# MEASUREMENT OF WORLDWIDE DIURNAL ATMOSPHERIC ELECTRICITY VARIATIONS

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ABSTRACT

An evaluation is made of techniques that have been or could be employed to determine the existence and nature of worldwide variations in atmospheric electric phenomena. In the course of a discussion of surface measurements, data from six sites on the surface of the earth are presented. The use of airborne vehicles in studies of global phenomena is discussed and results from soundings and transits are presented. It is concluded that the use of instrumented aircraft is potentially the most promising technique to use, but that the expenditure of more care and effort than has been employed in the past is required if this potential is to be realized.

## 1. INTRODUCTION

One prime objective in atmospheric electricity research is the separation of observed variations in the measured parameters into phenomena that are local in nature and those that are global in scope and effect. Whipple's [15] correlation between estimated thunderstorm activity and long-term averages of electric field recordings obtained aboard the *Carnegie* has for many years been the norm against which subsequent studies have been evaluated even though the data upon which these correlations are based were admitted to be less than perfect. The curves of hourly average electric fields measured aboard the *Carnegie* are shown with Whipple's thunderstorm estimate in figure 1. There has, in fact, been a subtle tendency toward the use of a form of circular logic in that Whipple's curve has been tacitly used to separate valid from invalid observations, good from poor instrument sites, and fair from non-fair weather conditions. In the light of these factors, an effort was initiated at the Naval Research Laboratory (NRL) to evaluate the numerous schemes that have been used or proposed to obtain data from which worldwide variations could be deduced.

Any measurement that purports to provide an output containing global variations in atmospheric electric activity must, obviously, be made either at the earth's surface or in the atmosphere through the use of some airborne vehicle. The following discussion is, therefore, divided into analyses of measurement techniques that can be employed at the surface and of those that employ airborne vehicles. Surface measurements may be further divided into three categories on the basis of the instrument site employed: land-based sites selected primarily on grounds of convenience, accessibility, or availability; shipboard installations that provide a continuously moving site always located in a marine environment; and, thirdly, carefully selected sites such as the polar ice caps at which local effects might be sufficiently small to allow global phenomena to appear in the direct data recordings without the use of averaging techniques.

Global variations can conceivably be seen in a variety of measurements. As mentioned, a repeatable pattern was first seen in hourly averages of the electric field measured at the surface of the earth. A global phenomenon caused by diurnal variations in charging processes should be seen also in measurements of the potential difference between the earth and the upper atmosphere and of the total current flux between these two. Every technique that has been proposed for the measurement of global electrical effects can be shown to be an attempted measurement of field, potential, or total flux. There are also, of course,

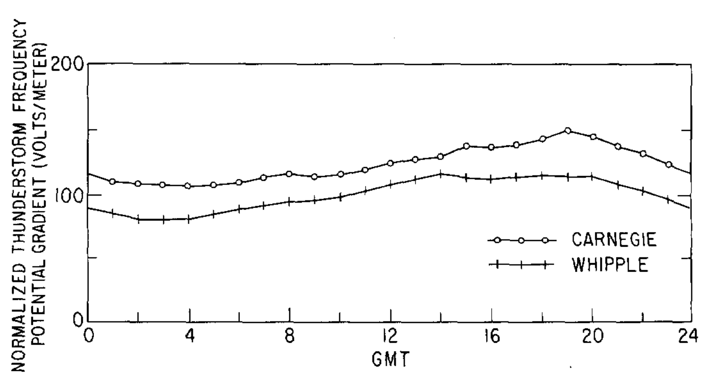


FIGURE 1.—Diurnal variation of potential gradient and of thunderstorm frequency given by Whipple [15].

many ideas for estimating total thunderstorm activity; but, since these do not involve electrical phenomena, they are outside the scope of this discussion.

## 2. SURFACE MEASUREMENTS

By far the greatest amount of effort in atmospheric electricity research has been expended at sites of the first type. NRL maintained stations consisting of a field mill [5] and a Gerdien conductivity meter [1] in continuous operation in the Shenandoah National Park during 1954–1956, and from 1957 to 1962, at Argentia, Newfoundland; Lakehurst, N.J.; Washington, D.C.; Norfolk, Va.; and Pensacola, Fla.

The data from these stations [3, 14] have been reduced to seasonal hourly average values which are shown for the four seasons in figures 2–5. Yearly hourly averages for the individual stations are shown together in figure 6, and a composite hourly average plot for all the data from all the stations is given in figure 7. Two facts can be readily deduced from these data: a variation pattern roughly similar to that seen in figure 1 is present, and the quality of this curve varies widely from station to station. In this connection, it is worth noting that both the Washington, D.C., and the Norfolk, Va., stations were located in regions frequently dominated by manmade pollution of an extremely local nature.

The prevalence of local pollutants at most sites in populated land areas leads naturally to the idea of seagoing and selected instrument locations. An analysis of electrical phenomena at such locations raises serious doubts, however, whether there is an improvement in the quality of the data that even approaches in value the increased difficulties inherent in the use of such sites. There are at least two major sources of non-global phenomena that will not be eliminated by site selection or data averaging. The first of these is the effect of the mechanical transport of charge by turbulent atmsopheric motion on measurements made at the surface. Kraakevik [12] has shown that such a current comparable in magnitude to the conduction current does exist in the mixing region. The direct measurement of total current flow has been employed in an attempt to include the mechanically borne component of the total flux, but it has been relatively unsuccessful probably because of the difficulty in achieving proper matching of the antenna to the atmosphere caused by the interrelations between terrain and instrument geometry, electrode layer formation, and atmospheric micro turbulence. Data obtained at the Shenandoah Park site indicate that true antenna matching factors [11] can, in extreme cases, range between one half and twice the indicated values.

Since the foregoing comments are equally applicable to all instrument sites on the earth's surface, whether selected or not, it is not surprising that the averaging of several years' worth of observations is necessary to obtain any sort of universal curve; nor is it surprising that the

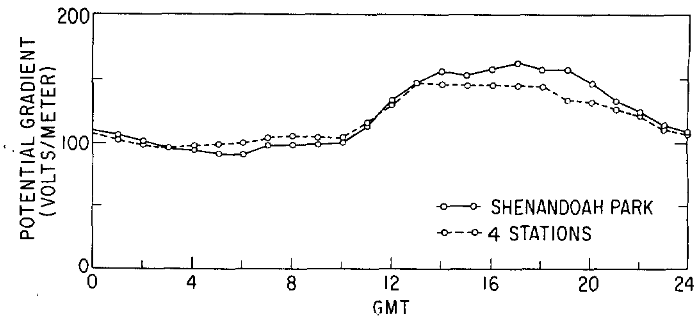


FIGURE 2.—Diurnal variations in potential gradient measured at NRL stations for spring months (March–May).

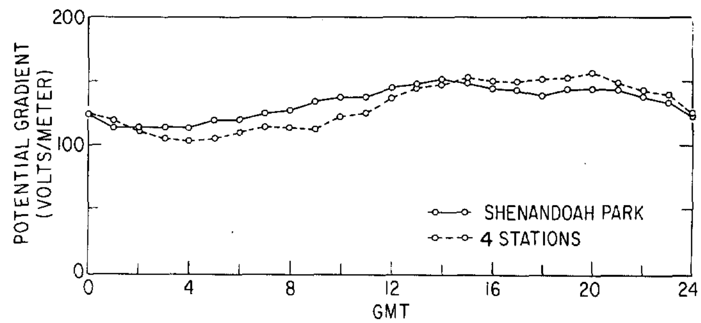


FIGURE 3.—Diurnal variations in potential gradient measured at NRL stations for summer months (June–August).

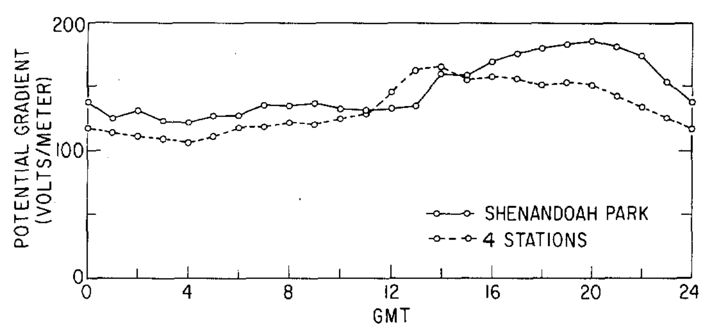


FIGURE 4.—Diurnal variations in potential gradient measured at NRL stations for autumn months (September–November).

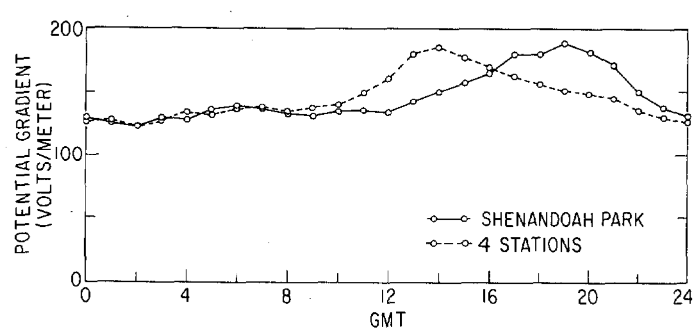


FIGURE 5.—Diurnal variations in potential gradient measured at NRL stations for winter months (December–February).

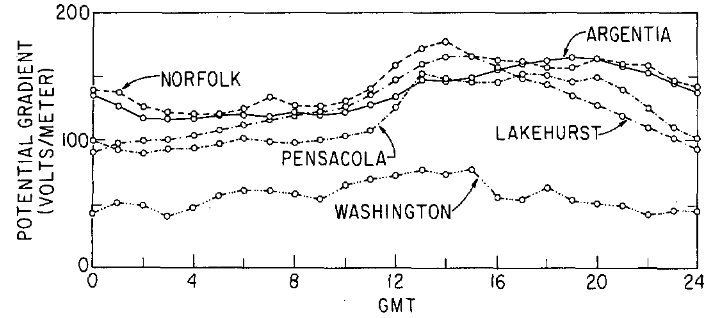


FIGURE 6.—All-season average hourly variations in potential gradient by location.

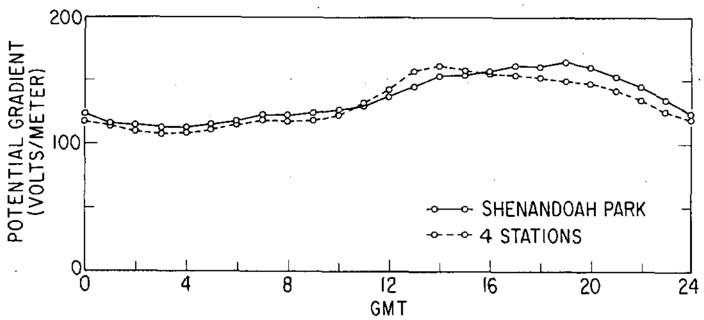


FIGURE 7.—All-season, all-station composite diurnal variation pattern.

agreement between stations in figure 6 is but fair. What is perhaps surprising is that there is any agreement at all. In conclusion it might be noted that the use of shipboard locations is subject to all the difficulties enumerated as well as the nearly insurmountable problem of obtaining a suitable reduction factor [6] and the enhanced electrode effect caused by the absence of ground radioactivity [13].

A final question that must be asked for any instrument site on the earth's surface is whether it is truly representative of both its region and of the entire global surface. It is, of course, possible for a site to be nonrepresentative and yet yield diurnal variation curves that have some validity, but any estimate of total global charge and/or current flux made from such data would be in error. Since no adequate criteria for representativeness now exist, this question must be answered experimentally through the use of many varied operating sites. It is obvious then that the use of instrumentation on the surface to deduce universal variations requires both the averaging of several years' data and the use of a multiplicity of stations however carefully and selectively they are located.

## 3. AIRBORNE MEASUREMENTS

The use of an airborne vehicle as a measuring platform from which to measure atmospheric electric parameters has many advantages most of which are well known to all investigators. In the present context, the chief advantages are (1) the ability to get above surface effects, local pollutants, and the turbulent mixing layer and (2) the mobility to operate in the most desirable areas such as over oceans, deserts, and other large plane surfaces. The disadvantages of using airborne vehicles are largely practical rather than scientific and include the procurement of suitable vehicles, the increased complexity of airborne instrumentation, the need to measure the effect of the vehicle on the measured parameters, and problems of logistics and supply. All of these are present in varying degrees with the use of any airborne vehicle be it a balloon, an aircraft, or a rocket.

Historically, the first airborne vehicle to be used in atmospheric electricity measurements is the balloon. The use of balloon radiosondes to measure electric field and atmospheric conductivity is by now familiar to all investigators, and little need be said about it except to point out the features of balloon operation that are pertinent to the measurement of universal diurnal variations. First, of course, is the fact that a sounding represents a reading at essentially a single point in time that requires, therefore, that many such flights be made in what then becomes a large long-term program. The effects of surface charge on the balloon and of the variation in size of the balloon with altitude may be minimized by the use of long attachment lines that support the instrument package, but there is no direct method by which the degree to which they are eliminated can be ascertained.

A balloon sounding of electric field must, typically, be integrated to obtain a value for the total potential between ground and the upper atmosphere in order to be useful in determining universal variations. A problem that then arises is due to the fact that the greatest number of data points are taken at high altitudes where the field is low and relatively slowly varying while there are but few points in the lowest 500–1000 m. in which is found the greatest variability and a large share of the total potential drop.

Balloon-borne instrumentation is seen, therefore, to be usable for the determination of the universal aspects of atmospheric electricity if a large-scale program utilizing many soundings and lasting for a considerable period of time is pursued. Implicit in this statement is the assumption that all problems of instrument interactions and calibration have been successfully resolved. Finally, there are conditions imposed by the necessities of launching and data telemetry that limit the use of balloon techniques to those locations where such facilities can be provided.

An instrumented aircraft as a vehicle for studies of global electrical effects has features which make its use attractive. The conducting skin and constant geometry of the airframe facilitate the procurement of repeatable valid data, and the nature of an aircraft as a vehicle inherently provides a flexibility and mobility that are difficult to achieve with any other system. Against this must be weighed the necessity of obtaining an accurate value for the geometric effect of the airframe on the field-sensing devices, the problem of vehicle self-charge, the size and spread of the aircraft, and the extensive logistics required to base, fuel, and maintain it. Also to be considered are the occasional problems encountered in obtaining clearances that permit the operations and maneuvers necessary to the data-gathering operation.

Gish [7] mentions the integration of potential gradient data from a balloon-borne instrument to obtain a value of potential for the upper atmosphere. Clark [4] subsequently sought to observe diurnal changes in total potential by using an aircraft to obtain several "profile" soundings repeated at intervals of a few hours in a carefully selected location. It was hoped to make seven profiles at intervals of 4 hr., thus spanning a complete day. Because, however, of logistical and operational problems beyond the control of the investigators, it was finally possible to obtain five profiles within a span of 15 days. It is obvious from this that these problems are indeed real and do reduce the potential effectiveness of the use of this method. It should be noted that each flight of the aircraft to an altitude of 6 km. will still yield only one data point as in the case of balloons.

Profile measurements of integrated potential were also used by Imianitov and Chubarina [8] who made approximately 150 ascents in 1958 near the cities of Leningrad, Kiev, and Tashkent. They concluded that the traditional "unitary" variation could not be observed in potentials integrated to 6 km. It would seem that this apparent lack of pattern might be due, at least in part, to the fact that all three sites employed were quite similar being populated areas of comparable longitude in the central Eurasian landmass. The effects of terrain and of local diurnal solar activity could easily be large enough to mask any global effects.

In addition, they made the assumption that "the variations in potential at 6 km. should duplicate the variations of the ionospheric potential," an assumption that has been found in general not to be valid. For example, Clark added to each measured value of 6-km. potential an increment derived by multiplying the measured total vertical current density by an incremental resistance calculated by extrapolating the actual observed high altitude exponential conductivity variations. It was found that neither the current density nor the extrapolated incremental resistance was at all constant since both depend strongly upon local conditions existing within the turbulent mixing region. Only by calculation of this incremental potential, which forms a significant fraction of the total, was even a semblance of a repeatable pattern obtained. Figure 8 shows the average diurnal variations measured by Imianitov and Chubarina at 6 km. and the single points measured by Clark.

In summary it may then be stated that the measurement of integrated potential using instrumented aircraft does hold a promise of providing data on global effects but that a much more extensive and ambitious effort is required than that employed by Clark while more care than shown by Imianitov and Chubarina must be exercised in site selection, data acquisition, and analysis. Consequently, the result of these considerations is again a rather extensive, long-term program. The use of a complete flight of an instrumented aircraft to obtain a single data point is both time consuming and an inefficient use of the aircraft.

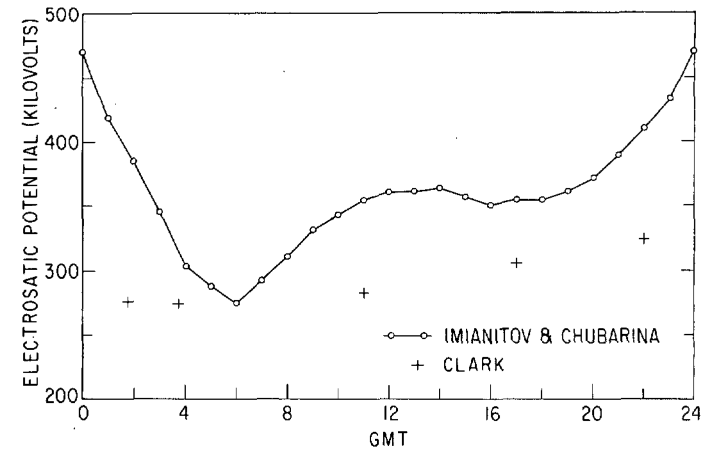


FIGURE 8.—Atmospheric potentials measured by Clark [4] and by Imianitov and Chubarina [8].

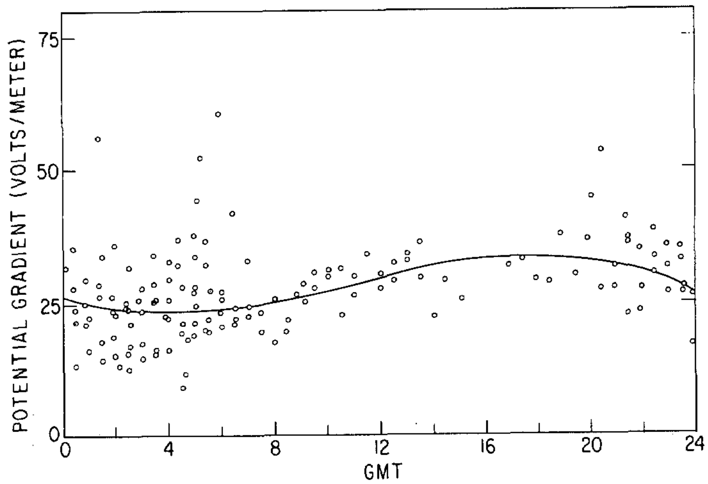


FIGURE 9.—Potential gradients measured during 43,000-km. round trip between Washington and Sydney.

There are two other techniques by which an instrumented aircraft may be employed to obtain data on global electrical phenomena. In a manner somewhat analogous to the use of ground-sited stations that are located on the basis of convenience, availability, or accessibility, it is possible to instrument transiting aircraft to make electrical measurements routinely as they go from place to place. To test this idea, routine measurements of electric field and conductivity were made at intervals of 30 min. or less with the instrumented NRL aircraft during a recent 43,000-km. round trip between Washington, D.C., and Sydney, Australia. In all, somewhat over 200 observations were made at whatever flight altitude happened to be assigned and in whatever weather was encountered. It should be noted that the assigned altitudes were always above the exchange layer and, in fact, were all between 2 and 3 km.

The record of the electric field measurements is shown in figure 9 in which each measured point is plotted on a 24-hr. scale as a dot and a "best fitting" smooth curve is shown as a solid line. The chief feature of this curve that is worthy of note is the almost total lack of any discernible pattern. Any global component of field variation is certainly not seen in these data.

In contrast, there is a similar plot for the current density computed from these measurements of field and the measured conductivity that is seen in figure 10. A definite bi-modal pattern is discernible with maxima at about 1200 and 2000 GMT and minima at 0200 and 1630 GMT. Since these points represent data taken in daylight and at night, at longitudes from 76°W. to 135°E., and in latitudes from 38°N. to 45°S., it is highly unlikely that all of the observed variations are due to some local phenomenon. The lack of pattern seen in the conductivity data from these flights, which is shown in figure 11, demonstrates that the variation is truly one of current density.

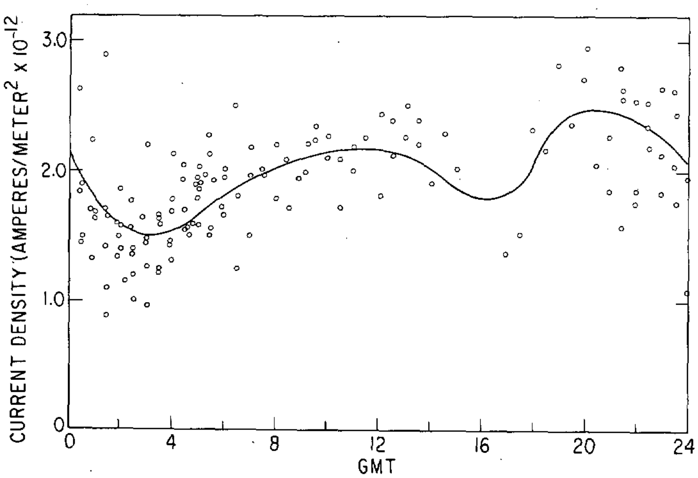


FIGURE 10.—Computed current densities obtained on Washington-Sydney trip.

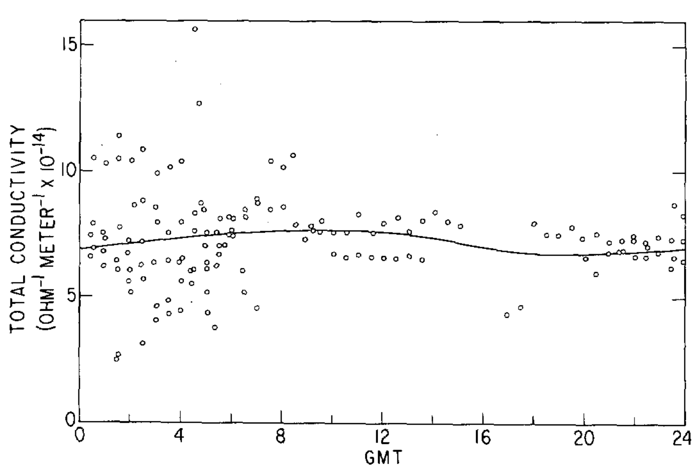


FIGURE 11.—Total atmospheric conductivity measurements from Washington-Sydney trip.

The value of using computed current density measured at altitudes above the turbulent mixing layer that is apparent from comparison of figures 9 and 10 stems from three considerations [2]. The first two of these are the absence of appreciable quantities of space charge at such altitudes and the relative lack of vertical air currents and/or turbulence. The result of these two facts is a complete lack of mechanically transported charge which then, with the equation of continuity, requires that the entire current flow between the earth and the upper atmosphere be ohmic in character. The third consideration is a contribution to the ease and accuracy of measurement through the relative absence of particulates, pollutants, and hydrometeors.

Another suggested use of airborne vehicles involves measurements made for an extended period of time from an aircraft or a ballon at a constant high altitude [10]. With a balloon, the investigator has no control over the location of the instrument package while this control can be complete when an aircraft is used. Consideration of the results shown in figures 9–11 indicates that current density is still the preferable parameter although the measurements of field would tend to have a greater significance under the rather idealized conditions of constant altitude, constant position, and constant weather. Since an operating area can be chosen that is far removed from the effects of human activity and of terrain and since the operation can be conducted during periods of perfect weather, it should be possible to obtain data that show nothing but temporal variations caused by large-scale phenomena.

In the light of these considerations, an attempt is being made at NRL to exploit this technique. It is felt that if two or three series of flights covering the entire 24-hr. day are conducted in widely different portions of the earth under uniformly ideal weather conditions, any agreement between the resultant data curves must be of universal origin. One such series has been made near the Australian coast. Preliminary analysis of the data shows excellent self-consistency and a bi-modal distribution quite similar to that in figure 10. Any further discussion of this technique must await final analysis of these data and the completion of measurement series in other locations.

## 4. CONCLUSIONS

Several salient facts become apparent from the foregoing discussion. The first and one of the most important is that future work in this field must be based on the expenditure of appreciably more care and effort than have been used in past investigations. The value of many investigations has been greatly diminished by the use of inadequate techniques and gratuitous assumptions and by premature termination of the effort.

It is also seen that any observations made at locations on the surface of the earth have a somewhat dubious value. Although some agreement can be seen between stations in figure 6, there are also significant disagreements. The same can be said for the records published from other stations [9]. It is further seen that although some degree of selection is of benefit in site location, the use of exotically placed instrumentation does little to eliminate the basic problems inherent in surface measurements since the effects caused by mechanically transported charge, terrain, electrode layers, and turbulence exist in some degree at all surface sites and can have an influence comparable in magnitude to variations that are global in scope.

The use of soundings to obtain data from which integrated potentials may be derived would seem to require an effort of such magnitude as to make them impractical. The problems experienced in deriving a reliable smooth curve from a scatter of data points would require a great number of soundings even if no discrepancies or anomalous effects were experienced. Even the more than 200 points in figure 10 are really inadequate to provide a good curve.

The use of instrumented transiting aircraft must be limited to aircraft that are instrumented for the measurement of both field and conductivity. Present field measuring instruments are not sufficiently sensitive to provide data at high altitudes without the use of precision banking of the aircraft, and theoretical considerations of instrument noise make it doubtful whether such apparatus can be developed. It would therefore seem that this technique would be restricted to use when research aircraft under the control of scientific personnel are available.

The measurement of current density by an instrumented aircraft flown at a constant altitude over a large body of water in perfect weather, therefore, appears to be a promising technique. It requires a considerable expenditure of effort and time for its accomplishment, but much less than if the same objective were to be accomplished by soundings. A further evaluation of the use of this technique must await the completion of the data collection and analysis processes.

Finally it must be reiterated that all atmospheric measurements are necessarily statistical in nature. An appreciable fluctuation is found to exist in even the best data recordings. Fluctuations of the order of 10 percent were observed within time spans of 3 to 5 min. while taking the data shown in figures 9–11 and could not be attributed to instrumental noise. Since the production of a smooth 24-hr. curve probably requires data at 15-min. intervals and since two or more points are seen to be required at each such point in time to insure confidence in the results, it is obvious that a minimum of several hundred observations are needed.

In conclusion, therefore, it can be stated that although airborne measurements can offer more than observations made within the turbulent mixing layer near the ground, they require a greater investment in time and facilities to exploit. A "final" answer to the nature of global electrical phenomena will probably, therefore, be based on a body of carefully measured airborne data that have been weighed against the extensive body of data obtained at surface locations in such a manner as to provide a self consistent, cohesive entity.

## REFERENCES


1. R. V. Anderson, "The NRL Semiautomatic Atmospheric Electricity Station," *NRL Report* 5787, Washington, D.C., June 1962, 21 pp.
2. R. V. Anderson, "Measurements of Total Current Density Above Active Snowstorms," *Journal of Atmospheric and Terrestrial Physics*, vol. 28, No. 8, Aug. 1966, pp. 789–793.
3. R. V. Anderson and E. M. Trent, "Measurements of Atmospheric Electric Conductivity and Field in the Shenandoah National Park, Virginia," *NRL Report* 5983, Washington, D.C., July 1963, 93 pp.
4. J. F. Clark, "The Fair-Weather Atmospheric Electric Potential and Its Gradient," *Recent Advances in Atmospheric Electricity*, L. G. Smith (Editor), Pergamon Press, New York, 1958, 631 pp. (see pp. 61–73).
5. S. G. Gathman and R. V. Anderson, "Improved Field Meter for Electrostatic Measurements," *Review of Scientific Instruments*, vol. 36, No. 10, Oct. 1965, pp. 1490–1493.
6. S. G. Gathman and E. M. Trent, "Absolute Electric Field Measurements Using Field Mills," *NRL Report* 6538, Washington, D.C., Apr. 1967, 8 pp.
7. O. H. Gish, "Evaluation and Intrepretation of the Columnar Resistance of the Atmosphere," *Terrestrial Magnetism and Atmospheric Electricity*, vol. 49, No. 3, Sept. 1944, pp. 159–168.
8. I. M. Imianitov and E. V. Chubarina, "The Structure and Origin of the Atmospheric Electric Field," *Studies of Clouds, Precipitation, and Thundsrstorm Electricity*, N. I. Vul'fson and L. M. Levin (Editors), transcribed and published by American Meteorological Society, Boston, Feb. 1965, pp. 257–268.
9. H. Israel, *Atmosphärische Elektriziät*, Teil II [Atmospheric Electricity, Part II], Akademische Verlagsgesellschaft, Leipzig, 1961, 503 pp. (see pp. 41–53).
10. H. W. Kasemir, "Zur Strömungstheorie des Luftelektrischen Feldes," [On the Current Theory of the Atmospheric Electric Field], *Archiv für Meteorologie, Geophysik und Bioklimatologie*, Wien, vol. 3, Series A, 1951, pp. 84–97.
11. H. W. Kasemir and L. H. Ruhnke, "Antenna Problems of Measurement of the Air-Earth Current," *USASRDL Technical Report* 2022, Fort Monmouth, N.J., Apr. 1959, 19 pp.
12. J. H. Kraakevik, "Measurements of Current Density in the Fair Weather Atmosphere," *Journal of Geophysical Research*, vol. 66, No. 11, Nov. 1961, pp. 3735–3748.
13. R. Mühleisen, "Electrode Effect Masurements Above the Sea," *Journal of Atmospheric and Terrestrial Physics*, vol. 20, No. 1, Feb. 1961, pp. 79–81.
14. E. M. Trent and R. V. Anderson, "Data From a System of Atmospheric Electricity Stations," *NRL Report* 6162, Washington, D.C., May 1965, 397 pp.
15. F. J. W. Whipple, "On the Association of the Diurnal Variation of Electric Potential Gradient in Fine Weather With the Distribution of Thunderstorms Over the Globe," *Quarterly Journal of the Royal Meteorological Society*, vol. 55, No. 229, Jan. 1929, pp. 1–17.


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