TEMPORAL FLUCTUATION OF ATMOSPHERIC ABSORPTION OF SOUND AND ITS EFFECT ON AIRCRAFT NOISE PROPAGATION DURING A YEAR

PACS REFERENCE: 43.50.Vt

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ABSTRACT

Attenuation coefficients for atmospheric absorption were calculated from meteorological data observed at Nagoya Observatory and at Tateno aerological observatory in Japan. The calculated results show that the variability characteristics of the attenuation coefficients during a year depend strongly upon both the sonic frequency and the altitude. Next the effects of the atmospheric absorption on aircraft noise propagation were examined using the calculated attenuation coefficients. It has been found that the A-weighted sound pressure levels and sound spectra of aircraft noise vary strongly due to the changes of real atmospheric conditions during a year.

INTRODUCTION

In order to perform the long-term prediction of outdoor sound propagation more accurately, it is necessary to examine the fluctuation of attenuation coefficients for atmospheric absorption during a year. There are large variations with time and place in actual meteorological conditions on which the attenuation coefficients depend strongly. These natural variabilities are often neglected in environmental impact assessments. We have investigated the variability characteristics of the attenuation coefficients for atmospheric absorption during a year by the calculations using meteorological data measured at various observatories.

CALCULATION METHOD

At first, Attenuation coefficients for atmospheric absorption were calculated from hourly meteorological data observed at Nagoya Observatory in central Japan from April 1, 1991 to March 31, 1992 by using the calculation method described in ISO 9613-1. The meteorological data used in the calculations were air temperature, humidity and atmospheric pressure at a height of 1.5m above the ground. Nagoya Observatory is in a suburb of Nagoya city and stands on high ground at a height of 51.1m above sea level. Next, The attenuation coefficients were calculated from meteorological data observed for the entire of 1991 at Tateno aerological observatory. The aerological data were observed at 9:00 and 21:00 everyday by rawinsonde measurements. The meteorological data used in the calculations were air temperature, humidity and atmospheric pressure at heights of range from 31m to 5000m above the ground. Tateno aerlogical observatory is in 50km to the northeast of Tokyo and stands on almost flat ground at a height of 25.2m above sea level.

CALCULATION FROM THE HOURLY DATA OBSERVED AT NAGOYA OBSERVATORY

Temporal Fluctuation during a Year

Figure1 shows the attenuation coefficients for atmospheric absorption at octave band center frequencies form 63 Hz to 8kHz, together with the air temperature and the relative humidity used in the calculation. Air temperature varies within the range from -2.9^{o}C to 36.8^{o}C, relative humidity varies with in the range from 17% to almost 100% during a year. The change of seasons is quite noticeable in Japan ; the air is relatively warm and moist in the summer, and cold and dry in the winter. It can be seen that the attenuation coefficients at low (63,125Hz) and high (4k,8kHz) frequencies in the winter are higher than those in the summer. On the other hand, the attenuation coefficients at middle frequencies (500,1kHz) become lower in the winter. The temporal fluctuation of attenuation coefficients at all frequencies become greater in the winter than in the summer. The mean, standard deviation, maximum and minimum of the coefficients (n=24*365=8760) are shown in Table 1. The attenuation coefficients vary strongly during a year. For example, the attenuation coefficients at 2kHz vary within the range from 7.8 dB/km to 34.0dB/km, while the mean annual attenuation coefficient is 11.5dB/km.

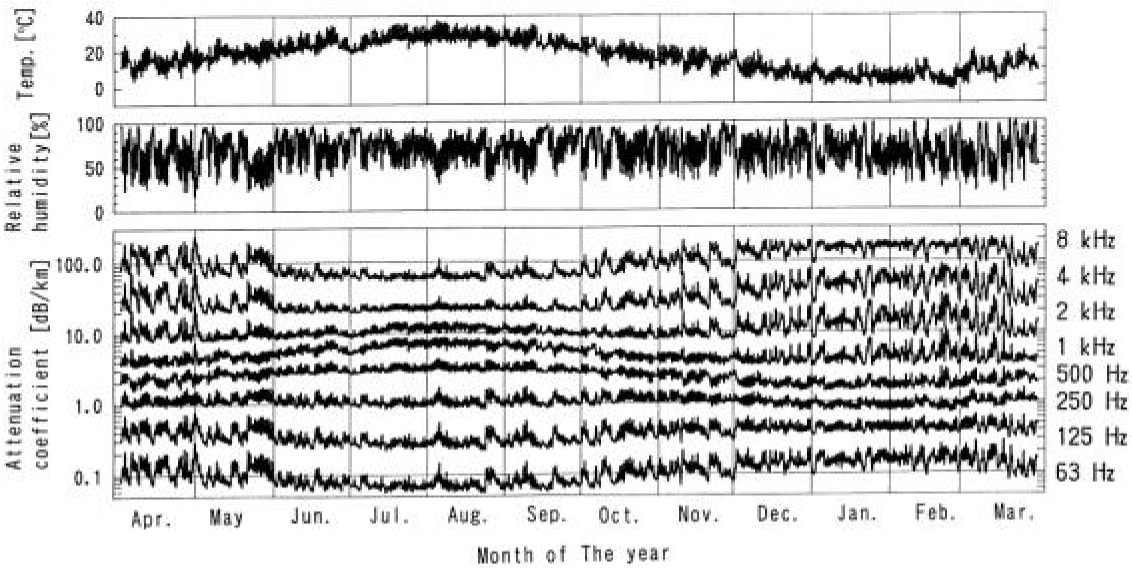


Fig.1. Air temperature, relative humidity and calculated attenuation coefficients for atmospheric absorption at octave band center frequencies form 63Hz to 8kHz during a year.

Table 1. Attenuation coefficients for atmospheric absorption calculated form hourly meteorological data during a year (n=24*365=8760).

	Temp. [°C]	R.H. [%]	Attenuation Coefficients for Atmospheric Absorption [dB/km]							
			63Hz	125Hz	200Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Mean	16.3	66.9	0.11	0.37	1.05	2.46	5.08	11.47	33.02	104.3
S.D.	8.9	16.9	0.04	0.09	0.16	0.59	1.25	3.26	13.81	38.67
Maximum	36.8	99.0	0.28	0.75	1.70	4.31	10.21	34.04	94.17	227.2
Minimum	-2.9	17.0	0.06	0.22	0.69	1.43	3.22	7.76	19.89	54.75
Max.-Min.	39.7	82.0	0.22	0.53	1.01	2.88	6.99	26.29	74.28	172.5

Differences of Attenuation Coefficients between Summer and Winter

The calculated mean coefficients in the summer (July and August, n=24*62) and those in the winter (January and February, n=24*59) were compared as shown in Table 2. The attenuation coefficients at high and low frequencies in the winter are higher than those in the summer. On the other hand, the attenuation coefficients at middle frequencies are low in the winter. It can be said that the seasonal changes in the attenuation coefficients depend strongly on the frequency. It is difficult to answer the question whether A-weighted sound pressure levels in the summer at a distant point form a sound source increase or not, without the information of the spectrum of the sound source.

Table 2. Mean attenuation coefficients for summer and winter calculated from hourly meteorological data at ground level.

	Temp. [^{o}C]	R.H. [%]	Attenuation Coefficients for Atmospheric Absorption [dB/km]							
			63Hz	125Hz	200Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Summer	26.7	70.5	0.07	0.29	1.04	3.11	6.59	11.19	22.61	65.25
Winter	6.2	64.1	0.15	0.42	0.93	1.84	4.47	14.16	48.18	144.6
Diff.	-	-	-0.08	-0.13	0.11	1.27	2.12	-2.97	-25.57	-79.34

The Effects of Atmospheric Absorption on Aircraft Noise Propagation

In order to examine the seasonal changes in the effects of atmospheric absorption on aircraft noise propagation, the aircraft noise heard on the ground were calculated from the absorption coefficients during a year. The sound pressure levels at a height of 1.5m above the ground of noise generated from an aircraft flying near the ground were calculated using the average sound power spectrum of 14 aircrafts (B-767, climbing)shown in Table 3. The sound spectra were measured around the Nagoya International Airport. Figure 2 shows the calculated A-weighted sound pressure levels of noise generated from an aircraft flying at horizontal distances from 100m to 3200m. The mean, standard deviation, maximum and minimum of the calculated A-weighted sound pressure levels of aircraft noise are shown in Fig.3 and Table 4 (n=24*365=8760). It can be seen that the sound pressure levels at short and long distances are highly variable as compared to those at middle distances (800m).

Table 3. Average 1/1 octave band sound power spectrum of 14 aircrafts (B-767, climbing).

f_c [Hz]	A.P	63	125	250	500	1k	2k	4k
L_W [dB]	152.5	145.2	146.5	144.7	141.8	140.2	141.3	144.8

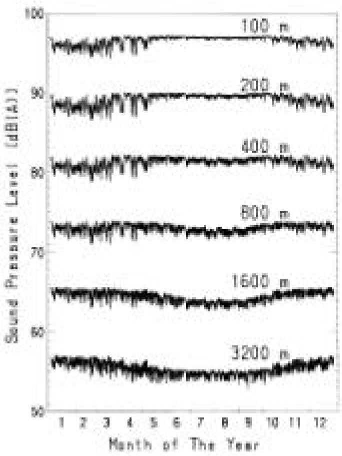


Fig.2. Calculated A-weighted sound pressure levels of noise generated from an aircraft flying near the ground at horizontal distances from 100m to 3200m.

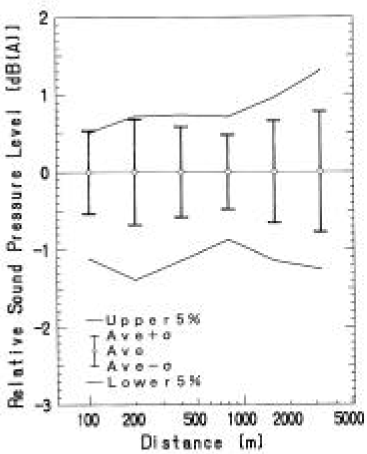


Fig.3. Fluctuation of A-weighted sound pressure levels of noise generated from an aircraft flying near the ground at horizontal distances from 100m to 3200m during a year.

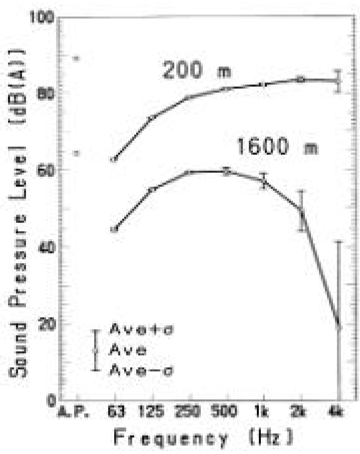


Fig.4. Sound spectra of noise generated from an aircraft flying near the ground at horizontal distances of 200m and 1600m.

One of the reasons of this phenomenon is considered that the high frequency components which are affected strongly by atmospheric absorption decrease drastically with increasing the distance as shown in Fig.4. It should be noted that the variability of A-weighted sound pressure levels due to atmospheric absorption dose not necessarily increase monotonously with increasing the distance.

Table 5 shows the comparison of the mean A-weighted sound pressure levels of aircraft noise for summer and winter. There is a tendency that the A-weighted sound pressure levels are higher at short distances up to 400m in the summer than in the winter, although those at long distances are higher in the winter. It is difficult to answer the question whether A-weighted sound pressure levels of aircraft noise in the summer increase or not due to the changes of atmospheric absorption, without the information of the distance from an aircraft to an observing point.

Table 4. The mean, standard deviation, maximum and minimum of the calculated A-weighted sound pressure levels of noise generated from an aircraft flying near the ground at horizontal distances from 100m to 3200m during a year (n=24*365=8760).

[dB(A)]

	Distance [m]					
	100	200	400	800	1600	3200
Mean	96.6	89.2	81.4	73.1	64.5	55.4
S.D.	0.54	0.68	0.58	0.48	0.66	0.78
Max.	97.2	90.0	82.2	74.0	65.7	57.1
Min.	94.4	86.5	78.8	71.1	62.7	52.9
Max.-Min.	2.8	3.5	3.4	2.9	3.0	4.2

Table 5. Comparison of the mean Aweighted sound pressure levels of aircraft noise for summer and winter calculated from hourly meteorological data at ground level.

[dB(A)]

	Distance [m]					
	100	200	400	800	1600	3200
Summer	97.0	89.7	81.5	72.7	63.7	54.7
Winter	95.9	88.4	80.7	73.0	64.9	56.3
Diff.	1.1	1.3	0.8	-0.3	-1.2	-1.6

CALCULATION FROM THE DATA OBSERVED AT TATENO AEROLOGICAL OBSERVATORY

Temporal Fluctuation during a Year

Figure 5 shows the vertical profiles of air temperature, relative humidity, atmospheric pressure and calculated attenuation coefficients for atmospheric absorption at frequencies of 250Hz, 1kHz and 4kHz. It can be seen that the profiles vary strongly during a year. Figure 6 shows the attenuation coefficients for atmospheric absorption at frequencies of 250Hz, 1kHz and 4kHz , together with the air temperature and the relative humidity used in the calculation. Air temperature varies within the range from –3^{o}C to 31^{o}C, relative humidity varies within the range from 26% to almost 100% during a year at a height of 31m above the ground. On the other hand, air temperature at a height of 3000m above the ground varies within the range from –23^{o}C to 15^{o}C, relative humidity varies within the range from 2% to almost 100%. The attenuation coefficients at a height of 3000m are apparently highly variable as compared to those at a height of 31m. The temporal fluctuations of attenuation coefficients at all frequencies become greater in the winter than in the summer at both heights.

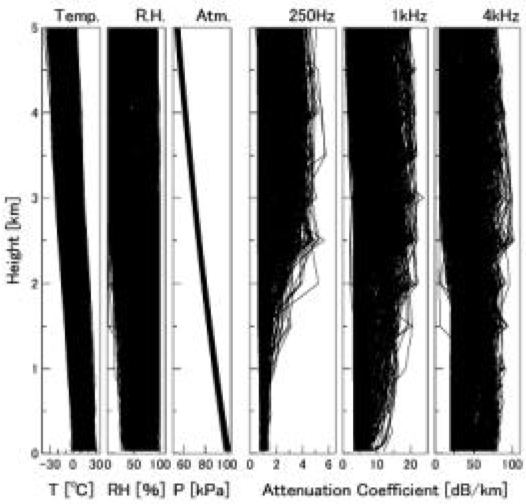
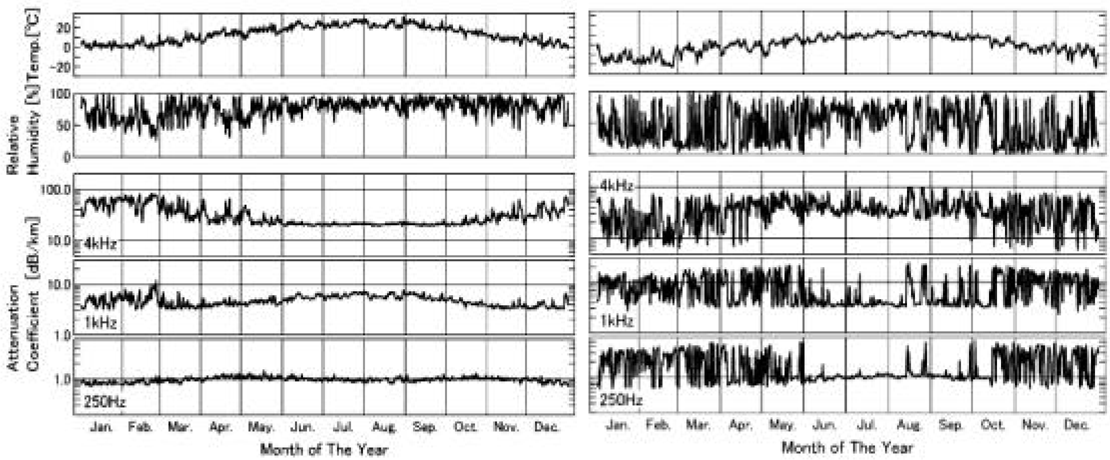


Fig.5. Vertical profiles of air temperature, relative humidity, atmospheric pressure and calculated attenuation coefficients for atmospheric absorption at frequencies of 250kHz , 1kHz and 4kHz during a year.

Annual Mean Attenuation Coefficients at Heights of 31m and 3000m

Table 6 shows annual mean absorption coefficients at heights of 31m and 3000m (n=2*365=730). The attenuation coefficients at high altitude are higher than those near the ground, except for at 8kHz.



(a) at the height of 31m above the ground   (b) at the height of 3000m above the ground

Fig. 6. Air temperature, relative humidity and calculated attenuation coefficients for atmospheric absorption during a year.

Table 6. Mean attenuation coefficients during a year at heights of 31m and 3000m above the ground.

Height	Temp. [°C]	R.H. [%]	Po [kPa]	Attenuation Coefficients for Atmospheric Absorption [dB/km]							
				63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
31m	13.7	76.8	101.1	0.11	0.35	0.97	2.31	4.87	11.24	32.10	97.84
3000m	0.1	45.7	70.5	0.25	0.70	1.75	3.90	8.05	16.57	37.12	90.41

Differences of Attenuation Coefficients between Summer and Winter

In order to examine the changes due to seasons, the calculated mean attenuation coefficients in the summer (July and August, n=2*62) and those in the winter (January and February, n=2*59) were compared as shown in Table 7(a) and 7(b). It can be seen that the attenuation coefficients at a height of 3000m for high frequencies (4kHz, 8kHz) in the summer are higher than those in the winter and the attenuation coefficients for middle frequencies (500Hz,1kHz) become lower in the summer. On the other hand, attenuation coefficients for 4kHz and 8kHz at a height of 31m become higher in the winter. It can be said that the seasonal changes in the attenuation coefficients depend strongly on the altitude.

Table 7(a). Attenuation coefficients for summer and winter at a height of 31m above the ground.

	Temp. [°C]	R.H. [%]	Attenuation Coefficients for Atmospheric Absorption [dB/km]							
			63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Summer	23.7	83.4	0.07	0.26	0.96	2.85	6.05	10.36	21.09	60.99
Winter	2.6	62.5	0.16	0.41	0.85	1.83	5.20	17.49	56.55	147.43
Diff.	-	-	-0.09	-0.15	0.11	1.02	0.85	-7.13	-35.46	-86.44

Table 7(b). Attenuation coefficients for summer and winter at a height of 3000m above the ground.

	Temp. [°C]	R.H. [%]	Attenuation Coefficients for Atmospheric Absorption [dB/km]							
			63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz
Summer	10.5	57.3	0.16	0.48	1.16	2.44	5.47	14.44	42.29	125.45
Winter	-13.9	40.9	0.30	0.86	2.20	4.71	8.73	14.69	24.75	45.27
Diff.	-	-	-0.14	-0.38	-1.04	-2.27	-3.25	-0.25	17.54	80.18

The sound pressure levels at a height of 1.5m above the ground of noise generated from an aircraft flying right overhead at heights from 200m to 3000m were calculated from the absorption coefficients at the range of frequency from 63Hz to 4kHz, assuming that the atmosphere is modeled by a stack of 21 horizontal layers over a range of altitude from 0 to 5000m, as mentioned in annex B, ISO 9613-1. Figure 7 shows the calculated A-weighted sound pressure levels of aircraft noise heard on the ground. It can be seen that the sound pressure levels in the winter are highly variable as compared to those in the summer, and that the mean sound pressure levels in the summer apt to be higher than those in the winter.

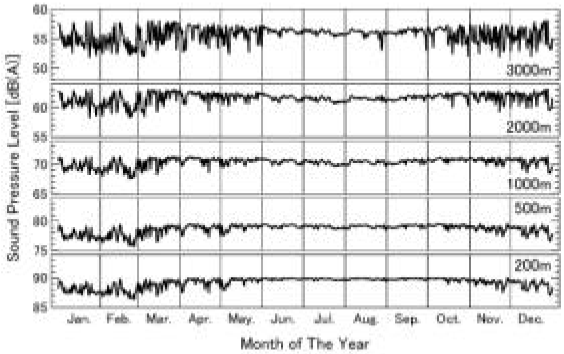
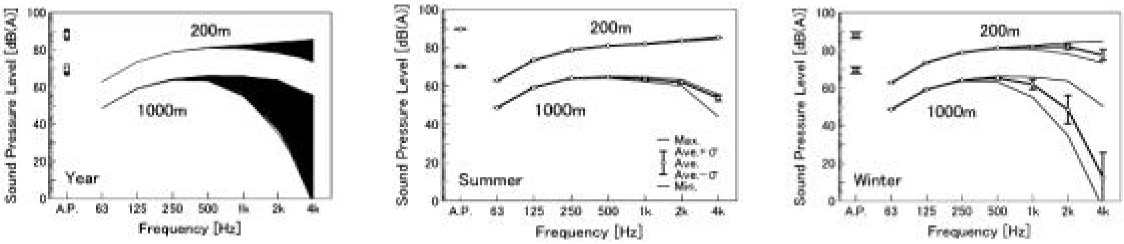


Fig.7. Calculated A-weighted sound pressure levels near the ground of noise generated from an aircraft flying right overhead at heights of 200m ,500m, 1000m, 2000m and 3000m.



(a) Year (b) Summer (c) Winter

Fig. 8. Calculated sound spectra of noise from an aircraft flying right overhead at heights of 200m and 1000m.

Figure 8(a) shows calculated sound spectra of noise generated from an aircraft flying right overhead at heights of 200m and 1000m. The sound spectra calculated from measured meteorological data at 9:00 and 21:00 change drastically during a year, particularly for sound at higher frequencies. Figures 4(b) and 4(c) show the comparison of sound spectra in the summer with in the winter. It can be seen that the high frequency components of aircraft noise are larger in the summer than those in the winter and the variability in sound spectra become much stronger in the winter than in the summer.

CONCLUSION

The authors have calculated attenuation coefficients for atmospheric absorption from meteorological data during a year observed at Nagoya Observatory and Tateno aerological observatory in Japan by using the calculation method described in ISO 9613-1. As a result of this study, it has been found that the attenuation coefficients for atmospheric absorption and A-weighted sound pressure levels of aircraft noise vary strongly due to the changes of real atmospheric conditions during a year in Japan.

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