# Comparative Chloride Concentrations Between Mauna Loa Observatory and Hilo, Hawaii[1]

RICHARD G. SEMONIN

*Illinois State Water Survey, Urbana 61801*

(Manuscript received 21 October 1971, in revised form 11 February 1972)

ABSTRACT

Millipore filter samples obtained at the Mauna Loa Observatory and at Hilo, Hawaii, were analyzed for chloride particle concentrations. These data are used in a transport model to determine the removal efficiency of particles.

The most interesting result from the analysis is that the percentage of particles removed is uniform from the shore to the mountain observatory regardless of size. These results lead to calculations of the impaction-sedimentation ratio which range from 212 for 20-μm diameter particles to 6413 for 4-μm particles. The total impaction factors (removal by trees and other vegetation) ranged from 0.267 to 0.323 along the 60-km path.

## 1. Introduction

During January and February of 1961, Kline conducted a series of aerosol and ice nuclei measurements on the island of Hawaii (Kline, 1972). These samples were obtained to determine the possible origin of ice nuclei at the Mauna Loa Observatory (MLO), at an altitude of 3400 m. The analysis and discussion of these data appear in Kline's companion paper.

A further treatment of the chloride particle concentration data is presented in this paper. The chloride samples were obtained by exposing a Millipore filter to the atmosphere for a period of time at MLO situated above the tropical inversion, and near the coast of Hilo, Hawaii. The filter samples were carefully handled and returned to the author for subsequent chloride analyses. At the time of receipt of the samples the analyst was not informed as to the meteorological conditions prevailing at the time of the measurement to prevent any possibility of bias in the counting procedures.

## 2. Experimental technique

The type HA, grided (0.45-μm pore diameter) Millipore filters were exposed to the air for approximately 1 hr, and the total airflow noted. The samples were treated according to the method developed by Lodge (1954) which provided a determination of the chloride particle concentration. Examples of the data obtained by this technique in the midwestern United States were reported by Semonin (1966) and by Byers *et al.* (1957).

The samples obtained by Kline in Hawaii were sealed in small petri dishes and mailed to the laboratory facility in Illinois. The exposed filters were immediately treated and counted so as to minimize loss of data due to exposure to local environment.

## 3. Results and discussion

The three curves shown in Fig. 1 illustrate the observed particle size distributions. The upper curve resulted from the observations near the coastline. The lower pair of curves were obtained from the observations taken at MLO under upslope and downslope wind regimes. The determination of the upward or downward motion of the air was based not only upon the wind direction and speed, but also upon the humidity conditions as observed with an infrared hygrometer. Typically, with a north wind component and high humidity conditions, the case was deemed upslope while with low humidity and any other winds, the case was categorized as downslope. Additional observations which did not fulfill the wind and humidity criteria were classed as indeterminate cases. These samples were eliminated from this analysis. The data points shown in Fig. 1 represent the average of 32, 16 and 18 size-distribution observations in the downslope, upslope, and the shoreline categories, respectively.

The data were fitted to an equation of the form

$$\log_e(N/N_0) = -bD, \qquad (1)$$

where $N_0$ is the hypothetical number at zero diameter, and $D$ is the particle diameter. The dashed curves represent the standard error of estimate for the distributions. The intercept $N_0$, the slope, and the correlation coefficients are given in Table 1.

[1] Presented at the Seventh International Conference on Condensation and Ice Nuclei, Prague, Czechoslovakia and Vienna, Austria, September 1969.

TABLE 1. The semi-logarithmic regression analysis for the three data stratifications.

| | Intercept | Slope | Correlation coefficient |
|---|---|---|---|
| Upslope | 1951 | −0.3139 | −0.9354 |
| Downslope | 130 | −0.2521 | −0.8762 |
| Shoreline | 383529 | −0.3856 | −0.9839 |

The most interesting feature of the distributions shown in Fig. 1 is the relative constancy of the slope of the various distributions. It should be remembered that the samples were obtained either at the 3399 m elevation on a mountain approximately 60 km inland or at the coastline.

Recently, Mendonca and Iwaoka (1969) have shown condensation nuclei measurements across the tropical inversion as observed from surface observations of temperature and mixing ratio on the slope of Mauna Loa. These values range from about 100 $cm^{-3}$ in the above-inversion air to greater than 1000 $cm^{-3}$ in the sub-inversion air. The ratio between the sub-inversion (upslope) and above-inversion (downslope) air is approximately 10:1. This ratio is also evident in the chloride particle concentrations reported here.

Tanaka (1966) and Toba and Tanaka (1968) have discussed a model of the transport and distribution of giant sea-salt particles over land.

The number concentration $\theta$, per class of weight per unit volume of air, is expressed by

$$u\frac{\partial\theta}{\partial x}=w\frac{\partial\theta}{\partial z}+D\frac{\partial^2\theta}{\partial z^2}, \tag{2}$$

where $u$ is the horizontal wind velocity, $w$ the particle terminal velocity, $D$ the eddy diffusivity, and $x$, $z$ the horizontal and vertical coordinates. The solution to (2), subject to the boundary conditions given by Tanaka (1966), is

$$\Theta=\tfrac{1}{2}\,\mathrm{erfc}\left(\sqrt{\xi}-\frac{\zeta}{2\sqrt{\xi}}\right)e^{-2\zeta}-\frac{1}{2}\left(1+\frac{1}{\gamma}\right)\mathrm{erfc}\left(\sqrt{\xi}+\frac{\zeta}{2\sqrt{\xi}}\right)$$
$$+\left(1+\frac{1}{2\gamma}\right)e^{2\gamma[\zeta+2(1+\gamma)\xi]}\,\mathrm{erfc}\left[(1+2\gamma)\sqrt{\xi}+\frac{\zeta}{2\sqrt{\xi}}\right], \tag{3}$$

where $\Theta=\theta/\theta_{00}$, $\xi=w^2x/4Du$, $\zeta=wz/2D$ and $\gamma=\lambda u/w$. The coastline concentration at ground level is given by $\theta_{00}$ and $\gamma$ is the impaction-sedimentation ratio.[2] The complimentary error function is defined as

$$\mathrm{erfc}(x)=\frac{2}{\sqrt{\pi}}\int_x^\infty e^{-u^2}du. \tag{4}$$

[2] For a more complete discussion of the meaning of the impaction-sedimentation ratio, the reader is referred to the paper by Toba (1965).

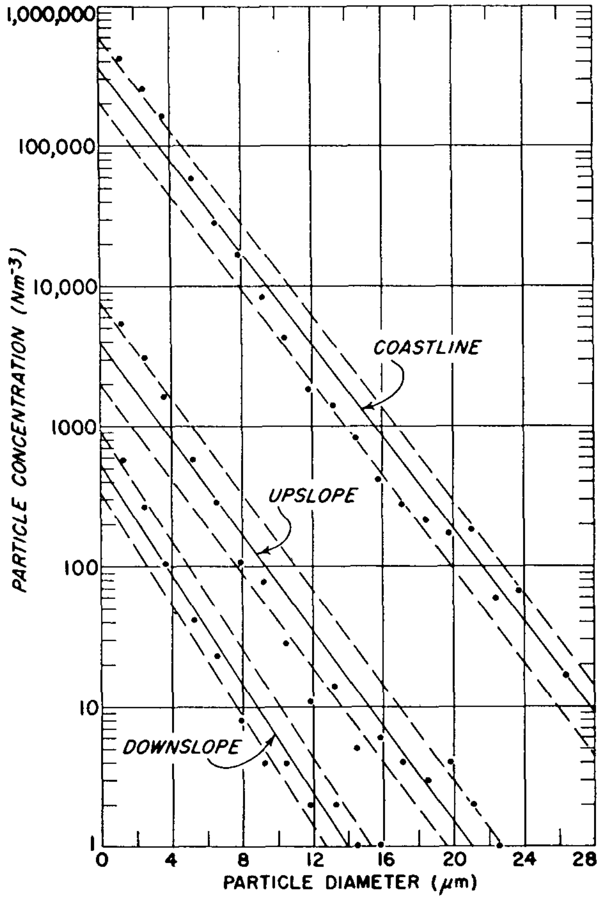


FIG. 1. Chloride particle concentration as a function of particle diameter. The upslope and downslope data were obtained at the Mauna Loa Observatory.

The model was applied to these observations by taking the particle concentrations at MLO and dividing by the shoreline concentrations to obtain the nondimensional number concentration. The resulting ratio (0.01) is nearly independent of particle diameter. The assumptions were made that the wind speed was 10 m $sec^{-1}$, and the particles were in the Stokes regime of fall velocities. The number concentration at ground level was calculated for various particle sizes for a travel distance of 68 km from the shore to MLO. The local terrain is in vegetation for the first 37 km and the remainder consists of barren lava.

Since the nondimensional concentrations were known as a function of particle size, various values of the impaction-sedimentation ratio $\gamma$ were derived. The results for values of diffusivity of 5, 10, and 20 $m^2\ sec^{-1}$ are shown in Table 2. The $\gamma$ factor increases with decreasing size for these samples which indicate a more efficient removal of the smaller particles. This result is somewhat surprising since the sedimentation of the smaller sizes should become negligible and the impaction factor should decrease according to the model. However, it appears from these data that the impaction-

TABLE 2. Impaction-sedimentation ratio and impaction factor as a function of particle size.

| Particle size (μm) | Impaction-sedimentation ratio $\gamma$ | Impaction factor $\lambda$ |
|---|---|---|
| | Diffusivity = 5 $m^2 sec^{-1}$ | |
| 20 | 137 | 0.173 |
| 16 | 238 | 0.192 |
| 12 | 459 | 0.208 |
| 8 | 1093 | 0.220 |
| 4 | 4520 | 0.228 |
| | Diffusivity = 10 $m^2 sec^{-1}$ | |
| 20 | 212 | 0.267 |
| 16 | 356 | 0.287 |
| 12 | 669 | 0.304 |
| 8 | 1556 | 0.316 |
| 4 | 6413 | 0.323 |
| | Diffusivity = 20 $m^2 sec^{-1}$ | |
| 20 | 318 | 0.400 |
| 16 | 523 | 0.421 |
| 12 | 966 | 0.438 |
| 8 | 2235 | 0.451 |
| 4 | 9090 | 0.458 |

sedimentation ratio increases with the particle concentration in such a way as to remove a constant percentage of the particles, regardless of size. The impaction factor $\lambda$, in Table 2, increases with decreasing particle size although it appears to approach a constant at very small sizes.

As a final point to be considered in relation to these observations, it must be remembered that the sea-salt nuclei enter into the cloud and precipitation development of the trade wind cumuli (Woodcock, 1952). The impaction-sedimentation ratio certainly incorporates the loss of particles by rainout or washout as the air is moved upward toward MLO. Additional, simultaneous data of chloride number concentrations at various points along the upslope trajectory are required to further examine the model.

*Acknowledgments.* The author would like to express his thanks to Mr. Dwight Kline, ESSA Laboratories, Boulder, Colo., for permission to use the observational data. This analysis was funded partly by the National Science Foundation under Grant GA-27746.

## REFERENCES

Byers, H. R., J. R. Sievers and B. J. Tufts, 1957: *Artificial Stimulation of Rain*. New York, Pergamon Press, 47–70.

Kline, D. B., 1972: Measurements of ice nucleus and associated chloride particle concentrations at Mauna Loa Observatory. *J. Appl. Meteor.*, **11**, 684–687.

Lodge, J. P., 1954: Analysis of micro-sized particles. *Anal. Chem.*, **26**, 1829–1831.

Mendonca, B., and W. T. Iwaoka, 1969: The trade wind inversion at the slopes of Mauna Loa, Hawaii. *J. Appl. Meteor.*, **8**, 213–219.

Semonin, R. G., 1966: Observations of giant chloride particles in the Midwest. *J. Rech. Atmos.*, **2**, 251–260.

Tanaka, M., 1966: On the transport and distribution of giant sea-salt particles over land: 1. Theoretical model. *Special Contr. Geophys. Inst. Kyoto Univ.*, No. 6, 47–57.

Toba, Y., 1965: On the giant sea-salt particles in the atmosphere: 1. General features of the distribution. *Tellus*, **18**, 131–145.

——, and M. Tanaka, 1968: A model of the transport and distribution of giant sea-salt particles over land. *J. Rech. Atmos.*, **3**, 17–18.

Woodcock, A. H., 1952: Atmospheric salt particles and raindrops. *J. Meteor.*, **9**, 200–212.