the observations in 1975, the equipment
used for the collection of particles was a 2-stage jet impactor in which air drawn through a 2 mm diameter hole in the upper stage and a 1 mm diameter hole in the lower stage. Suction of air was carried out by an air pump operated at 12 V DC and its rate was measured by flow meter adjusted at 580 mb pressure. The collection efficiency of an impactor can be estimated from the formulae given by Ranz and Wang (1952). The collection efficiency is given as a function of a dimensionless inertial parameter:

\[
\sqrt{\frac{\mathbf{r}}{\mathbf{f}}} = \left( \frac{C \rho_P U_o \sqrt{18 \eta d_j}}{d_P} \right)^{1/2} \]  

(1)

where \( \rho_P \) and \( d_p \) are particle density and diameter respectively, \( U_o \) is the velocity of the air jet, \( \eta \) is the viscosity of the air and \( d_j \) is the diameter of a round air jet or the width of a rectangular one. \( C \) is a factor depending on particle diameter and mean free path, \( \lambda \), as shown by the following equation

\[
C = 1 + \frac{2 \lambda}{d_P} \left( 1.23 + 0.41 \exp \left( -0.44 \frac{d_P}{\lambda} \right) \right) \]  

(2)

In 1975, the sampling rate was 9 l/min. Assuming the particle density as 2.0 g/cm\(^3\), it can be shown by these equations that the lower stage of the impactor collects all of the particles larger than 0.2 \( \mu \)m in radius.

The particles were collected on clean slide glasses which were coated with silicon oil and treated at 200°C for 30 minutes to make a hydrophobic surface. The samples of particles were observed under an optical microscope.

In 1976, the collection of particles was carried out by a hand-operated impactor in which air passed through a rectangular slit of 10 mm length and 0.1 mm width. In order to observe the particles under an electron microscope, they were captured on electron microscope screens which were covered with a nitrocellulose membrane (collodion) and strengthened with a thin film of vacuum-evaporated carbon. Three screens were mounted on a clean cover glass for the collection of aerosol particles. The collection efficiency of this impactor was calculated from equations (1) and (2) as shown in Fig. 1. The sampling rate was 50 cc/1.5 sec in this case.

Before the observations under an electron microscope, the screens were shadowed in the vacuum chamber by the evaporation of a gold-palladium alloy at an angle of arctan 1/2. Elevated particles cast a “shadow” allowing their heights to be estimated.

The slide glasses and cover glasses prepared in the laboratory were stored in a sealed plastic case for transportation between the sampling places and the laboratory.

3. Aerosol particles observed in 1976

3.1. Types of particles

Aerosol particles were collected at Shorong B.C. in East Nepal during the monsoon season and at Muktinath in Middle-West Nepal in November, the distance between two places being about 300 km.

As described above, the sampling place and time were different, but the types of particles were nearly the same at these two places. Therefore, we classified all of the particles sampled at two places into five types as shown in Fig. 2. Types 1 and 2 are particles surrounded by a ring or stain. Type 1 is a particle looking like an eroded landscape framed in a ring. Type 2 is a particle with electrondence nature surrounded by a stain. Types 3, 4 and 5 are simple particles without ring and stain. Type 3 shows the simplest shape. Type 4 is a single particle and type 5 is chains of small particles, both types being of electron-dence nature. Types 1 and 3 are flattened particles indicated by F in Fig. 2. The round outline of the particles of type 1 seen in Fig. 2 indicates that these particles were present in the form of droplets in the atmosphere. Since the relative humidity is high during the monsoon season (Inoue, 1976), it is reasonable to consider that some of particles exist as a droplet after the absorption of water vapor.

The predominant types of particles collected in East and Middle-West Nepal were types 1, 2 and 3. These particles have often been found in the troposphere and stratosphere, and identified as sulfate particles (mainly ammonium sulfate) by thin film chemical tests (Bigg et al., 1970 and Bigg, 1977). The types of particles vary with time, but
not with place except for type 5. A large number of particles of type 5 were collected at Muktinath, but few at Shorong B.C..

3.2. Chemical composition of particles

In order to detect sulfate content in particles, the thin film vapor method of barium chloride (Bigg et al., 1974) has been applied on the samples. This method has a great advantage in detecting the chemical composition of individual particles, and can be applied to small particles of $10^{-2} \, \mu m$ in radius, since the effect by this method can be examined under an electron microscope. A reagent of barium chloride was vacuum evaporated as a fine-grained thin film on the electron microscope screen after sampling, and then the screen was exposed to an atmosphere saturated with octanol vapor for 24 hours. After chemical reaction, a ring of insoluble barium sulfate is deposited around the particle if the particle contains any water soluble sulfate. Fig. 3 shows the reaction of collected particles on the barium chloride surface. Unreacted barium chloride is also seen as fine grains in Fig. 3.
In almost all of samples, the presence of sulfate in particles was identified. Since particles of types 1, 2 and 3 react with barium chloride, it is considered that these particles are composed of sulfate. But, the particles of types 4 and 5 are not, since they did not react with barium chloride. After reaction between particles and reagent, residues with electron-dense nature are found in the center of some of the particles as seen in Fig. 3. Therefore, these particles are considered as mixed particles of sulfate and other water insoluble materials. Though various types of particles are found in a wide size range in the Nepal Himalayas, it was found that the particles mostly contain sulfate.

3.3. Concentration and size distribution

Concentrations of particles were measured on the electron microscope photographs of particles taken along the line perpendicular to the impaction track with rectangular shape. The shapes of the particles were estimated on the basis of outlines of their “shadows”. The flattened particles of types 1 and 3 cast almost no “shadow”. It was assumed that such particles were spherical caps with a height about one-tenth of their diameter. In order to obtain a size distribution, a radius was defined as the radius of an equivalent sphere with the same volume as that of the particles.

Table 1 shows the number concentration of particles collected at Shorong B.C. during the period from July 7 to September 17 1976. The concentration of the particles with a radius smaller than 0.2 μm has been corrected according to the collection efficiency shown in Fig. 1. But the following effect is not considered in this correction. Since water soluble particles would increase their diameter in conditions of high relative humidity, they may be collected at higher collection efficiency than in a dry environment. Therefore, the concentration of such particles may be overestimated.

Fig. 4 shows the size distribution of particles collected at Shorong B.C.. This curve shows the average value during the monsoon season. The size distribution of particles in the continental troposphere at altitude 4.6 km collected by aircraft in Nebraska, U.S.A. has been analyzed by Blifford and Ringer (1969). It is found by comparison of our results with that of Blifford et al that aerosol particle concentration in a valley of Himalayas is higher than in the free atmosphere at the same altitude. Bishop et al (1966) compared the atmospheric turbidity in the valley of the Himalayas with that at the summit of mountains with the same altitude, according to the measurement of solar radiation in the Khumbu region. They found

![Fig. 4. Average size distribution of particles collected at Shorong B.C.](image)
that the former is higher than the latter. In considering that the conditions at the summits of mountains are similar to the free atmosphere, it can be said that their conclusion is in agreement with ours.

4. Aerosol particles observed in 1975 (Growth of particles as a function of the relative humidity)

When relative humidity is larger than a critical value, water soluble particles change their phase and grow by condensation. In order to study this process, the isopiestic method was applied to the sampled particles (Meszaros, 1971). Water-glycerine solutions were used to make air of the required relative humidity (Middleton and Spilhaus, 1953), and dry air was produced by dry $P_2O_5$.

The change of radius of particles was measured on photomicrographs of the particle under six different humidities such as dry, 70%, 82%, 86%, 95% and 98% at 25°C.

Fig. 5 shows the growth curve of particles with radius of larger than 1.0 $\mu$m in dry size. The solid line indicates the curve for particles collected during the monsoon season and the broken line that during the post-monsoon season. It can be seen that the growth curves are similar to each other, but the growth rate is more gradual in the post-monsoon season. Since the gradient of the curve in both cases changes discontinuously at about 82%, it can be said that particles contain a water soluble sulfate such as ammonium sulfate which changes its phase at about 80% (Twomey, 1954 and Covert et al., 1972).

5. Concluding remarks

According to the observations at Shorong B.C., it was concluded that particles mostly contained sulfate during the monsoon season in East Nepal. Besides, the composition of particles during the post-monsoon season in East Nepal can be considered to be the same as the during the monsoon seasons, since the growth curve of water soluble particles collected at Lhajung is similar in both seasons, but this conclusion is only applicable to particles larger than 1.0 $\mu$m in radius. Though few observations were made in Middle-West Nepal, the types and composition of particles in this area during the post-monsoon season are similar to those in East Nepal, according to the observations at Muktinath. Since no observations of aerosol particles have been made during the winter and pre-monsoon seasons, annual variations of types, compositions and concentrations of particles were not obtained yet, but will be studied in the future.

Particles of type 5 in Fig. 2 are considered as combustion products from the characteristics of their shape. It would be reasonable to consider that they are produced by human activity, since a large number of these particles were collected at Muktinath where the sampling site was located in the village. But, few of these particles were collected at Shorong B.C. which is far from the village. It is suggested, therefore, that particles of type 5 are one of the types of atmospheric particulates produced by human activity in Nepal.

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References


