4.4 Physical Analysis of Aerosols at Mountain Sites

Kazuhiko Miura
Tokyo University of Science

1. Effect of aerosols on the climate

An aerosol consists of liquid or solid particles suspended in air or another gas. The particles that make up atmospheric aerosols are several nanometers to micrometers in diameter. Particles larger than 2 μm mainly originate from wind-borne dust and sea salt particles formed from sea foam at the sea surface. They are mostly natural in origin. However, particles smaller than 2 μm in diameter are formed mainly through photochemical reactions of gases, such as sulfur dioxide reacting to form sulfate particles. These gases are released mainly by human activities. PM2.5 is composed of fine particles smaller than 2.5 μm in diameter, and the increase of PM2.5 is now a major concern because of its detrimental effect on human health.

Aerosol particles also affect the climate by direct scattering and absorption of sunlight and are essential for cloud formation. The effect of aerosols on the climate differs depending on the emission characteristics, which depend on the particle size (diameter) and chemical composition. Provided the amount of water vapor is same, the characteristics of cloud formation depend on the amount of cloud condensation nuclei. The larger the amount of cloud condensation nuclei, the bigger the cloud nuclei and the more effectively the cloud reflects sunlight. When there is a large amount of aerosol particles in the air, the cloud persists for a long time, effectively blocking sunlight and cooling the Earth. However, the magnitude of this effect remains unknown.

2. Observation of maritime atmospheric aerosols

Usually, the concentration of aerosols is high in big cities, although on a global scale, the effect of maritime aerosols cannot be neglected. Surprisingly, plankton plays an important role in maritime aerosols; aerosol particles are emitted from the sea surface in areas rich in marine plankton. In 1987, Charlson (USA) and Lovelock (UK) published a hypothesis that increasing the amount of aerosol particles could control global warming through cloud formation, which would cool the atmosphere.

I have performed onboard sampling and measurement of the particle size of aerosols since 1989, on the research vessel Hakuho-maru, which belonged to the Ocean Research Institute of the University of Tokyo at that time. I was trying to observe new particle formation events increasing particles of less than 10 nm in size. However, I did not observe any particle formation events. Because there is plenty of sea salt around, when precursors of new particles are formed they quickly react with sea salt particles and do not form new particles. Indeed, very few particle formation events near the sea surface have been reported. The rare events that have been reported are of particles that had been formed in the free troposphere and transported by the downward air current caused by high atmospheric pressure. Airplane observations often report new particle formation in the free troposphere. However, it is difficult to study the formation mechanism because of the high speed of airplanes. Then, I had an idea: Why not mountain observations?

3. Beginning of my Mt. Fuji research

While I was considering mountain observations for my research, Dr. Yasuhito Igarashi emailed me on August 11, 2004, asking whether I would like to join a field trip to Mt. Fuji Weather Station before it ceased manual operation. I was happy to accept his offer. The trip was to be by bulldozer instead of on foot, which dispelled my concerns about climbing to the top of the mountain.

The field trip was on August 17, 2004. At 05:00, we started from a hotel in Gotemba by car and arrived at Tarobo (1300 m above sea level) at 06:00. Then, we got on a bulldozer. It was drizzling and we could not see the mountain at all. Around 09:00, we arrived at the summit. I expected the summit to be above the clouds,

but everything, including the weather station, was surrounded by fog. Nothing was visible, including the volcano. In the weather station, the engineers explained the station to us. I had a headache that might have been mild altitude sickness. About an hour later, we were back on the bulldozer and we arrived in Tarobo at 12:30. Thus, my Mt. Fuji experience started without any sense of accomplishment.

After that, Dr. Igarashi quickly obtained a Grant-in-Aid for Scientific Research (JSPS KAKENHI Grant Number JP 17201007) for "Aerosol characterization using Mt. Fuji as an observation tower". As a member of his research group, I was involved in the research on new particle formation at the summit of Mt. Fuji and at Tarobo. Because I had done maritime research in 2005 and most of my instruments were still aboard the research vessel, I could only take Tarobo observations that year. From 2006, I started observations at the summit, and since then I have joined the summer campaigns at the summit of Mt. Fuji every year for the last 10 years.

4. New particle formation

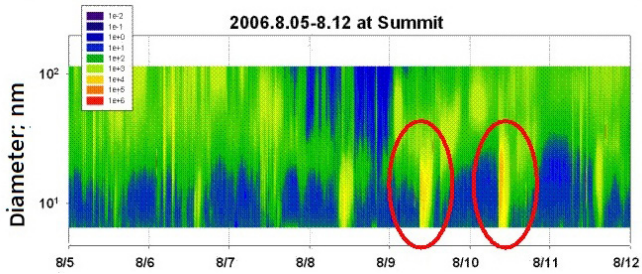

Fig. 4.4-1: Size distribution of aerosol particles

Figure 4.4-1 shows the size distribution of aerosol particles. The x-axis shows the time of day and the y-axis shows the particle size (in nanometers). Dark yellow represents high concentration areas. The daily concentration is high during the day and low at night. The formation of new particles occurs in the areas indicated by red circles. Therefore, new particle formation is occurring over a wide area and is not a local phenomenon. This new particle formation was also observed at Tarobo, although it was not always synchronized with particle formation at the summit. Thus, the new air mass was not transported from the lower atmosphere and was formed in the free troposphere.

The following year, new particle formation was also observed, but the particle formation at night was greater than that during the day, completely against my expectations. Usually, new particle formation takes place during the day, and high levels of particle formation during the night have not been reported in other mountain areas such as the Himalayas, Jungfrau, or Norikura. So, I suggested that the high nighttime concentration at Mt. Fuji might be caused by particles produced in the upper free troposphere falling to the summit during the night.

Over the last 10 years, we have performed 278 days of observations, even though we are limited to summer campaigns. We have observed 241 events: 106 during the day and 135 at night. This phenomenon has been observed only at Mt. Fuji, the reason for which has not been clarified yet. We think it may be caused by particles falling from the upper atmosphere or by long-range transport of particles produced during the day.

5. Transportation of air mass

We wanted to find out where air masses come from. One method for answering this question is to use a tracer gas. Radon (Rn) is a natural radioactive gas emitted solely from ground and does not undergo any chemical reactions, so it is used as a tracer gas originating from the ground. When an air mass comes from over continents, the concentration of Rn is higher than when an air mass comes from over oceans. Ozone and carbon monoxide and their ratio are also useful as tracer gases, as described by Dr. Kato in Chapter 4.2.

To determine the vertical transportation, we measured the vertical distribution of meteorological elements by using a weather radiosonde. We also interpolated weather data in a 1 km mesh by using the meso-objectivity observation data from the Japan Meteorological Agency with the WARF model. Using this method, we simulated the mountain wind and valley wind at Mt. Fuji.

6. Effect of small ions

Small ions (molecular clusters) are produced when atmospheric molecules are ionized by cosmic rays or radiation from the ground. These small ions sometimes produce particles that act as nuclei, known as ion-induced nucleation (IIN). IIN happens where there are few particles and the ion concentration is high. It does

not occur frequently near the surface. However, in the free troposphere, particle formation may occur by IIN, explaining new particle formation events. In the Himalayas, an increase in the number of small ions often accompanies new particle formations. Since 2010, I have observed only 3 new particle formation events at the summit where the amount of cosmic ray ionization was high.

In 1997, Svensmark et al. suggested that a decrease in the amount of cosmic rays has decreased the amount of clouds over the Earth, thereby increasing decreasing the reflection of solar the Earth's emissions reflectance and causing global warming. This scenario means that when the amount of cosmic rays increases, ionization should increase, and nucleation should be induced, forming clouds. Currently, this hypothesis is controversial and is not supported by the Intergovernmental Panel on Climate Change.

7. Cloud condensation nuclei and cloud formation

Clouds in the lower atmosphere are usually formed in an environment where the vapor content is slightly higher than saturation (around 0.03%). Particles are needed to form clouds; however, not all particles will work. What types of particles acts as cloud condensation nuclei (CCN) and form clouds, and in what conditions are clouds formed?

CCN are counted by collecting ambient air, adjusting the humidity to slightly supersaturated, and counting the particles formed. When the number is compared with the total number of particles, the ratios differ according to the direction from which the air mass came. In our 2010 results, there were more cloud condensation nuclei in the air mass transported long-range in the free troposphere than in the air mass transported from the lower atmosphere. This shows that the long transportation time allowed the cloud condensation nuclei to grow.

From 2013, we have been observing cloud condensation nuclei in actual clouds. As expected, the higher the degree of supersaturation, the easier the cloud formation. However, at the same degree of supersaturation, the particle size affected the cloud formation rather than the chemical properties of the particles. We also confirmed that the size of cloud particles decreased as the number of CCN increased (the Twomey effect).