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Evaluation of the Use of Atmospheric-Electricity Recordings in Fog Forecasting

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ABSTRACT

Atmospheric electric and meteorological data from four stations have been analyzed to determine the accuracy of fog forecasts made using atmospheric electrical recordings. A tabulation indicating the successes and failures in forecasting both fog and no-fog conditions shows success percentages ranging from 86 to 92 percent. These success percentages illustrate the assertion that the use of electrical recordings will effect a material improvement in the accuracy of forecasting. A theoretical discussion leads to the development of a possible physical mechanism for the phenomenon which is consistent with available information. Consideration of human and instrumental factors leads to a decision that a total-conductivity meter using a vibrating-capacitor electrometer and with suppressed-zero checks is the instrument most usable in regular forecasting use.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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EVALUATION OF THE USE OF ATMOSPHERIC-ELECTRICITY RECORDINGS IN FOG FORECASTING

INTRODUCTION

As early as 1955, Naval Research Laboratory personnel were observing changes in atmospheric electric conductivity and field preceding, during, and following fog (1). A detailed study of data taken in 1955 in Argentia showed a high degree of correlation between atmospheric-electricity trends and occurrence of fog (2).

As part of a continuing effort to exploit the possibility of using atmospheric-electricity variables to assist in forecasting fog, NRL initiated a small-scale program of investigation of the type and extent of the relationships between certain variables of atmospheric electricity and meteorology. This program was implemented with the establishment of atmospheric-electricity stations at four Naval Air Stations – Argentia, Lakehurst, Norfolk, and Pensacola, and, for a short time, aboard the USS Northampton (3).

The land stations are in general located in or near coastal regions, and have a topography characterized by low, relatively level plains, and a climate influenced by continental air-mass activity. The Argentia location is an exception, in that it is dominated by rugged, irregular hills up to 500 ft in altitude, and has a high incidence of rain, wind, and fog.

In regard to local contamination sources, the Argentia site is also an exception, being somewhat remote from large centers of population and industry. The remaining stations are in general located in or near suburban areas, adjacent in some cases to moderate industrial activity. The Norfolk location is affected quite severely at times by smoke, especially when the wind is from a westerly direction.

TYPE OF LISTINGS USED IN ANALYSIS

The atmospheric-electricity measurements were made and recorded using the NRL semiautomatic instrumentation (4). Continuous recordings of field and conductivity were taken over a period of several months. A typical record is shown in Fig. 1. The data were reduced and tabulated with concurrent meteorological data from WBAN listings. From these tabulations, all data which indicated fog and/or dew-point spread (difference between ambient and dew-point temperatures) $\leq 2°$ were extracted and a special listing compiled which included data four hours before and two hours following fog or dew-point spread $\leq 2°$.

Data listed were:

1. Positive conductivity $\lambda+$
2. Negative conductivity $\lambda-$
3. Ratio of positive to negative conductivities
4. Total conductivity λ_T (sum of the two polar conductivities)
5. Electric field E
6. Conduction-current density J

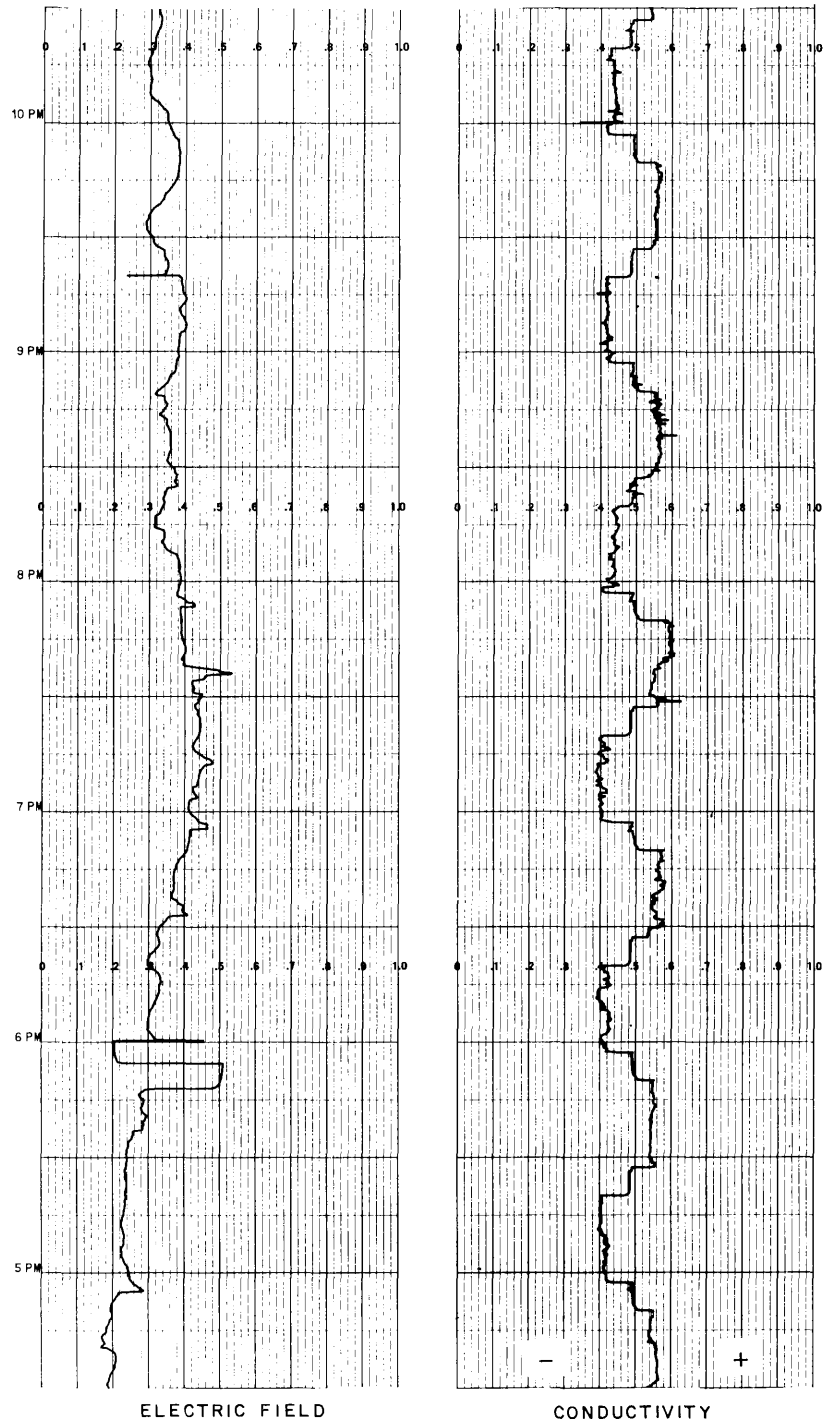

Fig. 1 - Typical fair-weather atmospheric-electricity recording

7. Operating conditions (applicable to instrumentation)
8. Relative stability of conductivity trace
9. Obstructions to vision
10. Visibility
11. Ceiling
12. Temperatures of dry bulb and dew point and their difference
13. Relative humidity
14. Wind speed and direction
15. Precipitation
16. Sky conditions.

With these special listings, an analysis was made to see if fog onset and dissipation could have been predicted using the trends of atmospheric electric conductivity and field by applying a set of rules involving increases and decreases in the values of the two electric variables. It is important to keep in mind that these forecasts of a fog situation made in this study were made after the fact.

It had been anticipated by NRL that the personnel at the Meteorological Offices where the atmospheric-electricity stations were installed would make "on-the-spot" forecasts using the recordings of conductivity and field, and compare these forecasts with those made using standard meteorological procedures. With but one exception, this procedure was not followed by the personnel at the air stations. Minton at Lakehurst, New Jersey, was the exception (5). So an evaluation of the technique had to be made which is necessarily less objective than an evaluation of "on-the-spot" forecasts. An ideal evaluating scheme would be one in which two forecasters work isolated from each other, one using conventional meteorological methods, the other also using atmospheric-electricity variables to aid him; then their successes (and failures) could be compared.

METHOD OF ANALYSIS

A set of rules, techniques, and definitions to be followed was established by which forecasts were to be made using the selected listings.

1. "Fog" is defined as visibility less than one mile and ceiling less than 200 ft, even though there may be fog observed with greater visibility and higher ceiling.

2. When fog as defined above was observed, trends in the atmospheric-electricity values were examined for four hours before and at least two hours following the observation.

3. All data were examined when the difference between dry-bulb and dew-point temperatures (dew-point spread) was 2° or less.

4. Obviously, no forecasts could be made when for any reason atmospheric-electricity data were missing.

5. No forecasts were made when obstructions to vision other than fog were observed, such as smoke, haze, etc., and during any liquid or frozen precipitation and thunder as defined by Manual of Surface Observations (WBAN)(6). (There were some instances when fog onset could have been predicted in rain, but these were not included in the analysis.

With the preceding techniques and definitions in mind, the following conditions were used to predict the onset of fog:

1. Conductivity decreasing to approximately 2/3 normal and dew-point spread less than 2°

    a. Stable conductivity indicates a fog of long duration in general.

    b. Unstable conductivity indicates fog of short duration.

2. Electric field increasing in the fair-weather direction.

The conditions looked for in forecasting dissipation are:

1. Increase in conductivity

    a. The increase may occur in total conductivity or in either polarity.

    b. Unstable conductivity is also an indication of dissipation.

2. Decrease in electric field or a field reversal

3. Increase in dew-point spread.

There are a number of considerations other than those contained in the basic rules which are helpful in using atmospheric electricity to forecast. Conductivity appears to be a better aid than electric field, although the field shows more erratic changes. In general, electric field increases in the fair-weather direction during and preceding a fog, and seldom is reversed during a fog. Since the two polar conductivities are measured during alternate half-hour periods, it is well to realize that at times there may be a sharp increase or decrease in one or the other, although total conductivity may appear to be more or less constant. As a rule, conductivity is low in haze and smoke and is not in those circumstances a reliable factor in forecasting fog, since the decrease may not predict fog. This fact accounts for no forecasts being made if WBAN observations listed haze or smoke.

Occasionally, in Argentia particularly, fog will occur with the dew-point spread greater than 2°, and often at all stations, the spread apparently remains less than 2° after dissipation. There are perhaps several reasons for this spread, including the facts that the air temperature and dew-point temperature are recorded only every hour and that they are based on relatively inaccurate sling-psychrometer measurements.

In the analysis, the following format was used to tabulate both forecasts and conditions following forecasts.

Present Weather	No Fog Ensued		Fog Ensued	
	No Fog Forecast	Fog Forecast	No Fog Forecast	Fog Forecast
No Fog				
Fog				

If, in the absence of fog, no fog was forecast even though the dew-point spread was $\leq 2°$, and fog occurred, the forecast failed. Similarly, if fog was forecast and fog occurred, the forecast was successful. Success and failure of forecasts of dissipation and persistence are indicated in the same manner.

At this point, it is well to note that forecasts were not made for each hour, but for each event. If there was a fog of long duration, say two days, only one forecast was made (Norfolk, Feb. 27-Mar. 1, 1959).

There are several reasons for the apparent inconsistencies in the number of fog onsets and fog dissipations (successes and failures alike). No forecast could be made if atmospheric-electricity data were missing before or during an event. Precipitation may prevent forecasts of either onset or dissipation, since neither forecast was made in precipitation. As stated previously, no forecasts were made when any other obstructions to vision were present.

Incidents then occur when the onset of fog could be forecast, but no forecast of dissipation was made. Similarly, on other occasions no forecast of onset was made, but because of a change in meteorological conditions or presence of atmospheric-electricity data, forecasts concerning dissipation could be made.

Table 1 shows the recapitulation by location of forecasts made over a period of several months indicating numbers of successes and failures in using atmospheric electric conductivity and field as aids.

Table 1
Forecasting Results

Location	Success			Failures			Success (percent)
	No Change	Onset	Dissipation	No Change	Onset	Dissipation	
Argentia	125	73	62	22	7	4	88.7
Lakehurst	63	19	18	5	6	1	89.3
Norfolk	144	24	30	15	3	0	91.7
Pensacola	115	44	26	15	14	0	86.5

Typical examples of forecasts are shown in Figs. 2 through 13. In these figures are plotted measured electric field and total conductivity and pertinent other observations taken from the hourly tabulations. Wind direction and wind speed are indicated by WD and WS, dew-point spread in degrees Fahrenheit by T - D, and visibility in miles by VIS. Obstructions to vision are shown in the line labeled WX, in which F denotes fog, R liquid precipitation, S frozen precipitation, and H haze. The stability number is an index of short-term stability of the conductivity trace, with zero being the least stable.

THEORY

The phenomenon of atmospheric conductivity, discovered in 1785 by Coulomb, was found by Wilson in 1900 to result from the migration of small atmospheric ions. These ions are generally thought to carry a single electronic charge (1.6×10^{-19} coulomb) and are usually characterized by their mobility, k, in an external electrostatic field. If $\vec{v}_d$ is the ultimate drift velocity and E the applied electrostatic field, then k is defined by the relation

$$\vec{v}_d = k\vec{E}. \tag{1}$$

WD	ESE	E	E	E			E	E	E	ENE	E	E	
WS	7	5	6	3			2	2	4	3	6	4	
T-D	8.0	6.0	4.0	2.0	2.0	0	1.0	0.0	0.0	0.0	0.0	1.0	4.0
VIS	15	15	15	15	15	15	15	15	7	½	½	3	7
WX	0	0	0	0	0	0	0	0	0	F	F	GF	0
STABILITY	2	2	2	2	2	1	1	2	2	2	2	2	2

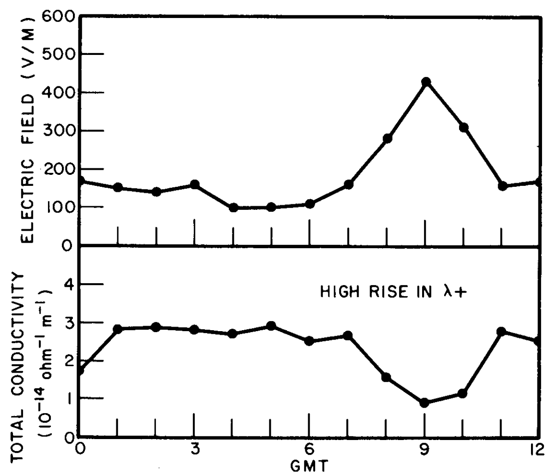

Fig. 2 - Example of successful forecast of onset and dissipation of fog, Argentia, Newfoundland, Sept. 21, 1958

WD			WNW	WNW									WNW	NE	NE
WS			2	2									1	6	7
T-D	5.6	4.8	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	19.0	28.2
VIS	15	15	15	15	6	4	2½	¾	¾	¼	⅛	⅛	1	5	12
WX	0	0	0	0	GF	GF	GF	F	F	F	F	F	GF	H	0
STABILITY	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

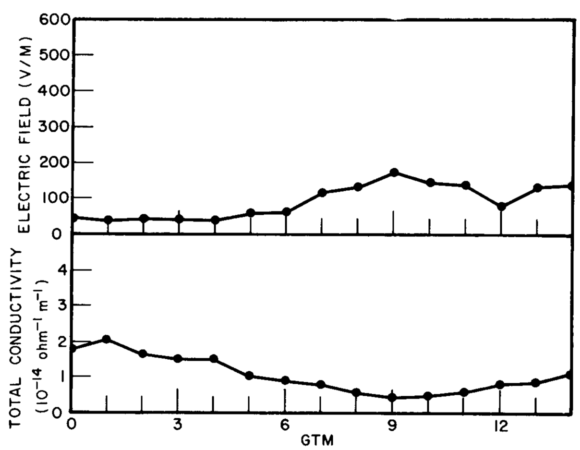

Fig. 3 - Example of successful forecast of onset and dissipation of fog, Lakehurst, New Jersey, May 12, 1962

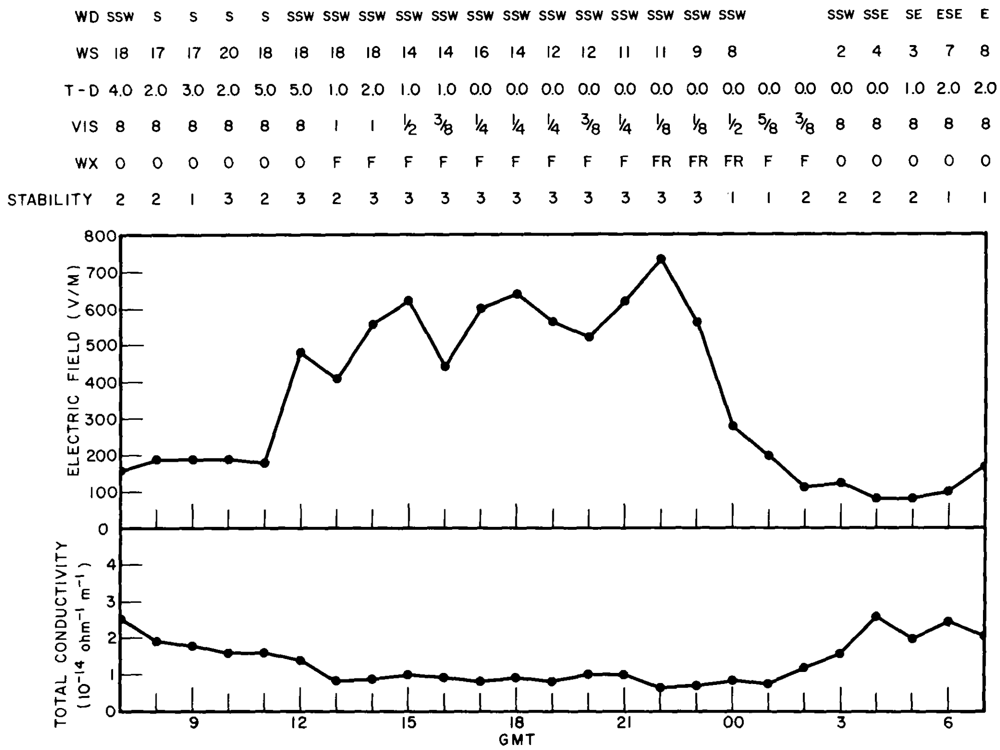

Fig. 4 - Example of successful forecast of onset and dissipation of fog, Argentia, Newfoundland, Aug. 4 and 5, 1958

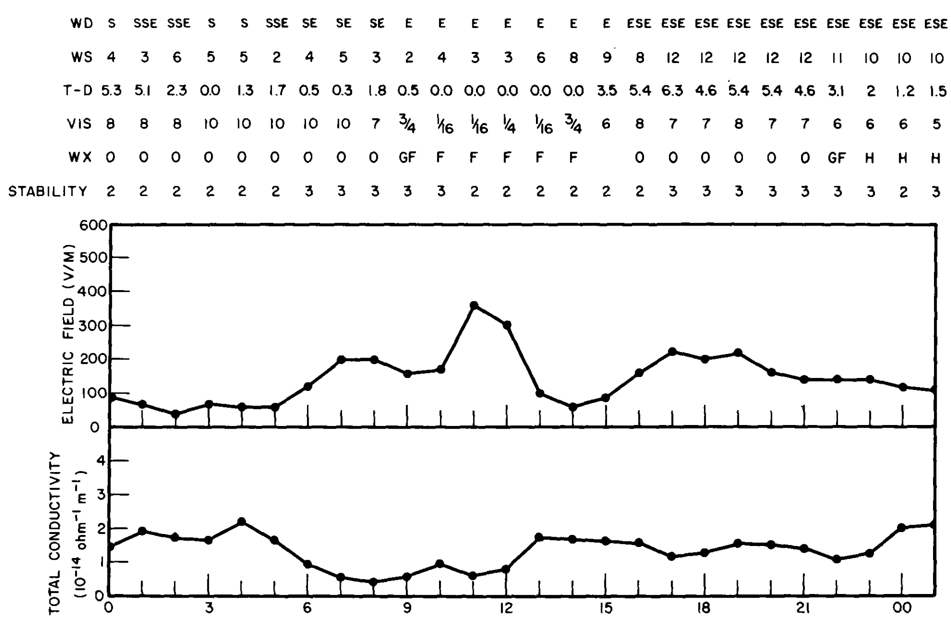

Fig. 5 - Example of successful forecast of onset and dissipation of fog, Pensacola, Florida, Mar. 25, 1959

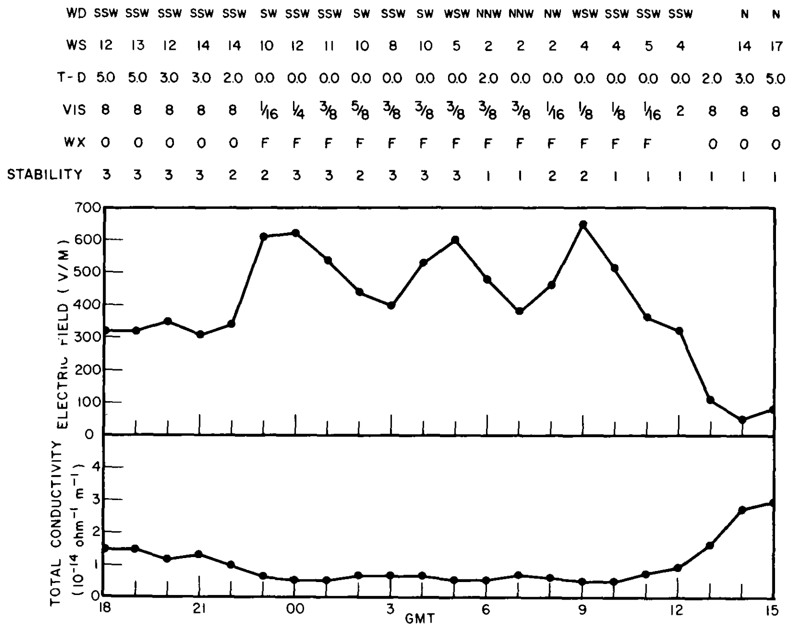

Fig. 6 - Example of successful forecast of onset and dissipation of fog, Argentia, Newfoundland, May 31, June 1, 1958

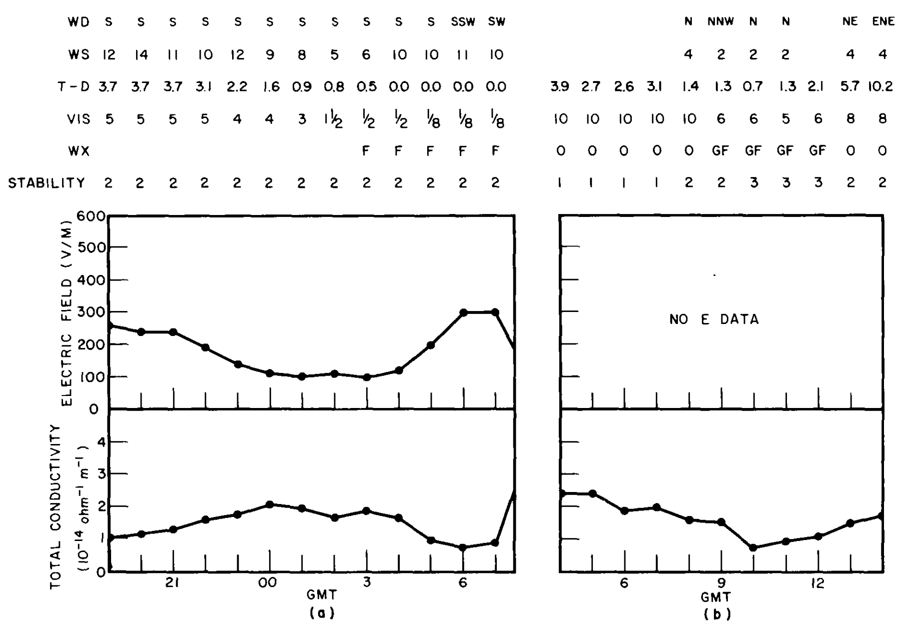

Fig. 7 - Typical forecast failures, Pensacola, Florida
a. Failure in forecasting no fog; Feb. 14 and 15, 1959
b. Failure in forecasting fog; July 5, 1959

WD	SSW	SSW	SSW	SSW	S	SSW	S	S	S	S	SSW	S	SSW	SSW	S	ENE	ENE	NNE
WS	15	15	17	18	20	18	15	17	15	18	20	14	10	9	2	2	5	7
T-D	1.0	1.0	1.0	0.0	1.0	0.0	2.0	1.0	2.0	2.0	1.0	1.0	1.0	1.0	0.0	1.0	1.0	2.0
VIS	1/2	1/2	1	1/2	8	3	7	12	12	12	4	8	8	8	8	8	10	10
WX	F	GF	F	F	0		0	0	0	0		0	0	0	0	0	0	0
STABILITY	3	3	2	2	2	2	2	2	1	1	1	2	1	1	1	1	1	1

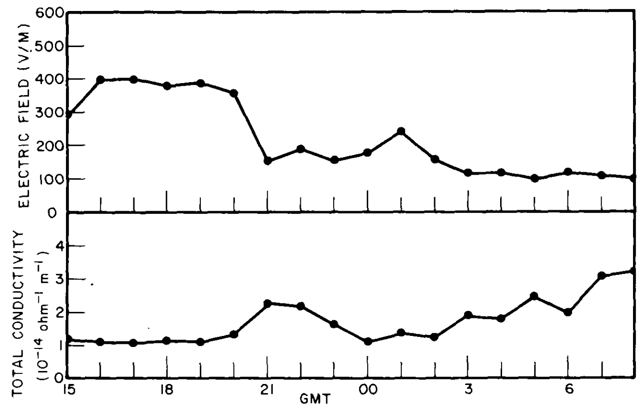

Fig. 8 - Failure in forecasting dissipation, Argentia, Newfoundland; June 24 and 25, 1958

WD	SSW	SSW	S	S	SW	WSW	SSW	WSW	WSW
WS	12	10	12	12	8	7	6	6	12
T-D	3.0	1.5	1.5	1.5	1.5	1.5	1.5	2.7	4.6
VIS	8	7	7	10	6	5	6	7	8
WX	0	0	0	0	GFH	GFH	GFH	0	0
STABILITY	2	2	2	2	2	2	2	2	2

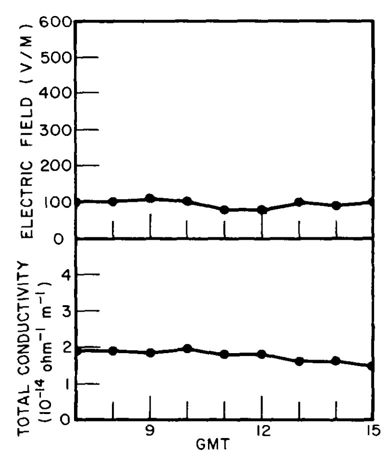

Fig. 9 - Occasion when (T - D) $\leq 2°$ but electric field and conductivity remained average - successful no-fog forecast; Pensacola, Florida, Apr. 28, 1959

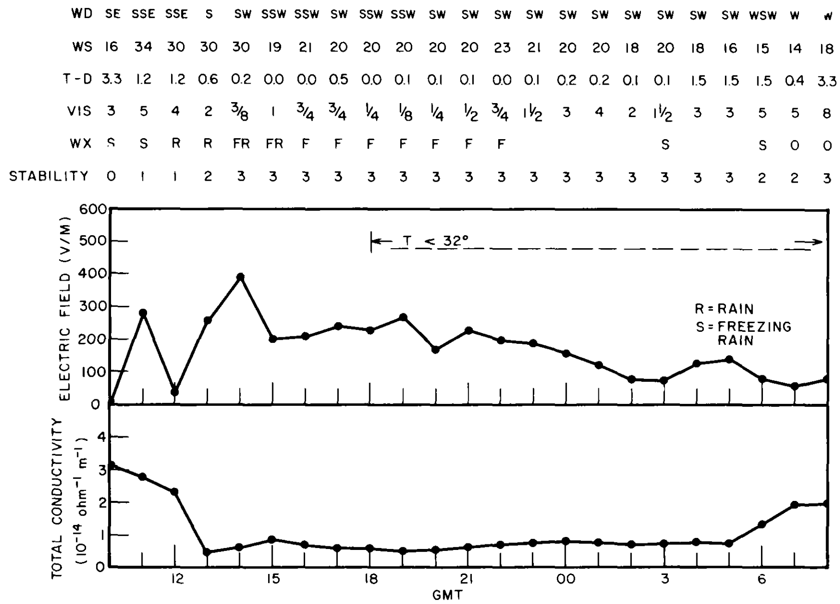

Fig. 10 - Occasion of fog, rain, and freezing rain, Argentia, Newfoundland, Mar. 7 and 8, 1959

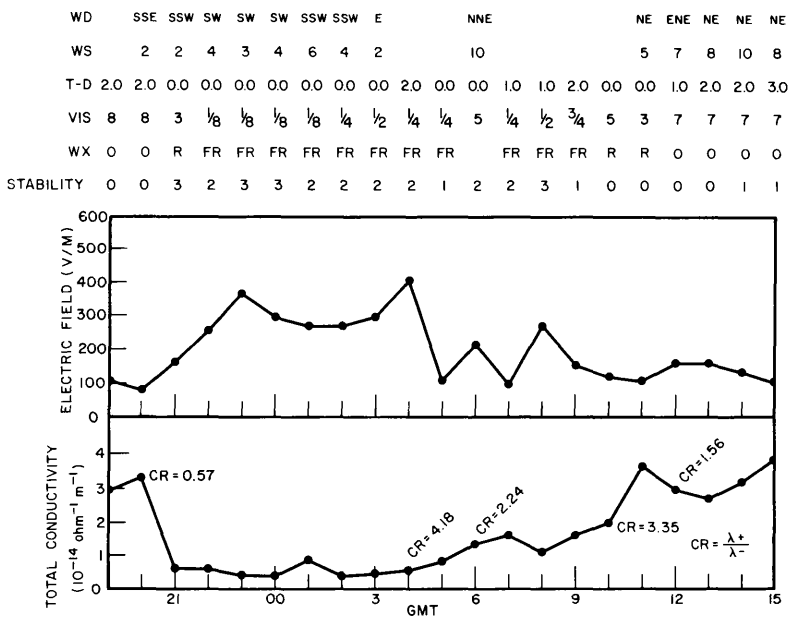

Fig. 11 - Example of low conductivity and high field in fog and rain (drizzle), Argentia, Newfoundland, Mar. 10 and 11, 1958

WD	NNE	NE	N	NNE	NE	N	NNE	NNE	NNW	N	N	NE	N	N	N	N	N	N	NNW	NNW
WS	6	4	5	4	5	6	3	3	3	3	8	5	4	10	2	6	10	7	6	7
T-D	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	1.0	2.0
VIS	7	2½	½	½	½	¾	8	5	5	3/8	3/8	¾	¼	3/16	¼	¾	2	1½	6	15
WX	O		FR	FR	FR	FR	O			F	FR	FR	FR	FR	FR	F		R	R	O
STABILITY	0	0	1	2	2	1	1	1	0	0	0	0	1	1	0	0	0	0	0	0

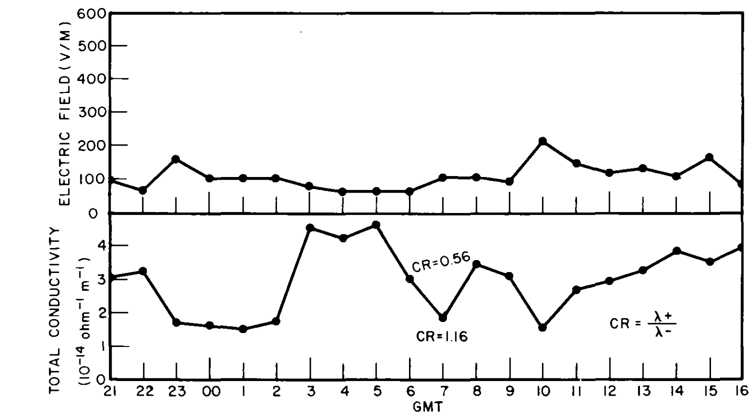

Fig. 12 - Example of high conductivity and low field in fog and rain (drizzle), conductivity unstable, Argentia, Newfoundland, Mar. 11 and 12, 1958

WD	SSE	SSE	SSE	S	S	SSW	SSW	SSW	SSW	SSW	SSW	SSW	SSW	SW	SW	SW	SW	SW	SSW	SSW	SSW	SSW	SSW	SSW
WS	16	18	22	20	22	26	22	22	24	22	17	21	24	21	24	21	15	14	19	19	18	18	18	14
T-D	0.0	6.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0
VIS	8	8	8	8	1	1/16	1/16	1/16	1/16	1/8	¼	¼	¼	3/8	¼	½	2½	3	1½	6	8	8	8	8
WX	O	O	R	O	RF	RF	RF	RF	RF	RF	RF	RF	RF	RF	RF	RF			GF	O	O	O	O	O
STABILITY	2	3	2	1	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	1	1	1	1

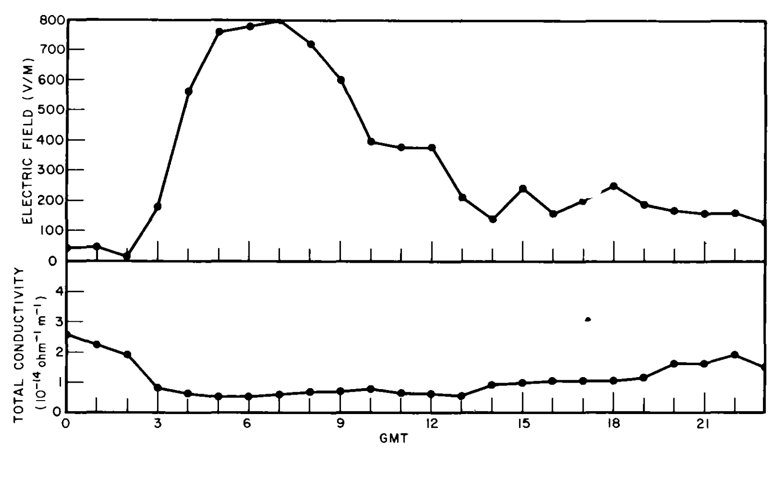

Fig. 13 - Example where fog onset could have been predicted even in rain, Argentia, Newfoundland, Aug. 26, 1958

In the atmosphere, a population of ions is found to exist having a range of mobility values up to approximately 10^{-3} meter^2/volt-sec. A mobility function, $f(k)$, is defined by the relation

$$dn = f(k)\,dk \tag{2}$$

where dn is the number of ions existing whose mobilities lie between k and $k+dk$. It can then be shown that the conductivity λ may be expressed as

$$\lambda = e\int_0^\infty k f(k)\, dk\,. \tag{3}$$

This may also be written in terms of the total ion density n

$$n = \int_0^\infty f(k)\, dk \tag{4}$$

and an "average" mobility $\bar{k}$ as

$$\lambda = n e \bar{k} \tag{5}$$

where λ calculated from Eq. (3) is used to define $\bar{k}$.

From the foregoing, it is seen that the decrease in conductivity prior to fog events must be due either to a decrease in n and/or to a reduced $\bar{k}$. An increase in the density of large subvisible particles (diameters in the range 0.01 - 0.1μ) during the prefog period could result in a reduction in the small ion density by providing many more possible targets for diffusive loss. Since the equilibrium ion density in "unclean" air (which is found at the earth's surface almost without exception) is almost completely an inverse function of the large particle density, the development of such particles would effect a corresponding decrease in small-ion density. The average mobility might be altered if the small conduction ions grow hygroscopically. The resultant increased mass would produce a lower value of mobility.

There are two considerations, however, which indicate that the change in n is more significant than that in $\bar{k}$. Measurements of ion mobility spectra in clouds have recently been made by Zwang and Gutman (7), and it was found that they did not differ significantly from spectra obtained in clear air. It appears, therefore, that even the saturated moisture levels found in clouds do not produce an appreciable reduction in the observed values of mobility. Secondly, by inference, it is seen that if the phenomenon of conductivity decrease prior to fog were merely a moisture-induced process, there would be no significant difference between the use of conductivity and a simple inspection of dew-point spreads. The fact that analysis of conductivity trends serves to predict the onset of fog in the great majority of cases of high relative humidity shows that the conductivity measurement is sensitive to something other than moisture. It is probable that the existence or nonexistence of a significant concentration of large subvisible particles during periods of high humidity determines whether a fog will form. The smoothing and integrating inherent in a conductivity measurement indicate that this is a particularly simple and reliable method to monitor the level of such condensation centers.

INSTRUMENTATION

The instrument used in these investigations used a single Gerdien condenser in which the accelerating voltage was programmed to give samples of positive and negative

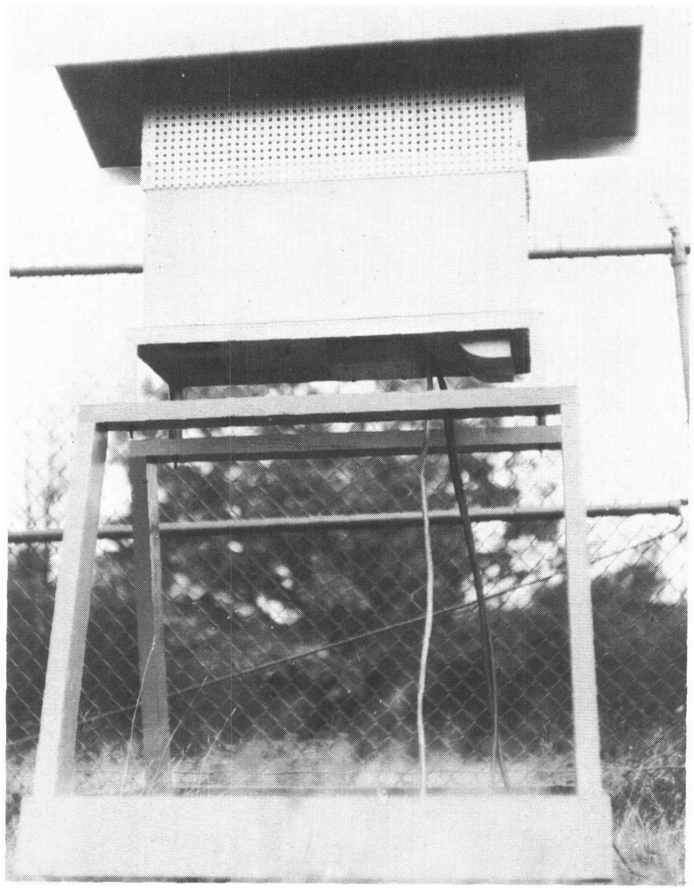

Fig. 14 - Overall view of total-conductivity chamber showing air-inlet scoops and exhaust ports

conductivity and of the system zero level. A rather involved system of time delays was incorporated to reduce the number and magnitude of the switching transients which would appear on the record. Although successful in preventing system overload, this system was never completely successful in eliminating "spikes" from the recording chart. The resultant record, although perfectly satisfactory for the research purpose in mind, was rather difficult to interpret; and it was found that a rather sophisticated observer was needed to obtain forecasting information from such a record. It was felt, therefore, that a more useful instrument would result if total conductivity were measured directly and presented on a chart record with the zero level at the left-hand edge of the chart. In addition, the number of switching operations should be minimized.

In an attempt to construct such an instrument, the availability of differential electrometers was surveyed. It was found that only one type was commercially available, and it used unstabilized electron tubes in the input. One such electrometer was procured and installed in a system containing two Gerdien chambers. The completed apparatus is shown in Figs. 14 through 17. It was found that the instrument zero level exhibited excessive variations with ambient temperature and with time (long-term drift). The addition of insulation, thermal lagging, and thermostatic heat control to the instrument housing sufficed to reduce this drift to a usable level but could not eliminate it.

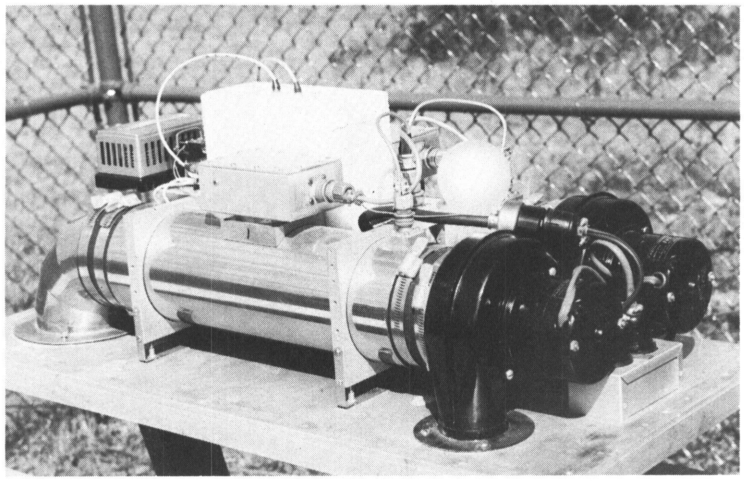

Fig. 15 - Interior view of total-conductivity chamber, with insulation and temperature control

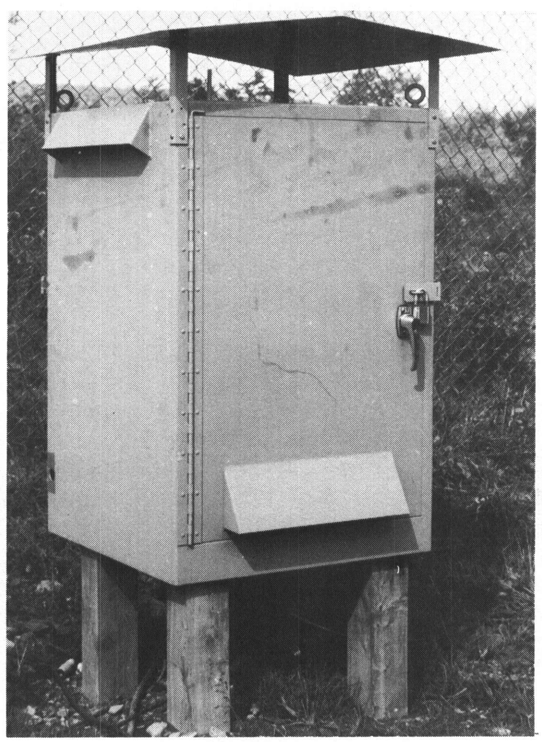

Fig. 16 - Outside view of amplifier enclosure

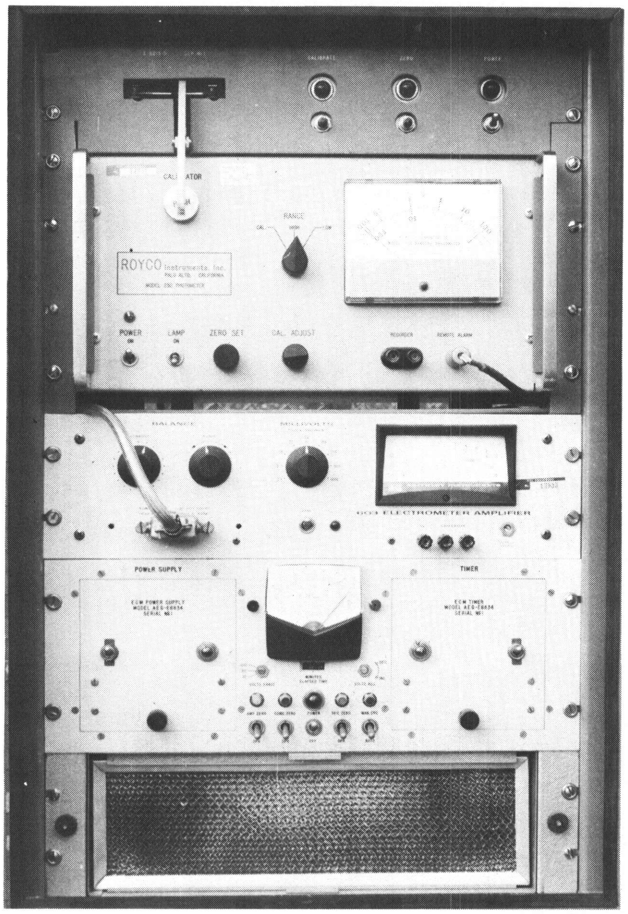

Fig. 17 - Amplifier assembly, showing electrometer, timer, and an aersol meter

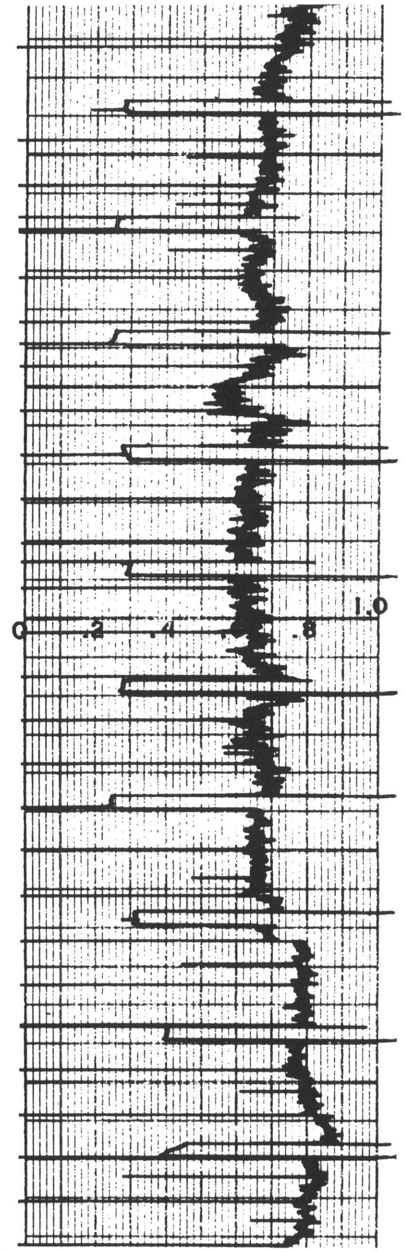

Fig. 18 - Sample chart from NRL Blue Ridge Station, showing total conductivity recording

A sample chart obtained at the NRL Blue Ridge Station is shown in Fig. 18. A comparison of this record with those previously obtained, such as in Fig. 1, shows the improvement in readability effected by the use of total conductivity and left-hand zero and by reducing the speed of chart transport. It is also apparent that the inclusion of the zero checks and the attendant transient spikes still constitutes a distraction. An ideal system would measure total conductivity with the stability of a vibrating capacitor electrometer and might possibly eliminate zero checks entirely from the record, substituting for them a system which would sample the zero while holding the recorder trace at its current value and provide an aural or visible warning if the zero had drifted outside some predetermined limits. Such techniques are well within the present state of the art but have never been developed commercially because of a lack of demand.

CONCLUSIONS

It is seen from the data and discussions presented that the change in atmospheric conductivity prior to the onset and dissipation of fog is a real effect. It is further seen that this effect is sufficiently consistent and repeatable to allow its use as a forecasting aid. The accuracy of fog forecasting should be noticeably improved with the proper use of such atmospheric electric recordings. It has also been pointed out that a theoretical explanation of the phenomenon is possible which, although not rigorously demonstrated, is at least consistent with available data and currently accepted theories.

It must still be understood, however, that no such technique can provide an ultimate idealized solution to forecasting problems, but only that the addition of another useful and significant piece of information to the forecaster's input data should lighten his load while increasing his probability of success. Also worthy of mention is the fact that the statistical results shown in Table 1 do not represent a totality of cases but were restricted to incidents in which the probability of fog was relatively high. The percentages of success would, of course, be much greater were this not the case. Further, it had been hoped that "before the fact" forecasts would be made at the several sites, in which case an additional evaluation would have been available; but, with one relatively brief exception, such was not the case. Therefore, the analysis presented is of necessity derived entirely from "after the fact" forecasts.

It is believed that the analysis and conclusions presented here represent the maximum level of reliability possible under the conditions imposed. Any attempt to achieve a more accurate and/or significant evaluation would have to be built upon actual "before the fact" forecasts in which two or more equally proficient forecasters simultaneously and independently prepared forecasts, one with and one without the use of the electrical recordings. A suitably controlled experiment of this type might provide increased assurance of the validity of the technique, but it is doubted that any significant changes in these conclusions would be obtained.

Complete specifications for an operational instrument, including a total-conductivity meter, could be readily prepared if the existence of sufficient need for such a forecasting aid is verified.

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13. ABSTRACT

Atmospheric electric and meteorological data from four stations have been analyzed to determine the accuracy of fog forecasts made using atmospheric electrical recordings. A tabulation indicating the successes and failures in forecasting both fog and no-fog conditions shows success percentages ranging from 86 to 92 percent. These success percentages illustrate the assertion that the use of electrical recordings will effect a material improvement in the accuracy of forecasting. A theoretical discussion leads to the development of a possible physical mechanism for the phenomenon which is consistent with available information. Consideration of human and instrumental factors leads to a decision that a total-conductivity meter using a vibrating-capacitor electrometer and with suppressed-zero checks is the instrument most usable in regular forecasting use.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fog						
Fog forecasting						
Weather forecasting						
Atmospheric electricity						
Conductivity						
Electric fields						

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