Some short-term, local influences of wind direction on atmospheric electricity at ground level at Saskatoon

By J. E. PAKIAM and J. MAYBANK, *Saskatchewan Research Council, Saskatoon, Saskatchewan*

(Manuscript received November 7, 1967)

ABSTRACT

Experimental observations of the potential gradient and the air conductivity at Saskatoon have indicated that wind direction may have a pronounced effect on the night time values of these parameters. Two examples with well enhanced effects are presented and it is suggested that these were due to the influence of man-made charge "generators". A third example of more subtle effects was analysed quantitatively and led to the conclusion that a 270 degree segment in a 360 degree directional circle at the site of observation was affected by local generators.

1. Introduction

In recent years, the influence of meteorological factors on atmospheric electricity has been increasingly realized (e.g. Israël, 1957; Reiter, 1960). As a result, Israël has stressed the need for examination of the "climatological" aspects of atmospheric electricity in order to determine the suitability of a station for observation of local, regional or global aspects.

Pakiam & Johnson (1967), observing at Saskatoon, found peculiar variations in the potential gradient (F) and the electrical conductivity (λ) during a large number of nights. They felt that many of their observations were due to uneven space charge distribution. Continued investigation has indicated that the physical situation is extremely complex, and some preliminary results which seem to show the influence of the wind direction are presented here; these results are of spatial length and duration to justify the terminology "short-term, local" in accordance with the nomenclature set out by Dolezalek (1958).

2. Observational site

The general area of observation was a piece of flat terrain 2 miles north-east of the town of Saskatoon. A map of the region is given in Fig. 1 and the region itself has been described in greater detail by Pakiam & Johnson.

Two sites of observation were used. One of them, the Radio Experimental Station (RS 5) has been described by Pakiam & Johnson. The other was a Climatological Reference Station (CRS), to the east of RS 5 and 700 yards from it. At the CRS, various masts were in close proximity to the instrumentation so that only relative values of the potential gradient could be obtained.

3. Instrumentation

At various times different instruments were operated at the two sites and a list of the instruments and their duration of operation is given below (the Gerdien apparatus, field mill

I. *At CRS*

Wind velocity:	10 m height, instantaneous (Bendix-Friez aerovane)	Permanent
Dewpoint and air temperature:	Ventilated Stevenson screen at 1.5 m height; LiCl variable resistance dewcel element for dewpoint and platinum resistance element for temperature	Permanent
Grass height temperature:	Exposed platinum resistance element, 3 in. above ground	Permanent
Air conductivity:	Gerdien apparatus	20.4.66 to present

Potential gradient:	Inverted field mill, 1.4 m above ground	1.5.66 to present
	Radioactive collector (Met. Research, Inc.)	Moved from time to time between CRS & RS 5
	Stretched wire passive antenna (length antenna = 0.3 m)	13.9.66 to present
II. *At RS 5*		
Air conductivity:	Gerdien apparatus	Sept. 1964 to 20.4.66
Potential gradient:	Inverted field mill, 2.5 m above ground	Sept. 1964 to 15.4.66
	Radioactive collector	Moved from time to time between RS 5 & CRS
	Stretched wire passive antenna (antenna length shortened to 0.3 m on 5.7.66)	Sept. 1964 to 13.9.66

and stretched wire passive antenna have been described by Pakiam & Johnson); in addition, hourly cloud data were obtained from the synoptic weather station at Saskatoon airport, some 4 miles to the west of CRS.

4. Experimental observations

4.1. A shift in wind direction

Fig. 2 shows a 90 degree shift in wind direction within the space of 20 mins. on a clear night (18–19 August, 1966) with almost constant wind speed. Accompanying the change in wind direction, there appeared to be a change in air temperature and humidity. No significant change in atmospheric pressure was detected on a microbarograph. The changes in potential gradient (F) and air conductivity (λ) could be explained in terms of a source of pollution (large ions) originating in the west since a beef-cattle research project and part of the city lie in that direction. Field pulses of this nature have been observed previously by Whitlock & Chalmers (1956) and Brasefield (1959) and were ascribed to local generators.

4.2. Extensive disturbances from local generators

Extensive changes in F and λ (see Fig. 3) were observed quite frequently and corresponded to Types II and III of the peculiar variations in F described by Pakiam & Johnson. The disturbances were associated with wind blowing from the direction of the city and were visually observed to be correlated with smoke trapped beneath an inversion layer in the atmosphere.

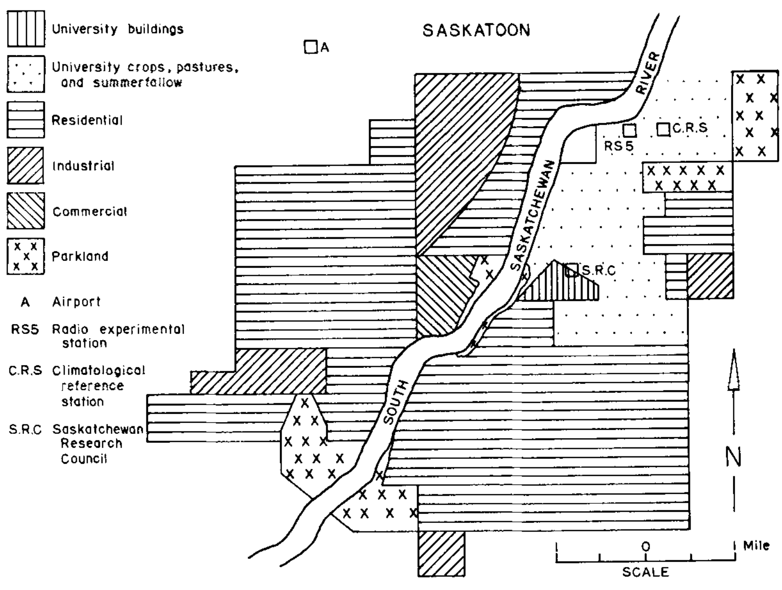

Fig. 1. Map of area of observation.

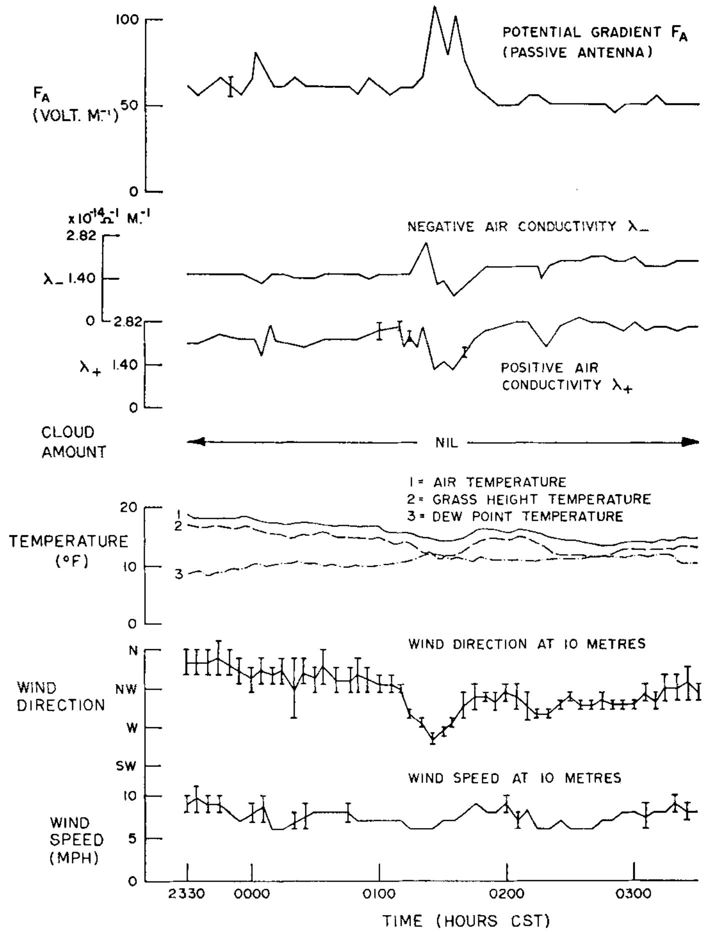

Fig. 2. Effect of wind shift on atmospheric electric parameters on night of 17–18 April, 1966 (error bars at any instant of time indicate the fluctuation in values at the same instant).

The increase in F and decrease in λ imply the presence of a positive space charge due to large ions, since the time of transmission from sources in the town would be several times the mean life time of small ions. The positive space charge was not surprising since sources such as exhaust from gasoline motors, chimney smoke and engine steam produce positive charge (Mühleisen, 1958).

4.3. *An apparent effect of wind speed on potential gradient*

The remarkable data of the night of the 18–19 August, 1966 (Fig. 4) showed wind speed apparently well correlated with potential gradient at the same station. Subsequent examination, however, showed an even more interesting effect. It was noticed that much fluctuation occurred in the wind direction and considering the directional effects previously observed, it was decided to analyze the data for directional variations in space charge density.

Let N = number of large ions, subscripts 1, 2 denoting the positively and negatively charged components, respectively,

n = number of small ions, with subscript notation as above,

K = mobility of large ions, with subscript notation as above,

k = mobility of small ions, with subscript notation as above,

λ_1 = positive air conductivity,

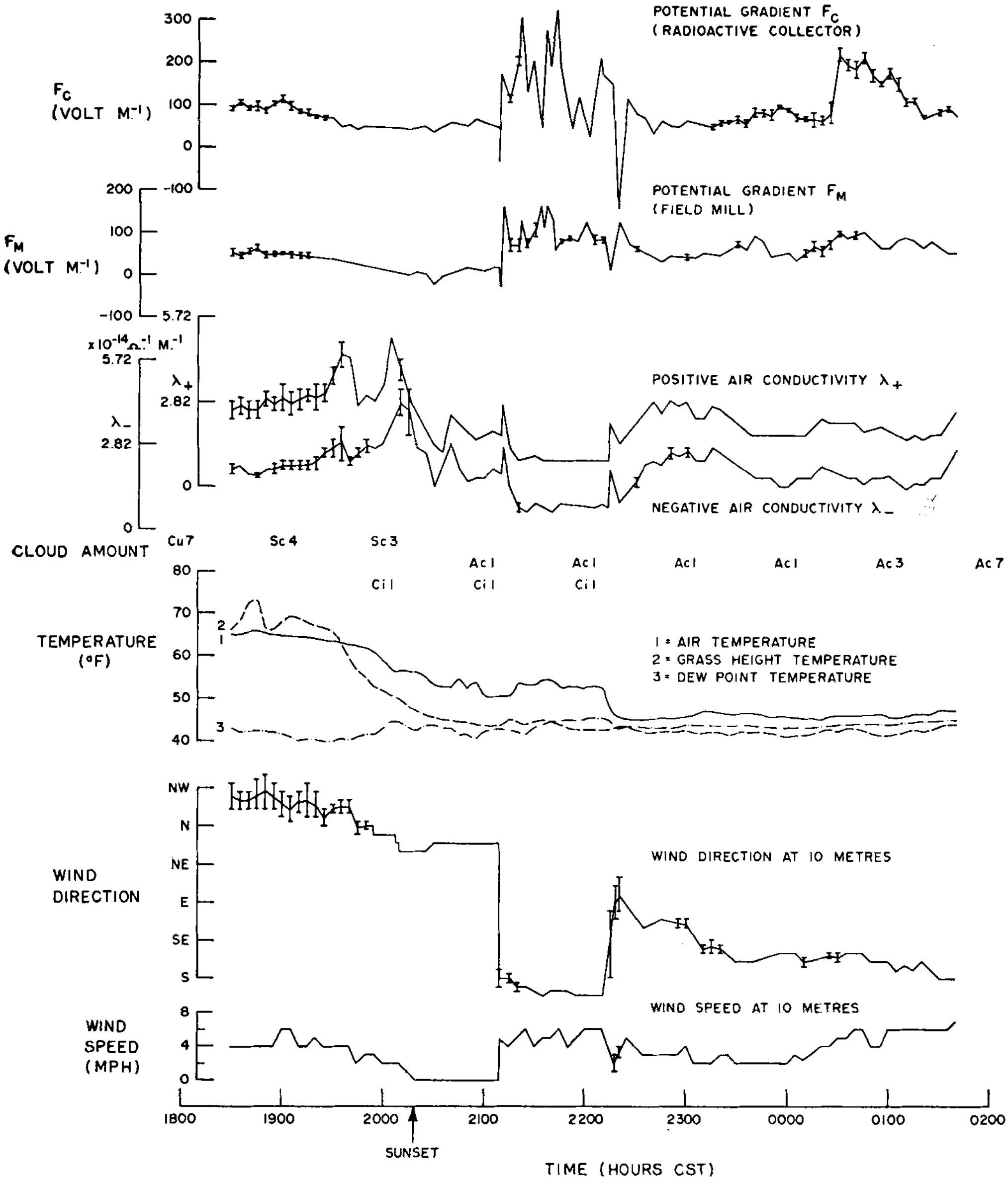

Fig. 3. Extensive disturbances in atmospheric electric parameters on night of 22–23 August, 1966 (error bars at any instant of time indicate the fluctuation in values at the same instant).

λ_2 = negative air conductivity,
$\lambda = \lambda_1 + \lambda_2$ = total air conductivity,
and ϱ = space charge density.

The conductivity of the air

$$\lambda = \int_{k1_{(a)}}^{k1_{(b)}} n_{1(k)} e dk + \int_{k2_{(a)}}^{k2_{(b)}} n_{2(k)} e dk + \int_{K1_{(a)}}^{K1_{(b)}} N_{1(K)} e dK + \int_{K2_{(a)}}^{K2_{(b)}} N_{2(K)} e dK$$

the last two terms are more appropriately represented by summation terms over the mobility "line-spectra" range (Israël & Schulz, 1932) but a mean mobility $K_{1(m)} = K_{2(m)} = 4 \times 10^{-4}$ cm^2.volt^{-1}.sec^{-1} is typical.

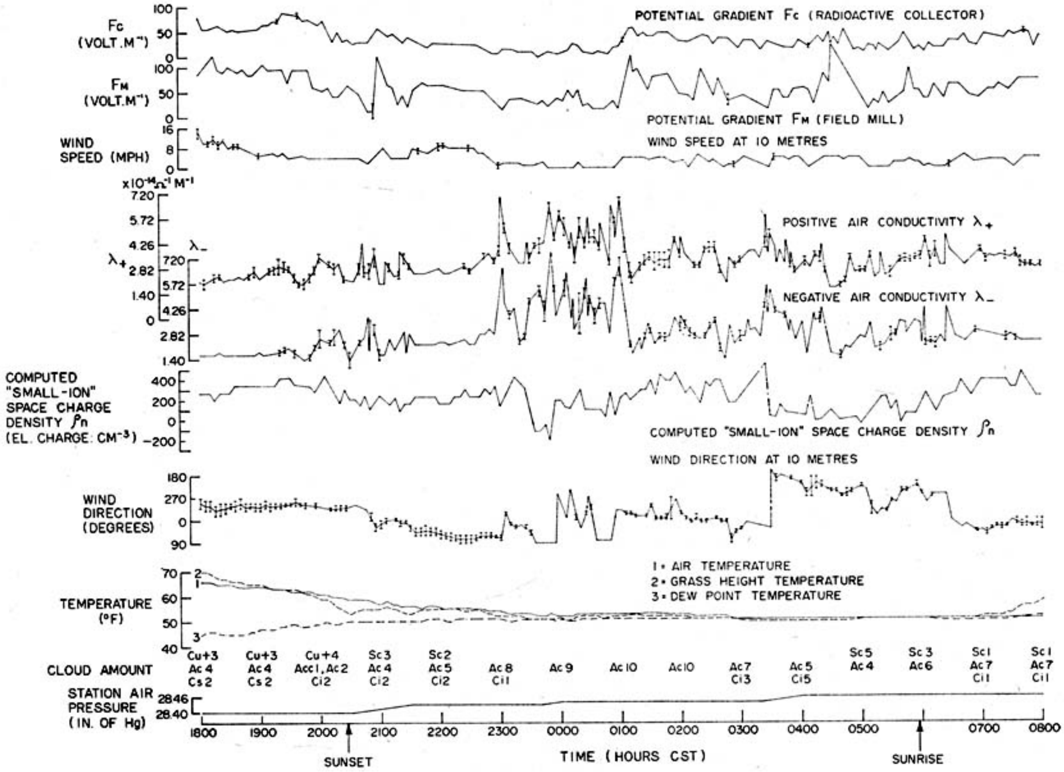

Fig. 4. Atmospheric electric parameters on night of 18–19 August, 1966 (error bars at any instant of time indicate the fluctuation in values at the same instant).

Hogg (1936), from measurements in the free atmosphere, obtained sampling distributions of $n_{1(k)}$, $n_{2(k)}$ and their limits $k_{1(a)}$, $k_{1(b)}$, $k_{2(a)}$, $k_{2(b)}$. It will be assumed, however, that

$$\int_{k_a}^{k_b} n_k e dk = nek_m$$

where k_m = mean mobility.

According to Hogg,

$k_{1(m)} = 1.29$ cm² volt⁻¹ sec⁻¹,
$k_{2(m)} = 1.40$ cm² volt⁻¹ sec⁻¹.

These values are in some disagreement with those obtained in laboratory studies by Bricard (1965), but will be used for present purposes.

Also, the assumptions are made that only singly charged ions are involved and that $k_{1(m)}$, $k_{2(m)}$, $K_{1(m)}$, $K_{2(m)}$ remain constant in value. The validity of these assumptions is not known; Chalmers (1957) has discussed the problem of multiply-charged ions and Hogg (1936) and Misaki (1961) have experimented on the variation of mobility with meteorological conditions. Now,

$$\lambda_1 = e\,(n_1 k_{1(m)} + N_1 K_{1(m)})$$

or

$$n_1 = \frac{(\lambda_1 - N_1 K_{1(m)})}{ek_{1(m)}} \tag{1}$$

and similarly,

$$n_2 = \frac{\lambda_2 - N_2 K_{2(m)}}{ek_{2(m)}} \tag{2}$$

Also, $$\varrho = e(N_1 - N_2) + e(n_1 - n_2) \tag{3}$$

From (1), (2) and (3),

$$\varrho = e(N_1 - N_2) + \left(\frac{\lambda_1}{k_{1(m)}} - \frac{\lambda_2}{k_{2(m)}}\right) + e\left(\frac{N_2 K_{2(m)}}{k_{2(m)}} - \frac{N_1 K_{1(m)}}{k_{1(m)}}\right)$$

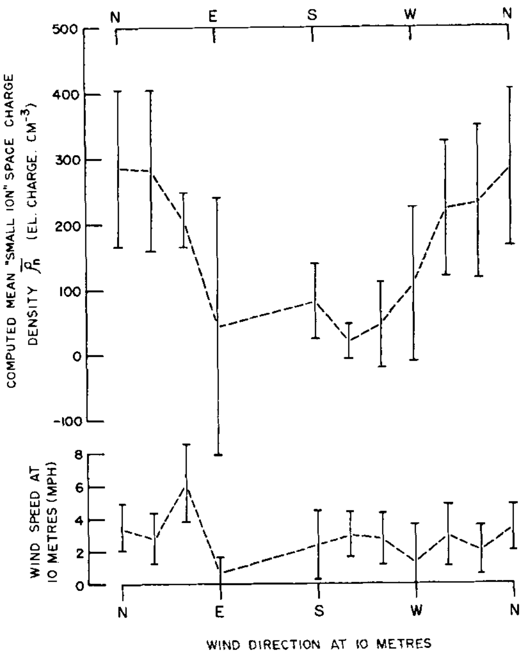

Fig. 5. Variation of computed mean "small-ion" space charge density and its standard deviation with 10-metre wind velocity on night of 18–19 August, 1966.

Let $N_2 = N_1 - \Delta N$.

Then,

$$\varrho = e\Delta N\left(1 - \frac{K_{2(m)}}{k_{2(m)}}\right) + \left(\frac{\lambda_1}{k_{1(m)}} - \frac{\lambda_2}{k_{2(m)}}\right) + eN_1\left(\frac{K_{2(m)}}{k_{2(m)}} - \frac{K_{1(m)}}{k_{1(m)}}\right) \quad (4)$$

Substituting the appropriate numerical values in (4),

$$\varrho = e\Delta N\left(1 - \frac{4\times 10^{-4}}{1.4}\right) + \left(\frac{\lambda_1}{1.29} - \frac{\lambda_2}{1.40}\right) + eN_1\left(\frac{4\times 10^{-4}}{1.40} - \frac{4\times 10^{-4}}{1.29}\right)$$

$$\approx e\Delta N + \left(\frac{\lambda_1}{1.29} - \frac{\lambda_2}{1.40}\right) - eN_1(2\times 10^{-5}) \quad (5)$$

The last term in (5) only becomes significant when $N_1 > 10^4$, a condition which could be satisfied in or close to large industrial cities (Israël & Schulz, 1932). For Saskatoon, (5) can be approximated further to

$$\varrho = e\Delta N + \left(\frac{\lambda_1}{1.29} - \frac{\lambda_2}{1.40}\right) \quad (6)$$

A "small-ion" space charge density ϱ_n was calculated by assuming that a quasi-static balance of large ions existed such that $\Delta N = 0$.

Then, $\varrho_n = e(n_1 - n_2)$

$$= \left(\frac{\lambda_1}{1.29} - \frac{\lambda_2}{1.40}\right) \quad (7)$$

Equation (7) was used to calculate an experimental value of ϱ_n. At 5-minute intervals between 2000 and 0600 hrs. CST, λ_1 and λ_2 were measured off from the recordings of conductivity with a time constant of 200 sec. ϱ_n was calculated from equation (7). The wind direction was read off to the nearest 30 degree interval at the same 5-minute intervals. The results were tabulated and for each wind direction, the mean of the space charge density $\bar{\varrho}_n$ and its standard deviation were calculated and plotted against the wind direction. The results for this date (Fig. 5), showed that space charge density $\bar{\varrho}_n$ was nearly constant in the directions *NW* to *NE* but gradually fell off to smaller or even negative values in the other directions. Looking at the map of the region (Fig. 1), the segment *NW* to *NE* appeared to be the only direction in which little or no human activity was present. This seemed to suggest that the value $(N_1 - N_2)$ assumed to be zero might not even be a constant but might vary with horizontal direction.

Alternatively, the directional change in ϱ_n might be due to an ionization imbalance due to stratification of air beneath an inversion layer. Moses, Stehney & Lucas (1960) and Peerson & Moses (1966) found large concentrations of radon emanations from the ground unevenly mixed at the air-earth interface during strong temperature inversions and the associated light winds. The conditions of the night of 18–19 August seemed to indicate a weak inversion so that it was possible to envisage intermittent build up of emanations dependent on the wind speed. (The behaviour of λ_1 and λ_2 with wind speed somewhat attested to this.) If, then, wind speed happened to be, on this occasion, a function of wind direction, the imbalance could conceivably be directional and could be the cause of the observed variation of ϱ_n with wind direction. To test this hypothesis, mean wind speeds and their standard deviations were plotted against wind direction for the same 5-minute intervals previously chosen (Fig. 5). No obvious directional effect of wind speed could be determined. Thus either the directional variation of ϱ_n along the horizontal was real or a directional imbalance of large ions was present.

5. Discussion

In Section 4.3, it must be admitted that the calculation of ϱ_n from λ_1 and λ_2 was likely to be considerably in error; the many assumptions made detract from the strength of the results and conclusions. Also, the peculiar results might be attributable to cloud charges. However, considering the observations of Section 4.1 and 4.2, it was felt that the directional anisotropy of space charge or of large ions was real and probably of human origin.

6. Conclusions

Experimental observations of the potential gradient (F) and the electrical conductivity (λ) of the air at Saskatoon showed that local generators were an important factor affecting the atmospheric electric state at night. In the first example presented, a shift in wind direction over a period of 20 min was clearly marked in the records of F and λ. These changes were thought to be due to the presence of large ions from local generators in the town brought over thestation by the wind. A second record showing more extensive disturbances in F and λ over the period of several hours was visually observed to be related to smoke from the town drifting over the station. The third example was of readings which showed potential gradient well correlated with wind speed over the period of a night. However, a rough calculation showed that either the space charge density was dependent on the wind direction or sources of large ions were affecting readings over 270 degrees of a 360 directional circle. The direction of the sources was well related to those of regions of human activity.

The results illustrated were a sample of those obtained under night-time conditions when it would seem that the presence of an inversion might play a large part in diffusion patterns from generators. It would be of interest to discover if other stations near large towns or cities have observed such directional effects.

Acknowledgements

The authors wish to thank the Institute of Space and Atmospheric Studies for the loan of much of the equipment and the use of facilities at the Radio Experimental Station. A grant from the Meteorological Service of Canada provided financial assistance for the project.

REFERENCES

Brasefield, C. J. 1959. Some observations of low-level ion clouds. *J. Geophys. Res. 64*, 2, 141–148.

Bricard, J. 1965. Action of radioactivity and of pollution upon parameters of atmospheric electricity. *Problems of atmospheric and space electricity*, p. 82–117 (ed. S. C. Coroniti). Elsevier Press.

Chalmers, J. A. 1957. *Atmospheric Electricity*, p. 74. Pergamon Press.

Dolezalek, H. 1958. Problems in atmospheric electric synoptic investigations. *Recent Advances in Atmospheric Electricity*, p. 195–212 (ed. L. G. Smith). Pergamon Press, London.

Hogg, A. R. 1936. The mobility of the small ions of the atmosphere. *Gerlands Beitr. Geophys. 47*, 31–59.

Israël, H. 1957. Atmospheric electric and meteorological investigations in high mountain ranges. *Final Report, Air Research and Development Command, USAF*, Contract AF 61 (514)–640.

Israël, H. & Schulz, L. 1932. Über die Größenverteilung der atmosphärischen Ionen. *Meteor. Zeit. 49*, 226–233.

Misaki, M. 1961. Studies of the atmospheric ion spectrum. I. *Papers in Met. and Geophys., XII, 3–4*, 261–276.

Moses, H., Stehney, A. F. & Lucas, H. F. 1960. The effect of meteorological variables upon the vertical and temporal distributions of atmospheric radon. *J. Geophys. Res., 65, 4*, 1223–1238.

Mühleisen, R. 1958. The influence of water on the atmospheric electrical field. *Recent advances in Atmospheric Electricity*, p. 213–221 (ed. L. G. Smith). Pergamon Press, London.

Pakiam, J. E. & Johnson, D. W. 1967. The effects of particle radiation from a disturbed sun on atmospheric electricity. *Canadian J. Phys. 45*, 1337–1351.

Pearson, J. E. & Moses, H. 1966. Atmospheric radon-222 concentration variation with height and time. *J. Appl. Met.*, *5*, *2*, 175–181.

Reiter, R. 1960. Das luftelektrische Erscheinungsnopbild des Südföhns in den Nordalpen nach Synoptisch klimatologischen Untersuchungen im Wettersteingebirge 1955 bis 1959. *Archiv Meteor. Geophysik Bioklimatologie*, A *12*, 72–124.

Whitlock, W. S. & Chalmers, J. A. 1956. Short-period variations in the atmospheric electric potential gradient. *Quart. J. Roy. Met. Soc.* *82*, 325–336.

НЕКОТОРЫЕ КОРОТКОПЕРИОДНЫЕ ЛОКАЛЬНЫЕ ЭФФЕКТЫ НАПРАВЛЕНИЯ ВЕТРА НА УРОВНЕ ЗЕМЛИ В САСКАТУНЕ

Экспериментальные наблюдения градиента потенциала и проводимости воздуха в Саскатуне показали, что направление ветра ночью может иметь заметное влияние на величины этих параметров. Приводятся два примера с хорошо выраженными эффектами и предполагается, что они имеют место благодаря влиянию искусственных «генераторов» заряда. Третий пример с более тонкими эффектами был проанализирован количественно, откуда был сделан вывод, что сегмент в 270° в полном круге направлений наблюдений подвергался влиянию локальных генераторов.