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SIMULTANEOUS MEASUREMENTS OF AIR-EARTH CURRENT AT TWO STATIONS

By

Toshio OGAWA and Kunihiko KODERA

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Abstract

The air-earth current was measured at two stations in Kyoto city simultaneously in the cold season, 1970 through 1971, obtaining the diurnal variation pattern. Cross correlation coefficient was calculated. It is demonstrated that differences of amplitude and phase of variations at the two stations are due to variations of the columnar resistance at each station. It is found that the columnar resistance is sensitively affected by surface wind.

1. Introduction

The air-earth conduction current may be given by the Ohm's law $i=V/R$, where V is the potential of the upper atmosphere or ionosphere, and R the local columnar resistance, as far as dealing with the conditions in fine or fair weather, in which the principle of the quasi-static state can be used. Taking logarithms and differentiating, $(1/i)(di/dt)=(1/V)(dV/dt)-(1/R)(dR/dt)$; the variation of air-earth current is expressed in terms of the universal change of V and the local change of R. When simultaneous measurements of the air-earth current are made at places not far apart from each other, useful comparisons of the results can be made to get local distribution of columnar resistance eliminating the effect of V. In this paper we made simultaneous measurements of air-earth current at two stations, one in a moderately populated area in Kyoto city and the other in a less populated area at the environs of the city, separated by 4 km each other. We compared both records obtained in the period from December, 1970 to March, 1971.

2. Observations

The air-earth current was measured with an elevated conducting aluminum ball and the electrometer operational amplifier "Keithly Model 300" with a feedback circuit of a resistance R and a capacitance C connected parallel. The amplifier "Keithly Model 300" has a high imput impedance ($>10^{14}\Omega$) and is used for an inverting type amplifier, so that the output voltage gives RAi where A is the effective receiving area of the antenna given by C_0h/ε_0. C_0 is the antenna capacitance, h the effective height of the antenna and ε_0 permittivity of the air. The time constant RC is set at about the relaxation time of the air. In the present case it is about 500 to 1,000 seconds, so that $1 \times 10^{11}\Omega$ is selected for R and 0.01 μF for C.

The first antenna is set at the Geophysical Observatory at Kamigamo (station X), which is on a small hill 190m above the sea level situated in the northern environmental part of Kyoto city. The area is less populated and the air seems less polluted. The second antenna is set at the Geophysical Institute at Kitashirakawa (station Y). The area is situated in the north-eastern part of the city and is moderately populated and the air seems more polluted. The topographical situation including the observing sites is shown in Fig. 1.

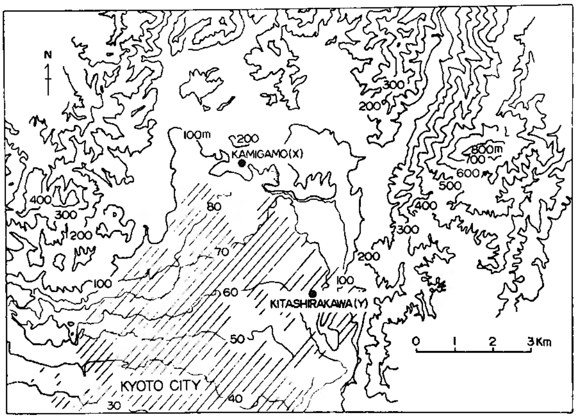

Fig. 1. Topographical map of the northern part of Kyoto city. Populated area is shown by hatching.

The ball antenna which is nearly spherical and insulated, the mean diameter being 26 cm, was mounted on a metal post about 2 m high and set on the roof of the building. The absolute value of the air-earth current is obtained through the antenna calibration, but the first antenna is not calibrated because of the complexity of the topographical situation near the observing site. Therefore only relative variations are analysed in this paper. The second antenna is calibrated, the effective height being 2.7 m and the effective receiving area 5.4m^2. With these values the average air-earth current was estimated 4.5×10^{-13} Amp/m^2. The method of calibration was described in the other paper (Ogawa and Tanaka [1970]).

An example of the records at both stations is shown in Fig. 2 which gives 53 hours records on 18 through 19 January, 1971. Chart speed of the recorders is 2 cm/hr, and the vertical axis is measured by the electrometer output in volts.

Both records look similar in some parts but not others. There are maxima at about 4h on 18 January and at about 5h on 19 January. Such similar maxima in the early morning are recorded most days except during disturbed weather. This

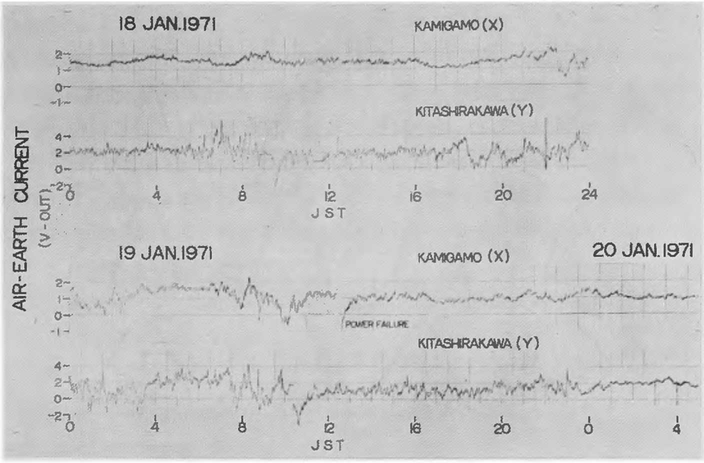

Fig. 2. An example of the simultaneous records of air-earth current at the two stations.

may be the diurnal peak of the universal change of the air-earth current, corresponding to the maximum worldwide thunderstorm activity. Shorter period variations than about one hour vary at the two stations.

3. Data Analysis

3–1 *Cross correlation*

In order to see the quantitative order of similarity and phase relation of air-earth currents recorded at the two stations, the cross correlation coefficients of both records are calculated. The amplitude values of every 15 minutes are digitally processed through the three kinds of digital filters which time responses are shown in Fig. 3. The responses are level to within −3 db between ∞ and 1.3 hours (A), 7.5 hours (B), and 15 hours (C) respectively.

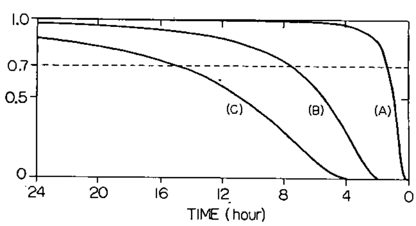

Fig. 3. Frequency responses of the three digital filters.

Fig. 4 is an example of the result of calculation. In this case data given in Fig. 2 were used. (A), (B), and (C) are the time sequences of cross correlation coefficient calculated after passing through the filters (A), (B), and (C) respectively. The time

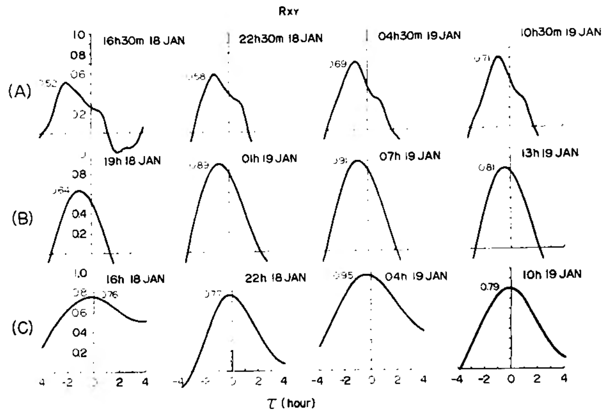

Fig. 4. Time sequences of cross correlation coefficient of air-earth current measured at the two stations. (A),(B), and (C) show the digital filters used.

shown at the right top of each figure is the center time of data processed. From Fig. 4 we see that the longer the filtering-out time, the larger the cross correlation is and the smaller the phase lag is. The largest correlation coefficient is 0.95 and the smallest is 0.52. The phase usually advances about one hour earlier at Kamigamo (X) than at Kitashirakawa (Y). The values of the coefficient and phase lag change with time.

3–2 *Mean diurnal variation*

In order to see the average feature of the air-earth current, mean diurnal curve at each station is made using data every hour for the period from 18 December, 1970 to 20 January, 1971 (period I), and for the period from 15 February, 1971 to 24 March, 1971 (period II), in which 9 calm days are respectively selected eliminating disturbed weather. The result is shown in Fig. 5. The diurnal amplitude is larger at Kitashirakawa (Y) than at Kamigamo (X).

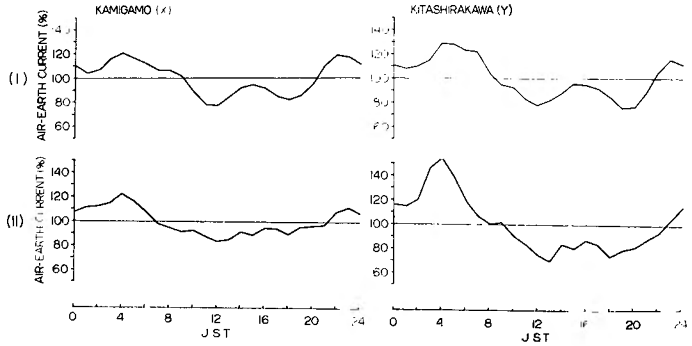

Fig. 5. Diurnal variations of air-earth current at the two stations for the periods of I and II

Using these curves of the air-earth current, mean diurnal variations of columnar resistance are calculated assuming the diurnal pattern of atmospheric potential which is represented by the Carnegie measurement of electric field over the ocean (Fig.2 of Ogawa [1960]). The results is given in Fig. 6. The diurnal pattern is very clear at Kitashirakawa (Y) with the minimum values at about 4h to 7h in the morning and the maximum values at about 18th to 20h in the evening, while no remarkable diurnal pattern is seen at Kamigamo (X) but a variation of several hours is seen especially in the period I.

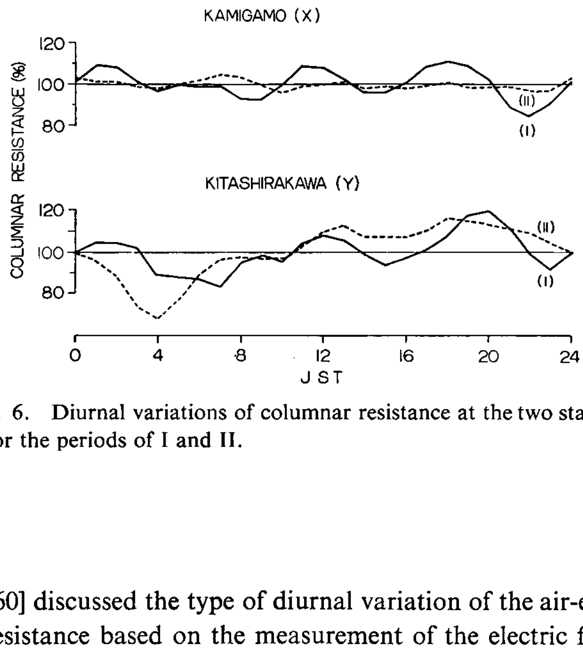

Fig. 6. Diurnal variations of columnar resistance at the two stations for the periods of I and II.

4. Discussion

Ogawa [1960] discussed the type of diurnal variation of the air-earth current and the columnar resistance based on the measurement of the electric field and conductivity at Kitashirakawa which is the same place as the present Kitashirakawa (Y). The diurnal patterns and their amplitudes at Kitashirakawa (Y) in the present experiment generally agree with the former. The diurnal amplitude of the columnar resistance at Kamigamo (X) is much smaller than at Kitashirakawa (Y). It is interesting to recall that the measurement was made at a place only about 4 km from Kitashirakawa (Y). This result, however, depends upon the diurnal amplitude of the assumed atmospheric potential in the calculation of the columnar resistance.

In order to compare the variation amplitudes in percentage at both stations, the following calculation was made: $\left(\frac{1}{i}\frac{di}{dt}\right)_X-\left(\frac{1}{i}\frac{di}{dt}\right)_Y=\left(\frac{1}{R}\frac{dR}{dt}\right)_Y-\left(\frac{1}{R}\frac{dR}{dt}\right)_X$, where suffixes $_X$ and $_Y$ represent Kamigamo (X) and Kitashirakawa (Y) respectively. The result is given in Fig. 7 for the periods I and II, in which curves are roughly negative in the morning and positive in the afternoon. This pattern of variation is same as a general variation pattern of columnar resistance. From this it is clear that

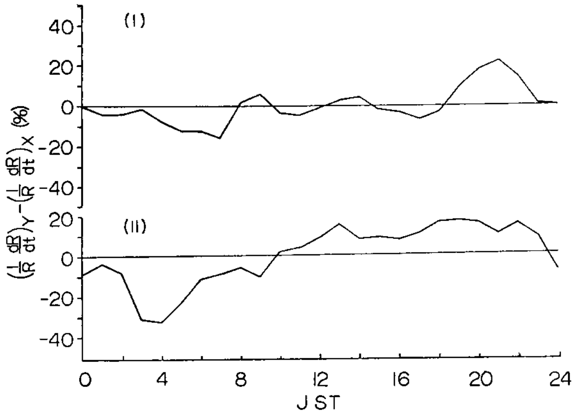

Fig. 7. Differences of variations of columnar resistances at the two stations for the periods of I and II obtained from the calculation: $\left(\frac{1}{i}\frac{di}{dt}\right)_X - \left(\frac{1}{i}\frac{di}{dt}\right)_Y = \left(\frac{1}{R}\frac{dR}{dt}\right)_Y - \left(\frac{1}{R}\frac{dR}{dt}\right)_X$

the variation amplitude at Kamigamo (X) is smaller than at Kitashirakawa (Y) by about 10–20%.

Seeing the characteristic feature of phase lag in relation to the filtering-out time which is shown in Fig. 3, it is understood that the variation period to cause such a phase lag may be several hours. Such variations are also seen in the diurnal variation of the columnar resistance in Fig. 6. The phase advance at Kamigamo (X) is related to the wind characteristics on the days when data were obtained. According to the observation of surface wind at Kyoto Meteorological Observatory which is situated at about 5 km WSW of Kitashirakawa (Y), mean surface wind velocity was 2.3 m/s N on 18 January, and 2.1 m/s NNW on 19 January. The air-earth current is given by $i=V/R$, and as there may be no phase difference of V between the two stations, the phase shift of the air-earth current is due to that of the columnar resistance. The variation of the columnar resistance is caused by production and disappearance of nuclei contained in the vertical air column over the observing station. Disappearance of nuclei depends largely on the transport of nuclei by wind. As the wind direction on 18 and 19 January was approximately from Kamigamo (X) to Kitashirakawa (Y), it is reasonably understood that the phase advanced at Kamigamo (X) than at Kitashirakawa (Y).

In Fig. 8 daily mean values of air-earth current density are plotted in terms of daily mean values of wind velocity for the data of period I, the mean current density at Kitashirakawa (Y) being 4.5×10^{-13} Amp/m and the mean wind velocity 1.7 m/s. It demonstrates a strong linear relation of the wind velocity with the air-earth current and hence with the local columnar resistance.

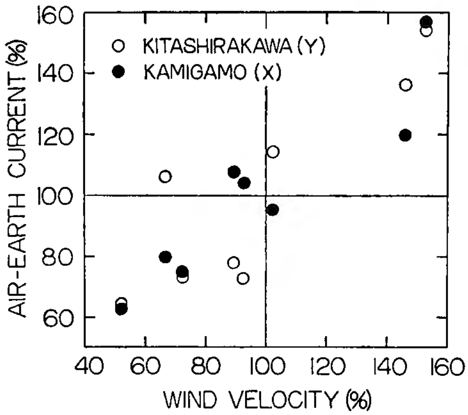

Fig. 8. Effect of wind velocity on the air-earth current.

The air-earth current varies depending upon the universal time change of atmospheric potential V and the local time change of columnar resistance R. At the longitude on which Japan lies, phases of V and R differ about 165° or 195° from each other so that the variation of R does not reduce the amplitude of the air-earth current but acts to amplify it.

At the station where the air is polluted the air-earth current shows large diurnal variation because of the large variation of R. R varies diurnally depending on air pollution affecting R. Besides, R can vary from day to day and with a period of several hours. These variations overlap the diurnal term and are caused by surface wind.

On the other hand at the station where the air is less polluted but not distant from an origin of pollution, the air-earth current does not change with large diurnal amplitude because R does little change diurnally, but R is varied by wind showing longer and shorter term variations. Therefore the diurnal variation of the air-earth current is due to that of V.

In this paper we have mostly concerned with only relative variations of the air-earth current at the two stations. In the future we will measure absolute values of the air-earth current at more than two stations and make more detailed discussions on the local distribution of the columnar resistance.

Acknowledgement

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