# Planetary-Scale Variability of the Fair-Weather Vertical Electric Field in the Stratosphere

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This paper reports the discovery of short-term variability in the planetary–scale-size vertical electric field measured in the stratosphere. Measurements were made on superpressure balloons at 26-km altitude separated by up to 3000 km. Data are presented which show that the large-scale current system is variable, with twice the amplitude of the average diurnal variations, on time scales of tens of minutes to hours.

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The modern conceptual framework for understanding global atmospheric electricity had its origins at the turn of the century[1,2] when it was demonstrated that molecular ions were the cause of the conducting atmosphere. The discovery of cosmic rays[3] explained the source of this ionization, and Wilson[4] first put together the picture of a global electric circuit. The global circuit is a hypothesis in which thunderstorms drive electric charge upwards, charging the ionosphere relative to the earth. This charge then leaks back to ground through the conducting atmosphere. According to Whipple and Scrase,[5] the global circuit has a daily variation which is explained by the observation that thunderstorms tend to occur in the local afternoon over land. Thus, the current in the global circuit should have a peak amplitude when the largest land mass is on the dusk side of the earth. This explanation fits the observations of the research vessel *Carnegie*,[6,7] which first produced a globally representative data set of surface electric fields. These fields ($\vec{E}$) are related to the globally averaged current density $\vec{J}$ through the conductivity $\sigma$ as $\vec{J} = \sigma\vec{E}$.

Today, the global circuit hypothesis remains an inference.[8] In spite of its extensive use in the literature,[9] the idea has not been proven or disproven, in part because neither global thunderstorm observations nor atmospheric electrical measurements have yet been made extensively and simultaneously over the globe. By use of balloon-borne electric field and conductivity measurements, it has been shown that individual thunderstorms drive a positive current upward well into the stratosphere.[10] However, the global current distribution due to individual thunderstorm sources is not known by observation.

The observations reported below suggest that the current flowing in the global circuit is variable on a day-to-day basis, and this cannot be explained by simple land-mass arguments.

Balloon-borne electric field measurements have been used since the late 1960's in studies of upper atmospheric electric fields.[11] Since then, much theoretical[12] and experimental[10,13] work has shown that stratospheric electric field measurements can be used to distinguish clearly between weather-related and extraterrestrial sources of the electric field. The recent development of long-duration, constant-altitude balloons called superpressure balloons[14] provides a platform in the stratosphere where electric fields and currents have been shown to be Ohmically related.[10,11,13] This paper describes a superpressure balloon experiment in which planetary–scale-size fields were measured on simultaneous flights. In the data to be presented, over 70% of the time the vertical electric fields were nearly identical on widely separated (typically $> 1000$ km) balloons. The conductivity was also measured and found to be relatively constant. Thus, when the measured vertical electric fields agree at the two widely separated balloons, the field is a good indicator of the large-scale current and its variability. The conclusion of this study is that the large-scale vertical current system in fair weather can differ from the average by as much as two times the amplitude of the average daily variation. This implies that the global current source may be considerably more variable than the average variation (first seen by the *Carnegie*[7]) suggests.

Two 5000-$m^3$ superpressure balloons were launched on 6 and 13 March 1983 (respectively) from Christchurch, New Zealand. These balloons

 

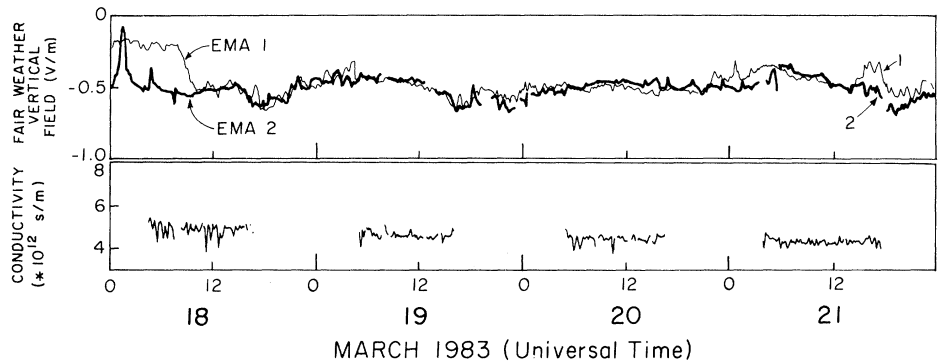


FIG. 1. Four days of electric conductivity and vertical electric field measurements from two widely separate balloons.

stabilized in altitude quite rapidly at 26 km, with radar observations of the vertical diurnal variability of less than 100 m. They both proceeded eastward near 45° south at between 5° and 7° per day. The average balloon separation was about 2000 km, and at no time were they closer than 750 km. The vertical atmospheric electric field was measured with the double-isolated-Langmuir-probe technique,[11,15] in which the high-impedance ( $> 5\times 10^{13}$ $\Omega$), vertical potential difference is measured between 30-cm-diam metal spheres each 1.5 m above or below the central conducting payload. The electric conductivity is measured by the relaxation-time-constant method[10] in which the upper and lower spheres are briefly biased to $\pm 6$ V, respectively, and then refloated. The exponential time constant $\tau_{\pm}$ is related to the conductivity $\sigma$ by $\sigma_{\pm}=\epsilon_0/\tau_{\pm}$ and $\sigma_{\text{total}}=\sigma_{+}+\sigma_{-}$. The conductivity measurements reported herein are nighttime values only because photoelectric emissions are believed to have increased the conductivity near the probes in the daytime. However, this local increase of conductivity did not perturb the electric field measurement.

As seen in Fig. 1, the two vertical electric field measurements, even though widely separated, were often within 10% of each other. The conductivity measurements are slowly varying and agree quite well with earlier measurements.[10]

The vertical electric field averaged about 0.5 V/m in a downward (fair weather) direction which is very close to previously reported fair-weather measurements at the altitude of 26 km.[10,13] Times when the fields disagree are probably due to local electrical disturbances such as thunderstorms or electrified clouds. In other data, thunderstorms are clearly seen and have been removed from the data considered herein by the method of Mozer.[13] During the two flights there were 16 d of overlapping data which are the subject of this report. The entire overlapping data set has been combined in Fig. 2 for all times when payloads 1 and 2 measured the same vertical electric field to within 50 mV/m (10% of the average fair-weather value). Since the diurnal altitude variation is much less than one conductivity scale height (approximately[16] 4 to 6 km), the balloons can be considered to be stationary in altitude electrically. The smooth diurnal variation of Fig. 2 is reminiscent of the *Carnegie* curve[6,7] which is also plotted for comparison. Note that the polarity is negative since the electric field is plotted instead of potential gradient. The two curves are very similar in amplitude and shape with some clear differences. This does not imply that the data from this campaign, if more heavily averaged, would more closely resemble the historic data from the

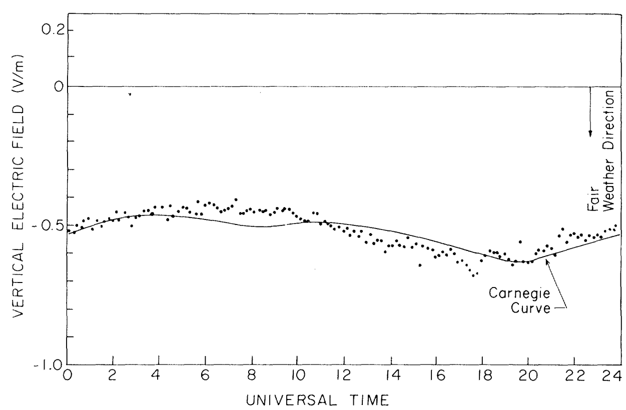


FIG. 2. The 10-min averages of the vertical electric field. All overlapping data from two payloads when the data agreed to within 50 mV/m (10% of mean) for a 16-d period are shown after they have been averaged together. Also shown is the *Carnegie* curve of average surface electric field measurements (Ref. 7).

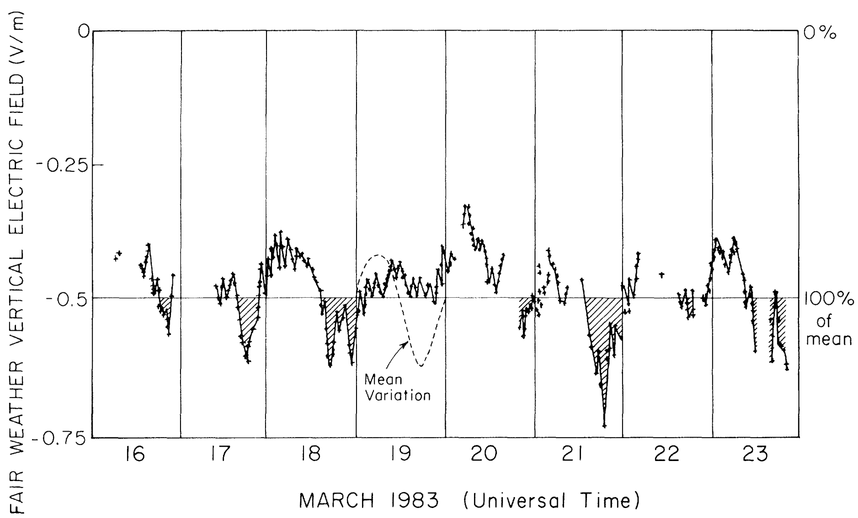


FIG. 3. Eight of the 16 d of data from Fig. 2, showing the real variability of the large-scale vertical electric field. The average electric field from Fig. 2 is shown as the mean variation.

1920's. However, the implication of Fig. 2 is that these balloons as instrument platforms appear to be appropriate for measuring the large-scale variations.

More important than the close comparison of data sets in Fig. 2 is the fact that the data on individual days of the present data set are highly variable. Figure 3 emphasizes this point by presenting 8 d of the data which went into Fig. 2. Each day is quite unlike the average, except for a frequent tendency for smaller absolute amplitudes in the morning and a higher one in the evening. The missing data from Fig. 3 are due to local electrical disturbances which only affected one payload, resulting in more than a 50-mV/m difference between the two payloads.

From the data presented in this paper one can conclude that two payloads in the southern hemisphere stratosphere, 750 to 3000 km apart, measured the same vertical electric field in fair weather to 10%. The overlapping data cover 7 h of local time; no local-time effect was found when comparing early data to late data in the interval. Furthermore, since the payloads were typically more than an order of magnitude further apart than the extent of effects of a thunderstorm,[13] we conclude that Figs. 2 and 3 represent the large-scale variations of the southern-hemisphere stratospheric vertical current system. Note that small horizontal gradients (tens of microvolts/meter) in the fair-weather field are not ruled out by these data.

The most important conclusion to be drawn from this data set is that the large-scale current system is highly variable on a day-to-day basis. Since the ionosphere (in daytime or nighttime) is several orders of magnitude higher in conductivity than the lower atmosphere, it may be presumed that a similar variability occurs in the northern hemisphere and thus globally. This variability of the conduction current on time scales of tens of minutes and longer times should not be confused with the much shorter time scales in the work of Ruhkne, Tammet, and Arold,[17] which were not attributed to source variations.

Contrary to the conclusions of some previous authors who have attributed all the nonaverage variability to local weather effects,[18,19] the large-scale conduction-current system appears to have considerable real variability which effectively masks its average behavior when viewed on short time scales. This is not explained by the conventional land-mass explanations[5,20,21] of the source for the atmospheric electric field. Simultaneous widely separated data points such as those shown in Fig. 3 could easily be combined to provide a geoelectric index similar to geomagnetic indices found to be so useful to ionospheric and magnetospheric physics. The discovery of large-scale vertical electric field variability offers the promise of testing many of the theories relating solar variability to terrestrial effects.

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