Atmospheric Electricity Measurements at Five Locations in Eastern North America

R. V. Anderson and Eva Mae Trent

Naval Research Laboratory, Washington, D. C.

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1. Introduction

The Naval Research Laboratory has maintained an atmospheric electricity research station in the Big Meadows area of the Shenandoah National Park near Luray, Va., since 1954. This location was chosen because prevailing winds at the site did not cross populated and/or industrialized regions but rather swept across sparsely populated areas of West Virginia, Kentucky and Tennessee. In addition, the existence of a large drop in elevation immediately to the west of the site forces an appreciable uplift to occur which has the result of providing an orographic cleansing of the air. It might be noted additionally that this assumption has been borne out in various measurements of contaminants (such as Aitken nuclei) at the site.

During much of this time, automatic instrumentation (Anderson, 1962) has been in operation which has provided continuous recordings of electric field and atmospheric conductivity. A report has been published which gives tabular listings of the measured parameters for a 2-year period, 1955 and 1956 (Anderson and Trent, 1963).

Similar instrumentation has also been installed at Naval Stations in Argentia, Newfoundland; Lakehurst, N. J.; Norfolk, Va.; and Pensacola, Fla., in connection with an investigation into the use of such instrumentation in fog forecasting (Anderson and Trent, 1966). Tabular listings of data obtained at these stations have been published for a 4-year period, 1958–1961 (Trent and Anderson, 1965). Since these stations are reasonably well separated geographically and are located in a wide variety of environmental settings, an analysis has been made of the raw data tabulations to compare and contrast the results. It is felt that any variations which are found to be common to all locations must represent the effects of large-scale phenomena which may be of global significance.

The Lakehurst, Norfolk and Pensacola stations are located on flat coastal plains in areas characterized by some degree of industrial activity. Lakehurst is not far

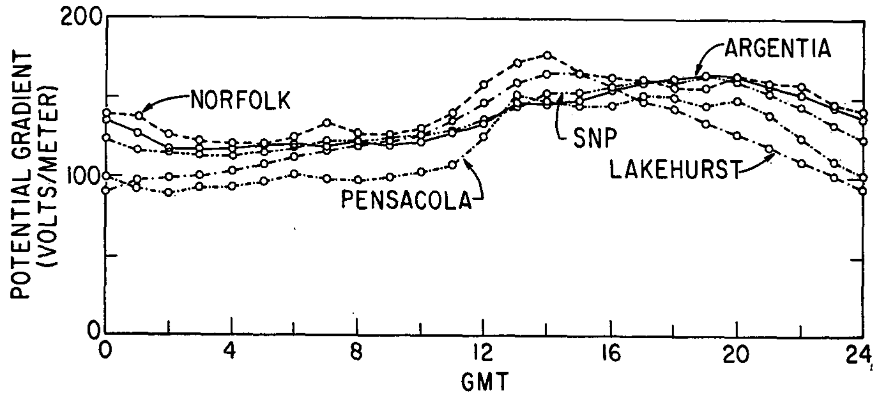

FIG. 1. Hourly average potential gradient curves for five stations: Shenandoah National Park (SNP) 1955–1956; others 1958–1961.

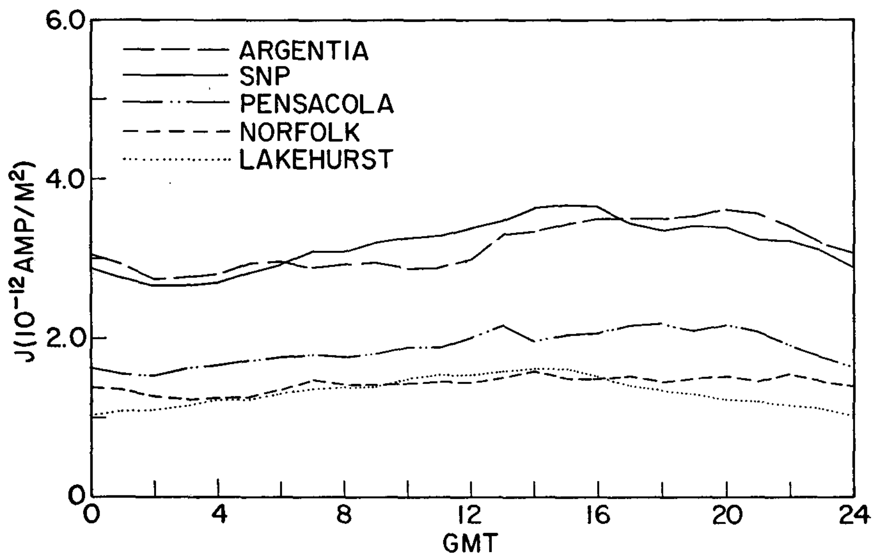

FIG. 2. Same as Fig. 1 except for current density.

from the immense New York industrial complex even though it is a small, relatively isolated town. The Norfolk station was located in the midst of that burgeoning center of shipping and manufacturing, and Pensacola has a large paper mill and chemical plant. The other two stations were located in sparsely populated regions far from any industrial activity. Argentia is dominated by water and rocky hills, although the instrumentation was located on a flat tract near sea level which is roughly of the order of 5–10 km square. The Big Meadows site is relatively flat, grassy, and about 3 km in diameter and is surrounded by dense forest. A fairly abrupt drop in elevation of 1000 m occurs upwind beyond the forested belt. It is seen, therefore, that three of the locations can be said to be quite typical of what is to be found in a modern industrialized nation, while the other two are representative of what can be found in an uncontaminated region.

The data recordings were averaged over 1-hr intervals, subtracted from automatically determined zero indices, and then multiplied by the appropriate calibration constants prior to their inclusion in the tabulated listings. The data are accurate to within ±10% on an absolute basis and have a precision 2–3 times better than this. Complete meteorological observations were made routinely at each of the Naval Stations on an hourly basis; no such data are available for the Shenandoah National Park (SNP).

Since these data have the same fluctuations that are common to most recordings of atmospheric electric parameters, the individual tabulated readings were reduced to hourly averages for this analysis. Such average values were computed from the tabular readings of field, total conductivity, and computed conduction current density. These computed average values were then plotted on uniform coordinates as functions of universal time. The remainder of this discussion consists of the presentation and analysis of these curves.

2. Data

The question has arisen whether electric field or current density is the more appropriate parameter to use when examining data for patterns of universal behavior. Although this question is generally resolved in favor

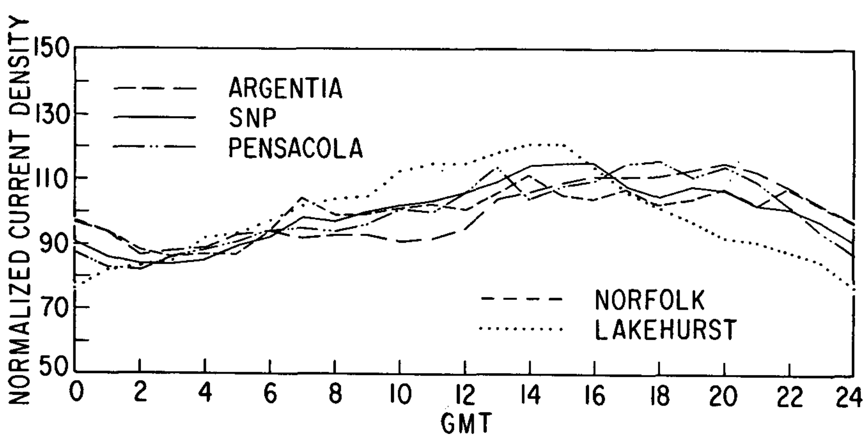

Fig. 3. Normalized potential gradient curves for five stations: Shenandoah National Park (SNP) 1955–1956; others 1958 through 1961.

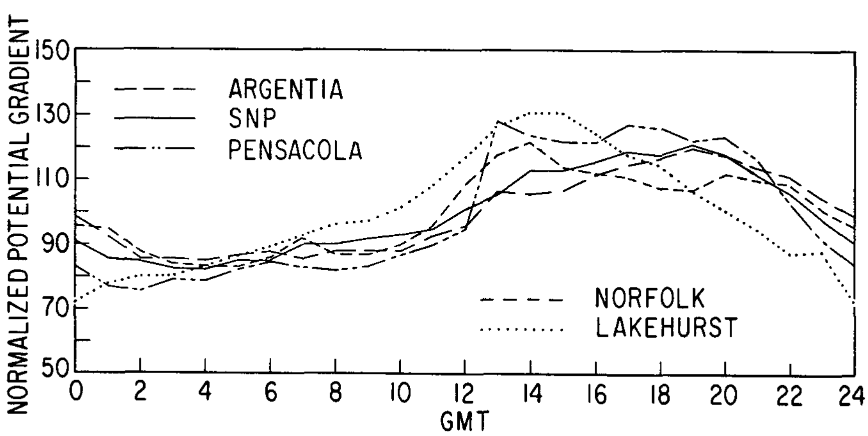

Fig. 4. Same as Fig. 3 except for current density.

of current density, no such *a priori* assumption was made in this study in order to make available another independent analysis of the question. Consequently, hourly average values of potential gradient are plotted in Fig. 1 for each of the five stations and corresponding values of current density are shown in Fig. 2. It is obvious that the potential gradient averages about 130 V m^{-1} at all stations while the average computed current density is markedly different from station to station. In order to provide a more accurate comparison of the daily variation in these curves, these data have been replotted in Figs. 3 and 4 normalized to their mean values. Since a significant difference in the magnitude of the current density between the three polluted air locations and the two with clean air was seen in Fig. 2, the data from stations within each category were combined and are shown in Figs. 5 and 6 as clean air and polluted air values of normalized potential gradient and current density, respectively. Since with one exception which will be discussed in the next section, there are no significant differences between normalized data curves from clean and polluted air stations, the two curves in Figs. 5 and 6 have been combined into one and are plotted in Fig. 7 to give a direct comparison of the variation patterns in potential gradient and in current density.

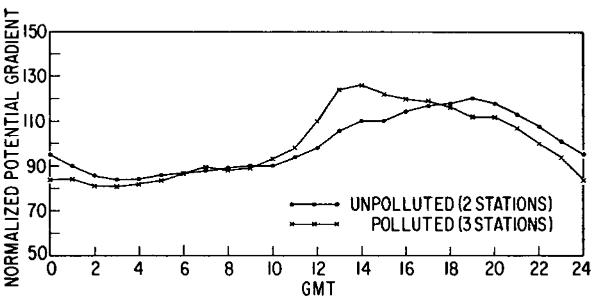

FIG. 5. Normalized potential gradient at clean and polluted locations.

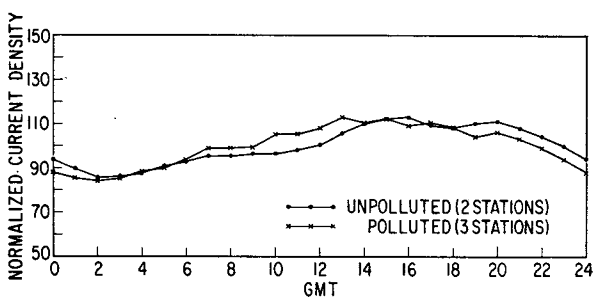

FIG. 6. Normalized current density at clean and polluted locations.

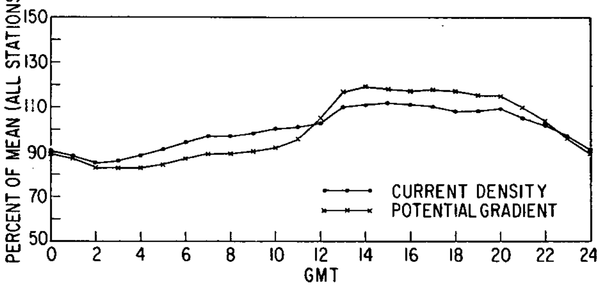

FIG. 7. Five-station averages of normalized potential gradient and current density.

3. Discussion

The first question which should be answered in an analysis of a body of data such as this is whether there are any obvious local phenomena which have had an observable effect on the measurements. One such phenomenon is observed in the peak in potential gradient observed between 1200 and 1500 GMT at the three industrialized sites. These hours constitute the morning "rush hour" in which extraordinarily heavy vehicular traffic is coupled with the firing of boilers and the starting of industrial machinery and processes. The local nature of this anomaly becomes more apparent when it is noted that no comparable effect is seen in current density recordings from these stations. There must, therefore, be a local decrease in conductivity in this time interval which does not reach a sufficiently high altitude to effect an appreciable change in the columnar resistance.

One obvious conclusion which can be drawn from this is that the use of several simultaneously operating stations is an invaluable tool with which to detect, identify and measure perturbations which are caused by locally anomalous phenomena. Had the "rush hour" maximum in field not stood out so clearly from the records obtained at unaffected stations, the phenomenon might have been quite difficult to isolate. A corollary to this is that the agreement of data from several stations gives considerable confidence that no such anomalies have been overlooked.

The difference in the magnitude of the current densities computed for the different locations has already been mentioned. Since this computation involves the product of potential gradient and total conductivity, the thought might arise that the roles of the two parameters separate nicely into global-scale phenomena represented through the gradient and local pollutant level reflected in the conductivity. The error in such a simplistic picture comes from neglecting the fact that the circuit from upper atmosphere to ground possesses many of the characteristics of a constant current circuit. This phenomenon has already been encountered in the discussion of the rush hour effect in which local conductivity changes produced by local pollution are not reflected in the current density but, rather, result in a local increase in potential gradient. It is obvious, therefore, that although conductivity may reflect the local pollutant level, the current density, by its action in effectively integrating the action of pollutants over a vertical column above the measuring site, provides a more realistic indicator of overall atmospheric contamination.

An examination of the data shows a consistent near equality between the two "clean air" sites, Argentia and SNP, and points to the idea that these values may represent a clean air norm which should be expected at any such location. It is also significant that Pensacola, which is considered to have the least polluted air of the three remaining locations, has current densities which are slightly, but consistently, greater than those measured in Norfolk and Lakehurst. It might well be concluded then that an average conduction current density of 3.2×10^{-12} A m^{-2} represents an uncontaminated site while the average of 1.5×10^{-12} obtained at Lakehurst and Norfolk can be considered representative of heavily polluted locations.

It can be further seen that there is a definite pattern of diurnal behavior which appears to be common to all sites in Eastern North America and which can be observed equally well by using either potential gradient or current density data. This is apparent in Figs. 3–6 and especially Fig. 7. It should be mentioned that the data presented were not selected on any basis of fair or non-fair weather conditions. Plots were made of many of the presentations in which only fair weather data were used, and little or no difference was found to exist with the all-weather plots. A similar comment may be made with respect to seasonal variations. The data were initially plotted by seasons; after it was observed that no significant differences could be observed between the results from any given station from one season to another, the yearly average curves herewith presented were drawn.

Finally, it should be stated that these unimodal curves may not represent in their entirety global phenomena. The use of airborne data and/or an analysis of effects which depend on local time such as turbulence, the electrode effect, and the sunrise effect are required if measurements made at the surface of the earth are to be rigorously related to global-scale phenomena. It is concluded, therefore, that the use of several locations allows the identification of local anomalies, that the magnitude of the conduction current density may be used as an indicator of pollution, and that it is possible to obtain entirely comparable unimodal diurnal curves with either potential gradient or current density recordings.

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REFERENCES

Anderson, R. V., 1962: The NRL semiautomatic atmospheric electricity station. NRL Rept. 5187, 21 pp.

—— and Eva Mae Trent, 1963: Measurement of atmospheric electric conductivity and field in the Shenandoah National Park, Virginia. NRL Rept. 5983, 93 pp.

——, and ——, 1966: Evaluation of the use of atmospheric-electricity recordings in fog forecasting. NRL Rept. 6426, 22 pp.

Trent, Eva Mae, and R. V. Anderson, 1965: Data from a system of atmospheric electricity stations. NRL Rept. 6162, 402 pp.