# Sea Salt Shifts the Range Sizes of Asian Dust

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A noticeable phenomenon of Asian dust particles during their trans-Pacific transport is that in cases where there is no precipitation, the mode diameters at different surface sites are approximately the same, about 3–4 microns for number distributions (particle number via particle size in per cubic unit of air) or a little larger for mass and volume distributions. This can be confirmed by comparing published data obtained in coastal areas of China, the Korean peninsula, Japanese islands, and the west coast of the United States.

While significant progress in the study of mineral dust particles in the atmosphere has been made, this phenomenon is not yet understood. Recent studies [e.g., *Zhang and Iwasaka*, 2004] suggest that the interaction between dust particles and sea salt is a significant process involved in the changes of dust particles in size and composition in the marine boundary layer. This process can lead to the growth of dust particles and is likely responsible for the consistency of the mode diameters at different sites.

The evolution of dust particles in size and composition during their transport is a key process for the assessment of their climatic and hydrological impacts and is also important for estimating their deposition to the land and sea surface. Larger particles usually have larger Stokes gravitational terminal velocities.

If variations in a dust plume are caused only by gravitational settlement, then it is to be expected that the mode diameter of dust particles should become smaller and smaller as the distance between the dust plume and its source areas increases. Rapid removal of dust particles has been shown from the mass concentrations of dust storm crustal metals at different areas within inland China [e.g., *Mori et al.,* 2002], suggesting that gravitational settlement does occur during dust dispersion as expected. Thus, there must be other processes working together with gravitational settlement to lead to the consistency of the mode diameters of dust particles at different sites in the marine atmosphere.

### *Analysis on Asian Dust*

A series of observations and measurements of Asian dust have been conducted by the author and colleagues at inland and coastal sites in China and in southwestern Japan since 1995. Dust particles were collected during eight dust events in China and nine events in Japan, and they were analyzed using electron microscopes equipped with X-ray spectrometers. Morphology and elemental composition of individual dust particles at different sites were obtained. With these data, the physical and chemical properties of Asian dust particles in China and Japan were compared, and their processes, in particular the mixing of dust and sea salt that led to their differences, were investigated.

Within the Asian continent and even in the coastal areas of China, sea salt is rarely detected in dust particles [e.g., *Zhang et al.,* 2003]. After the particles leave the continent and enter the marine atmosphere, they frequently become a mixture of mineral and sea salt, which has been identified in studies of Asian dust particles on the Korean peninsula, on the Japanese islands, and in the northern central Pacific. This is naturally expected because dust plumes meet marine air, which is abundant in sea salt, before arriving in these areas. The question is, How much does the combination of dust and sea salt alter dust particles?

To answer this, dust particles mixed with sea salt were compared with their residues after the sea salt was removed. [*Zhang and Iwasaka*, 2004]. The particles were collected at a surface site in southwestern Japan during three dust events. Water-soluble components in the particles, which were shown to be mainly sea salt, were removed from the particles by using water dialysis. Comparisons of dust particles before the dialysis and their residual particles after the dialysis indicate that mixing with sea salt can shift the number size distributions of the particles to larger ranges, approximately 0.4–0.8 microns.

Because of the shifts, the number size distributions of the dust particles showed their mode diameters around 3–4 microns. These shifts are substantial and cannot be ignored in the investigation of dust particles since they were accomplished in less than 24 hours, the time that the particles took to travel from the coastal areas of China to Japan. Further investigation of the shifts of mixture particles with different weight ratios of sea salt to mineral components shows that the more sea salt the particles contain, the larger the shift of their distribution. Therefore, the enlargement of dust particles by sea salt must be considered in the investigation of dust distributions in the downwind marine atmosphere.

### *Effects of Sea Salt on Dust Transport*

The analysis here revealed that there are two ways for sea salt to lead to the growth of dust particles. One way is the absorption of sea salt by individual dust particles, and the other way is the aggregation of multiple dust particles by sea salt (Figure 1). Most dust particles grow in the former way. The combinations of multiple dust particles by sea salt usually produce very large particles, but such aggregate particles occupy a very small fraction of total dust particles, which is probably due to the smaller production rate of such aggregate particles and their rapid removal by gravitational settlement. In addition, these processes should occur mainly in the marine boundary layer because of the abundance of sea salt there. As a result of recent research, the vertical mixing in the marine boundary layer did enhance the internal mixture of dust and sea salt particles [*Zhang et al.*, 2005].

With the hypotheses that dust particles smaller than a critical size (presumably 3–4 microns) have a preference to disperse to downwind areas and that dust particles grow due to the interaction with sea salt in the marine atmosphere, the consistency of their mode diameters along transport paths can be interpreted logically as shown in Figure 2. As dust particles disperse in the marine boundary layer or descend into this layer from higher altitudes, they grow in size and mass due to sea salt coagulation and combination. Particles becoming larger than the critical size are removed to the surface by gravitational settlement more quickly and efficiently than smaller particles. Most of those particles that are smaller than the critical size tend to continue to grow and disperse farther downwind.

In consequence, dust particles observed near the surface along their transport paths in the marine atmosphere always have their mode diameters around the critical size. This also means that the size distributions of dust particles in the marine atmosphere can be seen as the result of growth of smaller particles caused by sea salt interaction and the removal of larger particles due to gravitational settlement.

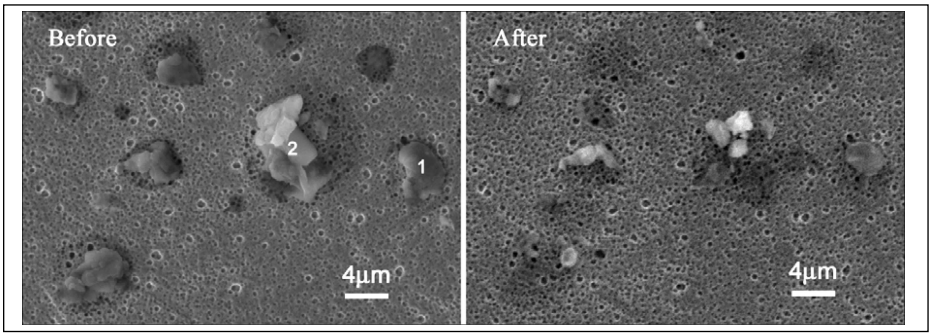


*Fig. 1. Electron microscope pictures of particles containing mineral dust and sea salt before and after the removal of water-soluble components. The water-soluble components were shown to be mainly sea salt [*Zhang and Iwasaka, *2004]. Particle 1 is a mixture of sea salt with a single original dust particle, and particle 2 is an aggregate of several original dust particles combined by sea salt. The particles were collected at Kumamoto (32°48'N, 130°45'E) in southwestern Japan on 8 April 2000.*

In this regard, while the mode diameters of the mass distribution of particles containing mineral elements such as aluminum, silicon, and iron are around 3–4 microns in Japan and North America, [e.g., *Ohta et al.*, 2003; *Perry et al.*, 2004], the actual mineral dust contributing to those particles would probably be much smaller.

*Maring et al.* [2003] reported that African dust collected at a site in North America after trans-Atlantic dispersion also showed mode diameters similar to those of dust collected at a site near Africa. They explained this similarity by assuming that some unknown atmospheric processes partially counteracted gravitational settling. However, they considered only particle motion and gravitational settlement and ignored any probable changes of the particles during their transport. Since their samples in North America were collected near the sea surface and therefore had probably been influenced significantly by sea salt, it is very likely that the particles had been enlarged by sea salt rather than the particle gravitational settling being partially counteracted.

The interpretation here based on dust and sea salt interaction is derived from limited data comparisons of observations in China and Japan. If this interpretation is valid, the interaction of dust particles with sea salt is also an important process influencing the sedimental flux of mineral dust onto the sea surface because the gravitational settling of a particle is governed by its size and composition. Consequently, understanding the interaction is also important for simulating and mapping the atmospheric input of minerals into the ocean.

Further comparisons with dust particles collected in the northern Pacific and the west coast of the United States will be helpful in validating this interpretation. Nevertheless, the interpretation offered in this article is reasonable in regard to the gravitational settlement of dust particles in the air, and it merits further investigation in studies on dust evolution and deposition in the marine atmosphere.

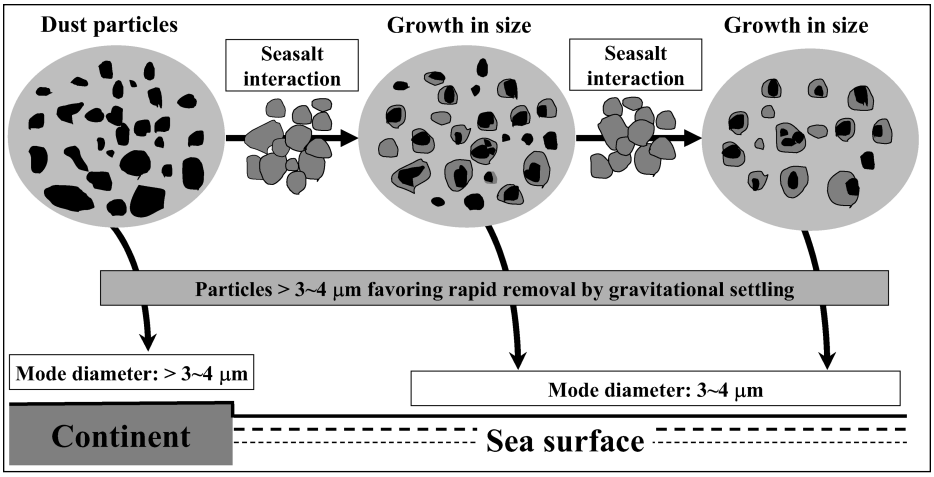


*Fig. 2. Diagram of the dispersion and deposition of dust particles during their long-range transport in the marine boundary layer.*

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