Opacity and Atmospheric Impurities

著者	Miura Akira
雑誌名	Science reports of the Tohoku University. Ser. 5, Geophysics
巻	4
号	3
ページ	116-124
発行年	1953-03
URL	http://hdl.handle.net/10097/44491

Opacity and Atmospheric Impurities

by Akira MIURA

Geophysical Institute, Faculty of Science, Tôhoku University

(Received February 15, 1953)

1. Introduction

The limitation of the range of vision depends on the extent to which the rectilinear propagation of light is upset by the presence of suspended matter in the atmosphere. Consequently the distance of vision is intimately associated with the number of condensation nuclei and the quantity of atmospheric impurities. A series of observations of these quantities at Tohoku University provides material for studying their association with the distance of vision and in the present paper these observations are considered in their relation to visibility.

2. Observations

We made simultaneous observations of visibility, relative humidity, wind speed, the number of condensation nuclei and the quantity of atmospheric impurities from August 1951 to July 1952 at Tohoku University of Sendai except those days of rainy and foggy weather. The observations were carried out about noon, in the range of ± one hour. Regrettably we could not carry out observations from March to April 1952 because we were engaged to other investigation at that time. The total number of observations obtained is 141. We shall next describe the methods of observations and the results.

1) Visibility ··· The visibility is expressed in international code numbers. Instead of the observed visibility, opacity, expressed in GOLD's (1939) practical unit of a nebule, was used to keep pace with WRIGHT's works (1940). We observed the visibility at Sendai by the Sichtmesser of WIGAND (1921). Table 1 shows WIGAND's code numbers of visibility and corresponding values of opacity in nebule / km unit. The mean value of opacity is obtained according to WRIGHT, from the formula, $\sum f_c x_c / \sum f_c$ where f_c is frequency of occurrence of visibility of WIGAND's code number c and x_c is the corresponding value of opacity.

Table 1

Wigand's code	3	4	5	6	7	8	9	10	11	12
Mean opacity (neb./km)	16.8	13.0	10.0	8.02	6.26	4.48	3.72	2.78	1.98	1.28

Mean values of opacity observed at each month and respective numbers of observation are shown in fig. 1, in which are also shown mean values of relative humidity and wind

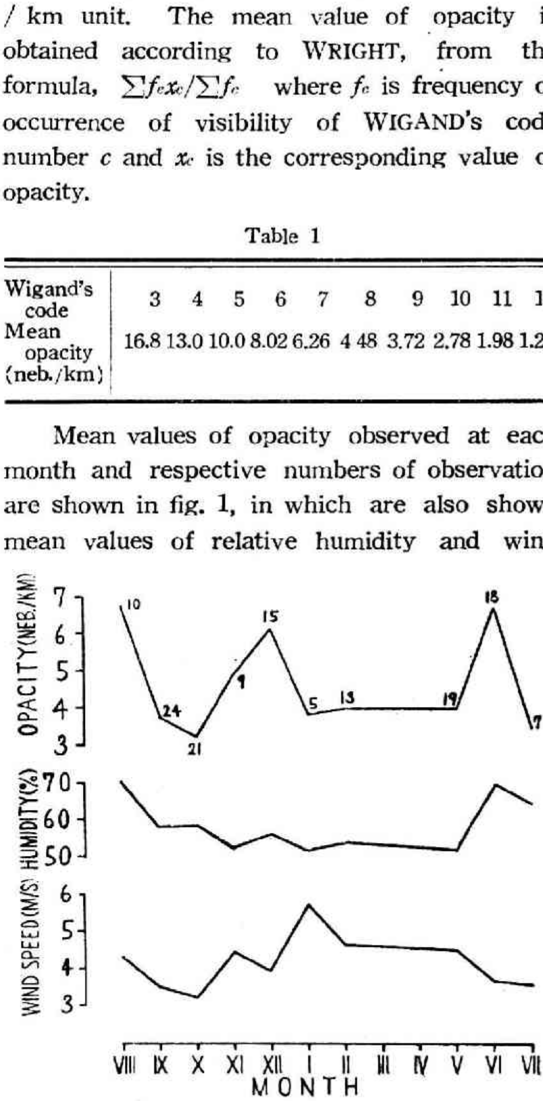

Fig. 1

speed at the time of observation. It will be seen that opacity is generally large in summer and winter and small in spring and autumn. The general trend of the annual variation is similar to that obtained by YAMAMOTO and MIURA (1951) as the five year's mean at Sendai. But there are some difference between the present curve and the previous curve. First, in the present curve opacity in December takes considerably large value, while in the previous curve it only showed small maximum. The reason is uncertain. Second, it is interesting to note that opacity in July in the present curve is extraordinarily small, corresponding to the abnormal dry July of 1952 at Sendai, which is seen from the annual variation curve of relative humidity of the period. Except this point the annual variation curve of humidity is quite similar to that of the previous investigation. The annual variation curve of wind speed also is quite similar to the previous curve, except some fluctuation due to the scarcity of the number of observation.

2) Number of nuclei … The dust counter was originally made by J. AITKEN (1888) to observe the number of condensation nuclei. Since then the improved type of the dust counter has been described by LÜDELING (1903), WIGAND (1928), SCRASE (1935) and SCHOLZ (1932). Recently OHTA (1950) made a new dust counter of the AITKEN type which uses a rubber sheet at the pump, just as in WILSON's cloud chamber, to prevent the leakage of air. We made the new dust counter of OHTA's type (Photo. 1) and observed the number of condensation nuclei in the atmosphere. The diameter of the chamber of the dust counter is about 3 cm and the depth about 0.5 cm. The expansion ratio of this dust counter is 1,22. For counting drops a microscope was used instead of a lens. It made counting easier in all the observations and moreover, with another eye-piece of a different power of magnification, we could count a much larger number of drops without using a dilution-pump. For the dilution pump, the number of drops was calculated by WAIT's formula (1932).

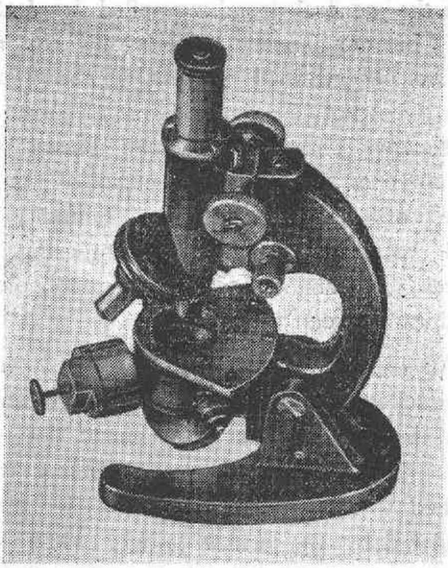

Photo. 1

The annual variation curve of the number of condensation nuclei is shown in fig. 2, together with the numbers of observation at each month. The observed number of nuclei at Sendai shows maxima in November and February and takes small values during summer season. According to data compiled by LANDSBERG (1938), the number of nuclei generally takes large values during winter season and takes small values during summer season. In the present curve the secondary minimum of January shows some discrepancy

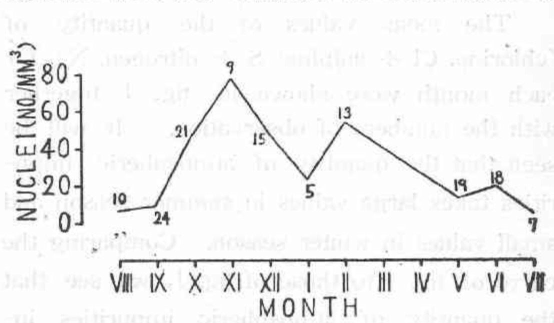

Fig. 2

from the general trend compiled by LANDSBERG, but our January value is only the mean of five observations and its reliability as to the representative mean value is doubtful.

Next we shall compare the annual variation curve of the number of nuclei of fig. 2 to those of opacity, relative humidity and wind speed of fig. 1. Comparing both figures we cannot find out any conspicuous relations between them.

3) Atmospheric Impurities ·· The outer air was sucked by the gear pump through the three washing-bottles which have fine glass filters making sufficiently fine bobbling in the distilled water. The volume of sucked air was calculated by the orifice gauge. The speed of this air was 0.9-1.0m^3/hour. Fig. 3 shows schematically the apparatus. Chlorides, sulphuric acid, ammonia and nitrite contained in the atmosphere were chemically estimated in water through which the air had passed.

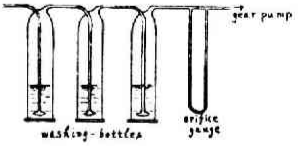

Fig. 3

The mean values of the quantity of (chlorine, Cl + sulphur, S + nitrogen, N) for each month were shown in fig. 4 together with the numbers of observation. It will be seen that the quantity of atmospheric impurities takes large values in summer season and small values in winter season. Comparing the curve of fig. 4 to those of fig. 1, we see that the quantity of atmospheric impurities increases and decreases according to humidity and consequently it is nearly parallel to the opacity curve except December value and is nearly anti-parallel to wind speed curve.

Next it will be interesting to investigate the amount of each constituent of the atmospheric impurities. As the mean of all observations throughout the year, we obtained following values.

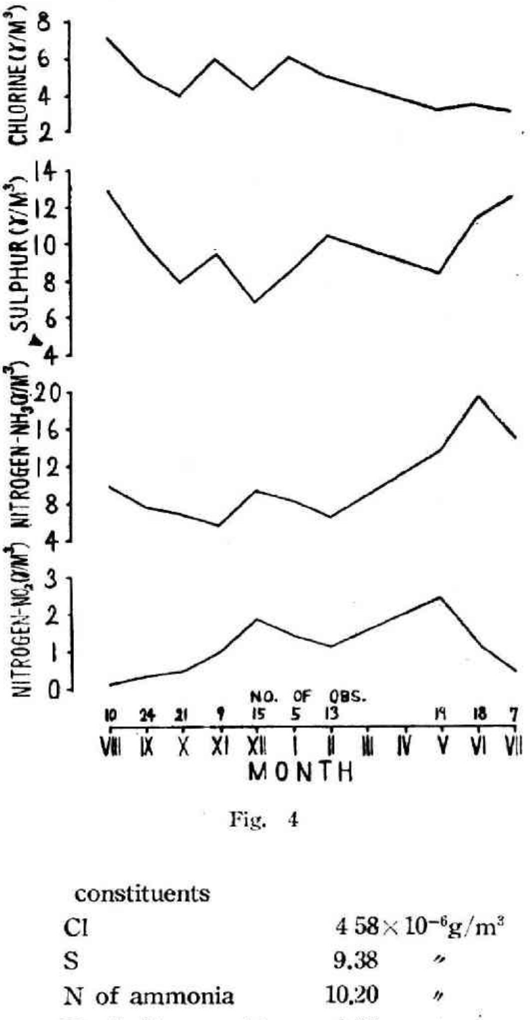

Fig. 4

constituents		
Cl	4 58$\times 10^{-6}$g/m^3	
S	9.38	〃
N of ammonia	10.20	〃
N of nitrous acid	1.08	〃

If we assume that Cl is taken from NaCl and S taken from H_2SO_4 neglecting some error, the amount of NaCl (representative of sea salt), H_2SO_4, NH_3 and NO_2 in the air at Sendai will be as follows.

NaCl	7.4$\times 10^{-6}$ g/m^3	
H_2SO_4	27.9	〃
NH_3	12.3	〃
NO_2	3.5	〃

We can see from above figures that in the air at middle city such as Sendai, the amount of impurities due to sea salt is rather smaller than those derived from combustion and

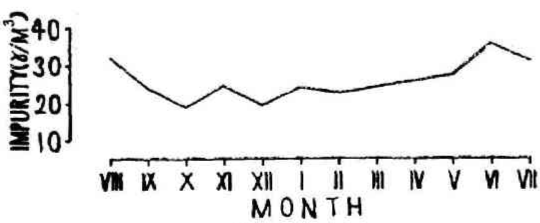

Fig. 5

organic action. The annual variations of each constituent of impurities are also obtained and are shown in fig. 5. These curves show nearly similar trends as the curve of fig. 4, however, naturally the fluctuations of these curves become larger than that of fig. 4.

3. Opacity and Relative Humidity

The mean values of opacity for each humidity group of 10 % interval are obtained and the relation between opacity and relative humidity observed at Tohoku University is shown in fig. 6, in which are also shown the corresponding relations at Valentia by WRIGHT (1940) and at Sendai by YAMAMOTO and MIURA (1951). In the curve at Tohoku University the number of observation of opacity for humidity range 81-90 % is only two and for humidity range 91-100 % is only one, so that the reliability of the curve is very small for those ranges of the curve. Except those ranges the present curve is nearly parallel to the previous curve at Sendai, although the value of opacity is larger in the present observation than in the previous one for any given value of humidity. However, this point is not so essential, because in the present observations we took the largest value of opacity around the place as the value of opacity, whereas in the previous observation the value of opacity toward northern direction was taken. From the present curve we can say that the opacity increases with relative humidity. However, there seems no such critical humidity value as 70 % which was suggested by WRIGHT that below that value of humidity, opacity is nearly independent of humidity. The present opacity-humidity curve seems to give another example to support the discussion of SIMPSON (1941) that hygroscopic nuclei, which are responsible for the determination of opacity, are not composed of sea-salt alone but contains considerable numbers of nuclei of acidic nature, at least in populated regions. And this conclusion is in good agreement with the result of the preceding paragraph.

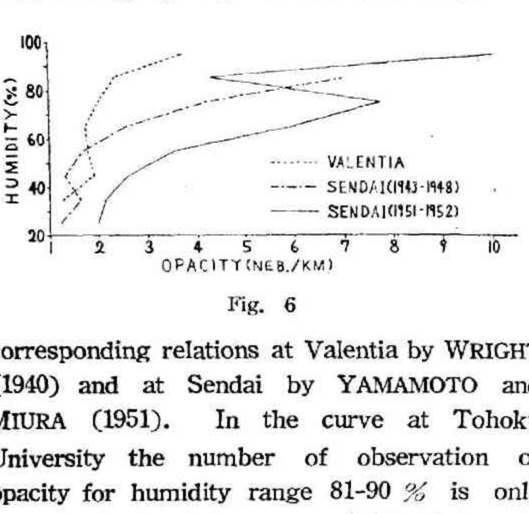

Fig. 6

4. Opacity and Nuclei

Fundamentally there can be no doubt that any kind of suspended matter will have some bearing on the visual range in the atmosphere. Consequently, correlations between nuclei and visibility are to be expected. They have been suspected ever since AITKEN made his first exact nuclei counts, and most investigators were careful to include visibility estimations among their observations. For reports on the results of nuclei we may refer to the excellent monographs by LANDSBERG (1938). According to LANDSBERG, seventeen series from twelve different localities are available for analysis. Ten of these series show a general trend of decreasing nuclei with increasing visibility and four are irregular without any visible trend, while three series show an increasing number of nuclei with the increase of the visual range.

To examine the relation, we calculated the mean values of opacity for each nuclei group of 20 per mm^3 interval. The relation between opacity and nuclei at Sendai is shown in fig. 7, in which we see that opacity is nearly independent of the number of nuclei or slightly increases with the number of nuclei.

Now, it has been described by many investigators that the opacity may be explained in some part by the change of sizes of nuclei, together with the number of nuclei. To clarify this point the data are separated into two groups according to the value of humidity greater than 70 % or not. For both groups the opacity-nuclei relation was obtained and is shown in fig. 8.

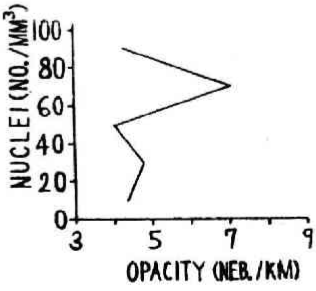

Fig. 7

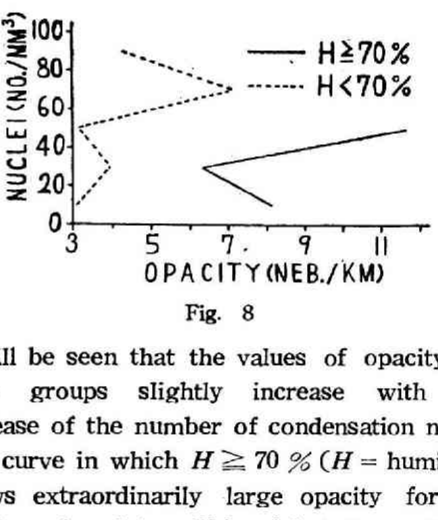

Fig. 8

It will be seen that the values of opacity for both groups slightly increase with the increase of the number of condensation nuclei. The curve in which $H \geqq 70$ % (H = humidity) shows extraordinarily large opacity for the number of nuclei = $50/\text{mm}^3$ but its reality is doubtful because the frequencies of observation are scarce. In general, the values of opacity are larger for the group of $H \geqq 70$ % than for the group of $H < 70$ %. The difference of the values of opacity at a given number of nuclei is due to the difference of sizes of nuclei caused by the difference of the relative humidity.

Fig. 9 shows the relation between the number of nuclei and the relative humidity. It will be seen that the number of condensation nuclei is nearly independent of relative humidity, however for large number of nuclei exceeding 90 $/\text{mm}^3$ somewhat large value of relative humidity may be seen to correspond. According to LANDSBERG, a general tendency is for an increasing number of nuclei with a decreasing relative humidity, which is contrary to our result. But according to LANDSBERG the four series taken in or near a big city show the same relation which is obtained at Sendai. Also at Osaka, ITO (1940) obtained the relation that the relative humidity increases with the increase of the number of nuclei.

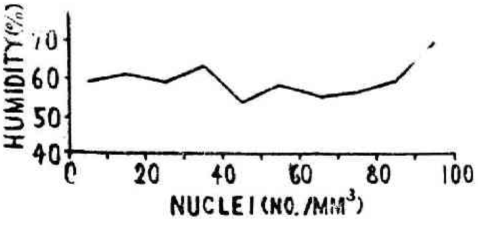

Fig. 9

Recently D. J. MOORE (1952) has investigated the contribution of the large nuclei to atmospheric opacity on the sea. According to him opacity increases with wind speed on the sea and an increase of opacity with wind speed is noted at all humidities, which is at variance with the findings of other workers (e.g. YAMAMOTO and MIURA (1951)). However, it seems to me that the observations of MOORE and YAMAMOTO & MIURA are not unreconcilable. On the sea the spray increases with wind speed which will cause increase of opacity with wind speed, while on the land factors affecting opacity are more complex than on the sea so that the decided conclusion such as MOORE's is difficult to obtain on the land. For instance, the opacity-wind speed relation in the present observation is as shown in fig. 10, which is at variance with that of MOORE on the sea and is in accordance with the previous result of YAMAMOTO and MIURA. The relationship between opacity and wind speed for the occasions when $H \geqq 70$ % and $H < 70$ % is also shown is fig. 10 which also is in accordance with the previous result of

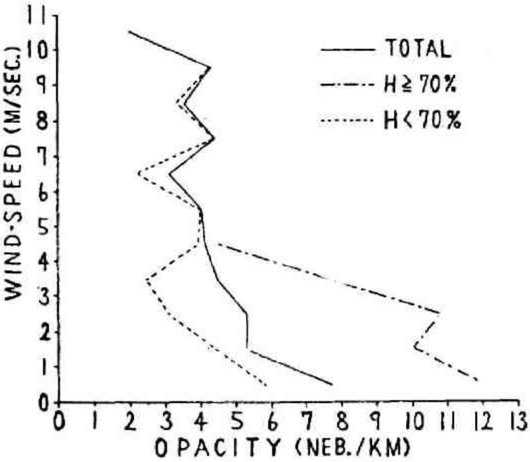

Fig. 10

YAMAMOTO and MIURA. In the previous paper YAMAMOTO and MIURA have investigated between opacity and relative humidity for the occasions when wind speed is smaller than 4 m/sec and larger than that, and have obtained the result that the opacity-humidity relationship is inaffected by wind speed (see fig. 3 of YAMAMOTO-MIURA's paper). If we construct same curves using the present data we have curves as shown in fig. 11, which will be said to confirm the previous result, although the plotted data are considerably scattering. Next if we construct similar curves dividing the groups by wind speed of 7 m/sec as has been done by MOORE, we have curves as shown in fig. 12, which seems to show some tendency that opacity increases for large values of wind speed in accordance with MOORE's result on the sea. It will be interesting in this connection to show the relation between the observed concentration of nuclei and wind speed at Sendai, as was shown in fig. 13. The concentration of nuclei decreases at first with wind speed until wind speed is nearly 4-5 m/sec, and then it increases with wind speed. Thus, it will be said that on the land, too, opacity is to some extent affected by wind speed, that is, it increases with wind speed, however, the dependency is not so evident as on the sea, so that it is generally hidden by the more strong negative correlation between wind speed and humidity pointed out by YAMAMOTO and MIURA.

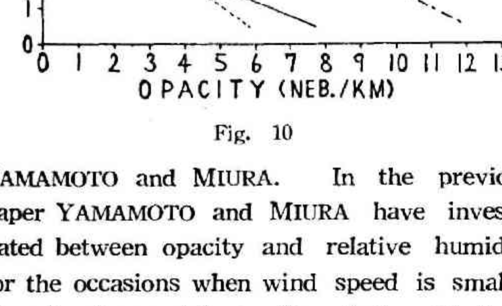

Fig. 11

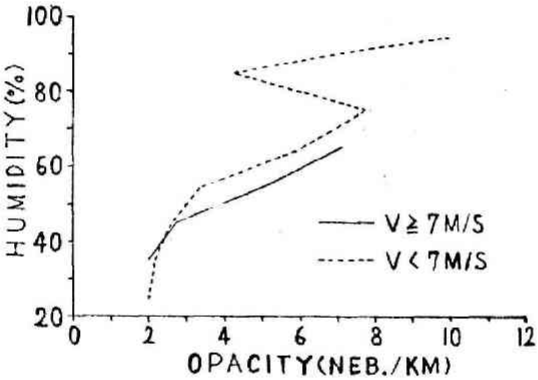

Fig. 12

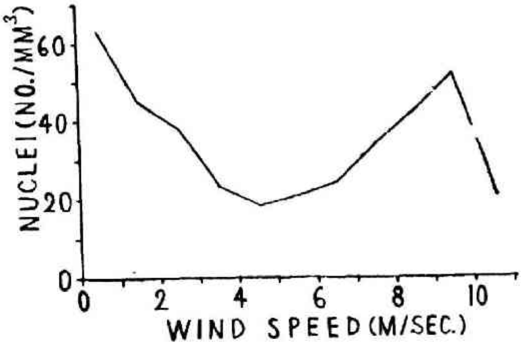

Fig. 13

5. Opacity and Atmospheric Impurities

It is well known that opacity is conspicuously influenced by the suspended impurities in the atmosphere, but we do not know the relation between opacity and the chemical components of atmospheric impurities. We shall examine the relation by our observation at Sendai. At first we shall investigate the relation between opacity and each constituent of atmospheric impurities.

i) Opacity and chloride.

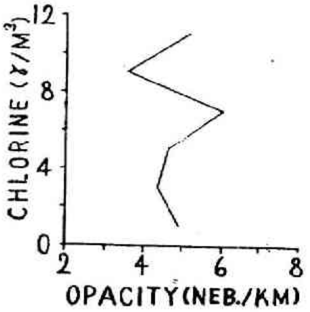

Fig. 14

The opacity-chloride relation at Sendai is shown in fig. 14. It will be seen that opacity is nearly independ of chloride content. This result is somewhat unexpected. It may need further investigation. Next the opacity-chloride relations are obtained for both groups in which respectively $H \geqq 70$ % and $H < 70$ %. They are shown in fig. 15. An increase of opacity with relative humidity is noted at nearly all concentrations.

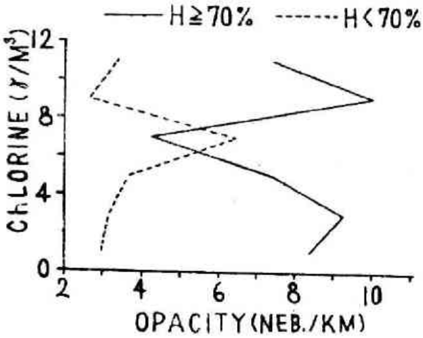

Fig. 15

ii) Opacity and sulphur (SO_2 and H_2SO_4).

The relation between opacity and sulphur (SO_2 and H_2SO_4) at Sendai is shown in fig. 16. It will be seen that opacity is also nearly independent of sulphur.

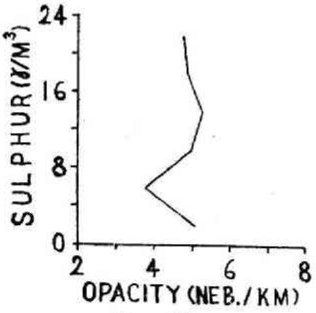

Fig. 16

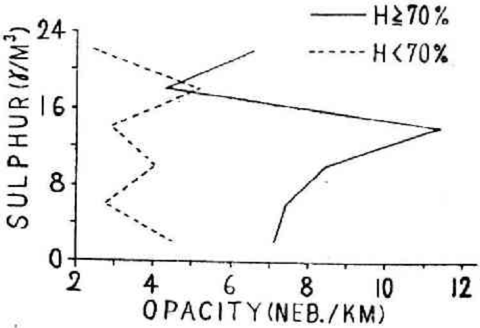

Fig. 17

Next in fig. 17 are shown the opacity-sulphur relations for $H \geqq 70$ % and $H < 70$ %. It will be seen that opacity increases with the increase of relative humidity for the same sulphur quantity.

iii) Opacity and ammoniacal nitrogen.

The opacity-ammoniacal nitrogen relation at Sendai is shown in fig. 18 in which we see that the opacity increases with the increase of ammoniacal nitrogen. Next the opacity-ammoniacal nitrogen relations for $H \geqq 70$ % and $H < 70$ % are shown in fig. 19. It will be seen that the values of opacity for $H \geqq 70$ % are larger than those for $H < 70$ % at each value of ammoniacal nitrogen. It will be noted that opacity for $H < 70$ % is constant

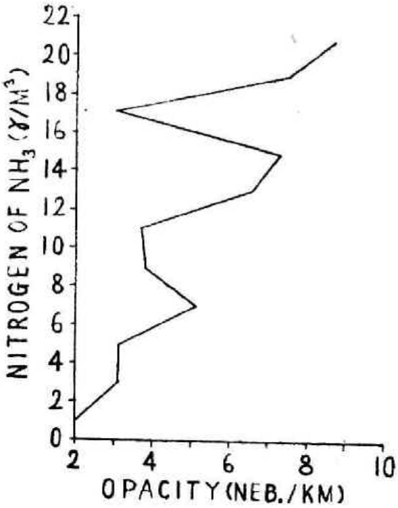

Fig. 18

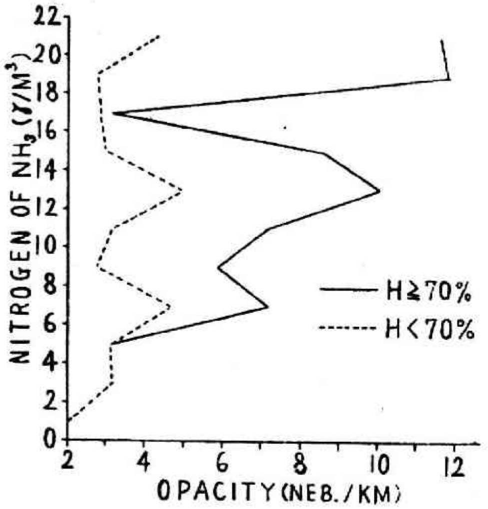

Fig. 19

and the values of opacity for $H \geqq 70\ \%$ increase with the increase of ammoniacal nitrogen.

iv) Opacity and nitrite nitrogen.

The relation between opacity and nitrite nitrogen at Sendai is shown in fig. 20. It will be seen that generally opacity increases with the increase of nitrite nitrogen. Next the relations between opacity and nitrite nitrogen for $H \geqq 70\ \%$ and $H < 70\ \%$ are shown in fig. 21. In general, the values of opacity for $H \geqq 70\ \%$ are larger than those for $H < 70\ \%$ at each value of nitrite nitrogen.

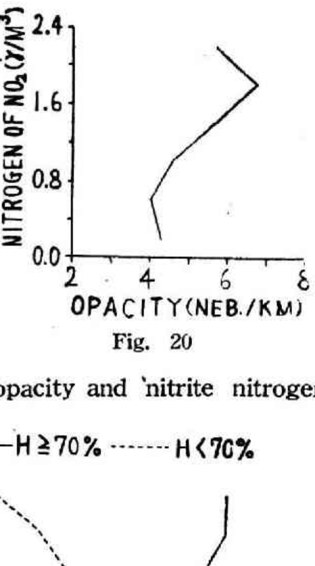

Fig. 20

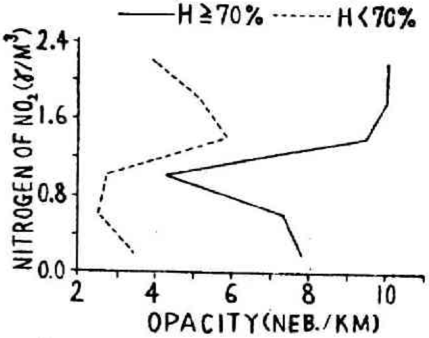

Fig. 21

v) Opacity and total quantity of impurities.

Fig. 22 shows the relation between opacity and the total quantity of atmospheric impurities. It shows that opacity increases with increase of atmospheric impurities, which is coused mainly by ammoniacal nitrogen and nitrite nitrogen as was shown above. The opacity-impurity relation is also affected by relative humidity as shown in fig. 23.

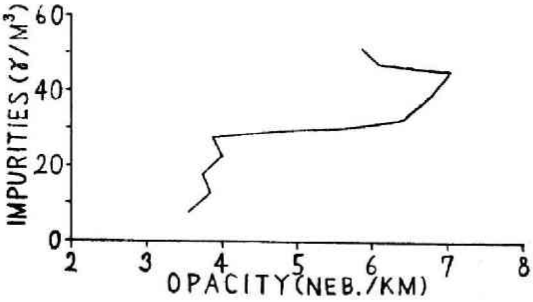

Fig. 22

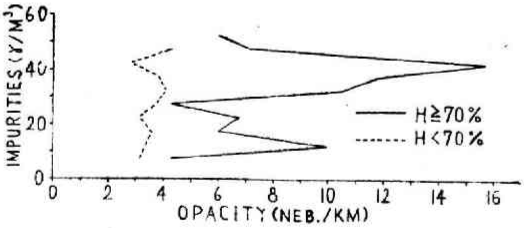

Fig. 23

Next, we shall see some supplementary relations between observed quanties. The relation between the number of nuclei and the quantity of impurities is as shown in fig. 24,

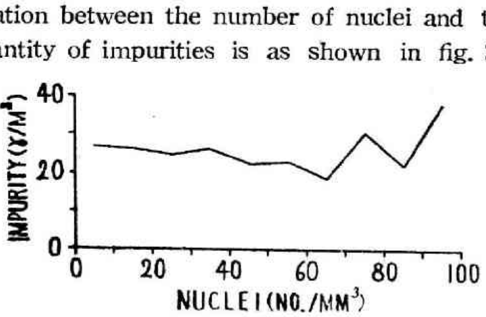

Fig. 24

which shows the slight increase of the quantity of impurities with the increase of the number of nuclei.

The impurity-wind speed relation is as shown in fig. 25, which shows that the quantity of impurities decreases slightly with increase of wind speed.

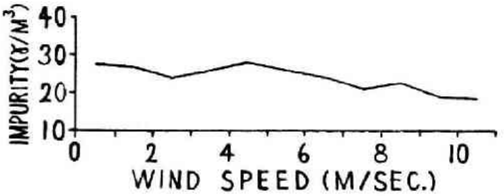

Fig. 25

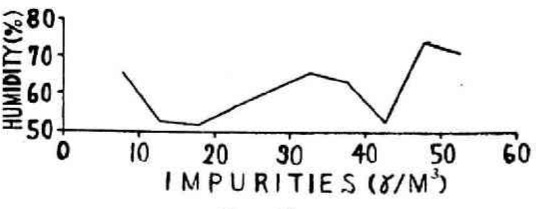

Fig. 26

The relative humidity-impurities relationship is shown in fig. 26, which shows that the quantity of impurities is nearly independent of relative humidity, however for large quantity of impurities corresponds somewhat large values of relative humidity.

6. Conclusion

Following results are obtained in the present investigation.

1. The value of opacity at Sendai increase continuously with the increase of relative humidity and there seems no such critical humidity value as 70 % which was suggested by WRIGHT that below the value of humidity opacity is nearly independent of relative humidity. This suggests that hygroscopic nuclei which are responsible for the determination of opacity at Sendai are not composed of sea-salt alone but containes nuclei of acid nature.
2. The relation between opacity and the number of condensation nuclei was examined. It is seen that opacity is nearly indepent of the number of nuclei or slightly increases with it.
3. As to the relation between opacity and wind speed, the relation obtained, *e.g.* YAMAMOTO and MIURA, that opacity decreases on the land with wind speed was ascertained. However, it was also shown that above result is reconcilable with MOORE's contrary result on the sea.
4. The relation between opacity and atmospheric impurities was examined and it was shown that opacity increases with the increase of impurities, and that in this contexts the role of ammoniacal nitrogen and nitrite nitrogen is important.

7. Acknowlegement

The author wishes to express his sincere thanks to Prof. G. YAMAMOTO for his kind guidance and encouragement given throughout this work, and also to the Department of Education for his financial support.

References

AITKEN, J. : 1888/89 *Proc. Roy. Soc. Edinb.*, **16**, 135

GOLD, E. : 1939 *Q. J. Roy. Met. Soc.*, **65**, 139

ITO, K.: 1940 *Rep. of Inst. Prev. Disasters*, No. 4 (in Japanese)

LANDSBRG, H.: 1938 *Beitr. z. Geophys.* (Supp.) **3**, 155

LÜDELING, G.: 1903 *Illustr. Aeronaut. Mitt.*, **7**, 321

MOORE, D. J.: 1952 *Q. J. Roy. Met. Soc.*, **78**, 596

OHTA, S.: 1950 *Journ. Met. Soc. Japan*, **28**, 157

SCHOLZ, J.: 1932 *Meteorol. z.*, **49**, 381

SCRASE, F. J.: 1935 *Q. J. Roy. Met. Soc.*, **61**, 367

SIMPSON, G. C.: 1941 *Ibid.*, **67**, 99 & 163

WAIT, G. R.: 1932 *Beitr. z. Geophys.*, **37**, 429

WIGANT, A.: 1921 *Phys. ZS.*, **22**, 484

WIGANT, A.: 1928 *Meteorol. z*, **45**, 275

WRIGHT, H. L.: 1939 *Q. J. Roy. Met. Soc.*, **65**, 411

WRIGHT, H. L.: 1940 *Ibid.*, **66**, 66

YAMAMOTO, G. and MIURA, A. : 1951 *Sci. Rep. Tohoku, Univ.*, 5th Ser., Geophys., 3. 23