



# Global scale comparison of simultaneous ionospheric potential measurements

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## Abstract

A unique series of simultaneous ionospheric potential ( $V_I$ ) balloon soundings were obtained every 3 h over 2 full days at Weston, MA and Darwin, Australia, on the other side of the earth. These comparisons were to test the assumption that the ionosphere at sub-auroral latitudes is an equipotential and that a single measurement can provide a globally representative number. Another objective was to evaluate meteorological conditions affecting the measurements in a clean dry continental atmosphere (Darwin) compared with a more variable moist less clean atmosphere (Weston). The results indicate that for the Darwin data the  $V_I$  measurements were within 10% of the classic Carnegie curve diurnal variation while the Weston data were more variable and often too large. The major source of error appears to be due to hydrated aerosol at Weston causing high electric fields in the exchange layer that were not fully compensated by electric fields above the inversion. The prototype instrumentation also contributed some error. The major finding of this experiment is that a layer of low conductivity air near the ground can have an unexpectedly large effect on electric field sounding data leading to error in the estimates of  $V_I$  magnitude. This finding would not have been possible if simultaneous measurements in different airmasses had not been made since the individual electric field profiles appeared normal. © 1999 Elsevier Science B.V. All rights reserved.

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## 1. Introduction and background

An attractive feature of utilizing ionospheric potential ( $V_I$ ) measurements as a proxy index for monitoring the variation of global temperature is that only a single sounding is required to provide a globally representative value. This is because the ionosphere can

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be considered essentially an equipotential at latitudes below the polar cap region; at high latitudes upper atmosphere electric generators add to the potential caused by convection at lower latitudes and can influence the data. Thus, the measurement can be obtained at any convenient sub-auroral latitude location with favorable meteorological conditions. To test the equipotential concept and the affect of local conditions, simultaneous soundings were made over the course of two full days at Darwin, Northern Territory, Australia (12S, 131E) and Weston, MA, USA (42N, 71W).

Previously there have been two experiments where simultaneous aircraft or balloon measurements at remote locations were used to test the equipotential concept. Mühleisen (1971) summarizes 15 simultaneous balloon soundings between a ship in the equatorial Atlantic and southern Germany 6000 km away. Twelve of the measurements agreed to within 10% of each other, 8 were within 3%, 1 pair was 16% and 2 were 20% apart.

Markson (1985) reported simultaneous aircraft  $V_1$  soundings made over a 12-h period between the ocean east of Boston and Scheferville, Quebec, 1400 km to the north, which closely paralleled each other. The absolute difference in  $V_1$  between the locations was less than 5% and when the effect of the high latitude upper atmosphere generator was removed each of the sets of measurements were practically identical. The temporal variation closely matched the Carnegie Curve diurnal variation.

In order to obtain a truly global data set, it was decided to make simultaneous measurements on opposite sides of the world and in different hemispheres. Darwin, Australia, 17,000 km distant, was chosen as the remote site because of favorable meteorological conditions and an offer of support from the Australian Bureau of Meteorology in Darwin.

## 2. Instrumentation

The electric field was measured with an electrometer and radioactive probes 2.5 m apart interfaced with a standard VIZ meteorological radiosonde. Calibrations were performed for each radiosonde both in the lab and in the field before launch by directly applying known voltages. A new type of resistivity meter based on constant current biasing was designed and flown as part of the project (Ruhnke, 1996). This instrument was used because it is particularly sensitive to low conductivity air in the lower atmosphere compared to the normal Gerdien instrument which is most effective at high altitudes. In addition, the standard temperature and relative humidity soundings were obtained. The resistivity data provided diagnostic information about the electrical structure of the atmosphere that was useful in evaluating the electric field data.

## 3. Measurements and data analysis

Because of the diurnal variation of the global circuit, which, on the average, can be approximated by the Carnegie Curve (Markson, 1985), the experimental design called for measurements over the period of a day. Coordinated soundings were made on a 3-h schedule so 9 sets covered Day 1, 20 May 1995. On the second day, 1 June 1995, 10

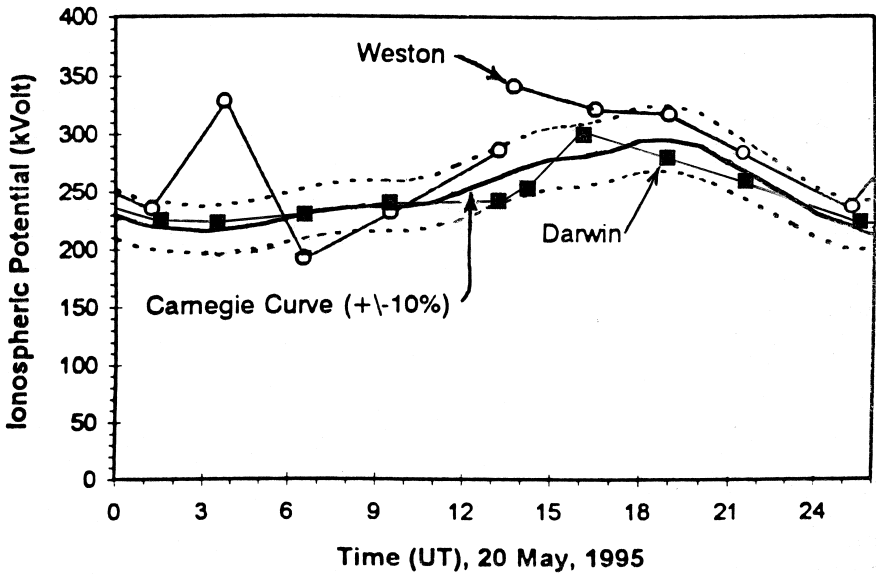


Fig. 1. Summary of  $V_1$  data (14 h 20 May–14 h 21 May).

sets were obtained covering a period of 27 h. Generally launches at both locations were within about 10 min of each other.

$V_1$  is calculated by integrating the field up to about 10 km where the zero drift of the electrometer becomes evident from the profile no longer following the Gish curve

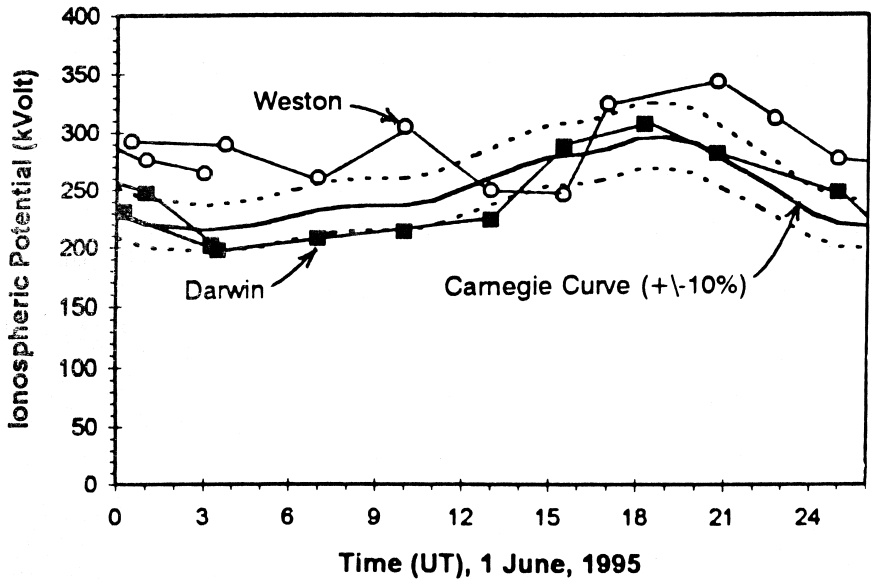


Fig. 2. Summary of  $V_1$  data (00 h 1 June–03 h 2 June).

(Israel, 1971). From this point, the remaining potential to the ionosphere (about 10%) is calculated by integrating the Gish curve upward.

Fig. 1 summarizes the 9 measurement pairs made on 20–21 May 1995. The Carnegie curve diurnal variation with a  $\pm 10\%$  envelope is shown for comparison. Most of the data fall within or near the envelope. The Darwin data are remarkably close to the Carnegie curve. The second Weston measurement (03 UT) appears too large. The average of the  $V_1$  measurements for the more reliable Darwin data on this day is 247 kV.

Fig. 2 summarizes the 10 pairs made on 1–2 June 1995 (plus an extra one at Weston with no comparison at Darwin). On this day, the Darwin data closely parallel the Carnegie Curve but the Weston data are consistently above the envelope except for two soundings. The last 6 of the Weston soundings (daylight hours with lower relative humidity) vary like the Carnegie Curve. The average of the more reliable Darwin  $V_1$  data for this day is 241 kV.

#### 4. Discussion

A significant source of error in the electric field instrument appears to be caused by the  $10^{12} \Omega$  resistor in the input. Due to long lead time in acquiring high quality glass encased high ohm resistors and constraints on when we could go to Australia, the decision was made to use resistors that were readily available but of lower quality. These resistors had non-linear temperature and voltage characteristics so calibration was difficult. While analysis indicates that most of the discrepancies between the measurement pairs was due to atmospheric conditions, there was also some error from the instrument. Better resistors and other improvements to the electric field system have been incorporated for future soundings.

We conclude that the dominant source of error in these soundings, which occurred for the Weston data, is related to large electric fields beneath the inversion which are not fully compensated adequately by lower electric fields above the inversion. The large electric fields are caused by aerosol in the exchange layer which grow rapidly when the relative humidity reaches about 75–80%. This is the ‘deliquescence point’ of salt aerosols when they begin to grow rapidly lowering the conductivity of air. If the low conductivity air is sufficiently wide in extent horizontally, then the electric field above the exchange layer will adjust to smaller values so the integrated potential to the sounding is unaffected. However, if the horizontal extent is insufficient the upper level electric fields will not decrease as much as they should. Sounding balloons typically are carried 50 or more km horizontally during their ascent by the winds. If they measure anomalously large fields in the lower atmosphere and subsequently move into a region where the columnar resistance through the exchange layer is less than in the region of the launch, then the electric fields aloft will be larger than they would have been over the launch region. Therefore, both the lower level and upper level electric fields will be enhanced and their integration over the flight path will lead to a larger  $V_1$  than the actual value. Because the ocean is only 25 km east of Weston and complex onshore–offshore wind patterns exist, the winds carrying the balloon into nearby regions with different columnar resistance is believed to be the major source of error in these measurements.

Fig. 3 depicts the sequence of Weston soundings at 01, 03 and 06 UT on 20 May. The 03 UT sounding (dark line) has much larger values below the inversion than the before and after soundings. (The area under the curve represents  $V_1$ .) The enhanced potential comes mostly from below the inversion which is readily identified by a characteristic decrease in field intensity. The upper sections of these soundings are practically identical. In each instance where the pairs of  $V_1$  values are not well matched, there is an enhanced electric field bulge in the lower part of the Weston sounding which produces the larger  $V_1$  value.

Fig. 4 depicts a pair of simultaneous soundings (the first pair on the left side of Fig. 1) which illustrates how reliable measurements occur when there is proper compensation in the atmosphere; the profile with highest electric fields in the lower atmosphere has the smaller electric fields in its upper portion. While these profiles are quite different, their integrated potentials are about the same (15 kV, 6% difference). The sharp spikes at the inversion in both soundings and at 1 km in the Weston sounding are caused by thin cloud or aerosol layers of low conductivity which create enhanced electric fields.

In the past, it has not been possible to determine if variations in columnar resistance of the air masses sampled by atmospheric electrical sounding balloons affect the measurements. If only a single sounding is made and it looks about right (sharp drop in field at inversion and exponential decrease in field above inversion), the assumption has been made that the data are reliable. In these experiments, however, there were simultaneous soundings which individually looked reasonable but sometimes yielded quite different  $V_1$  values. From past measurements (Mühleisen, 1971; Markson, 1985) and theory we assume that the ionosphere should have been at about the same potential over Weston and Darwin. Therefore, we conclude that the discrepancy must be due to the variable columnar resistances along the balloon sounding path.

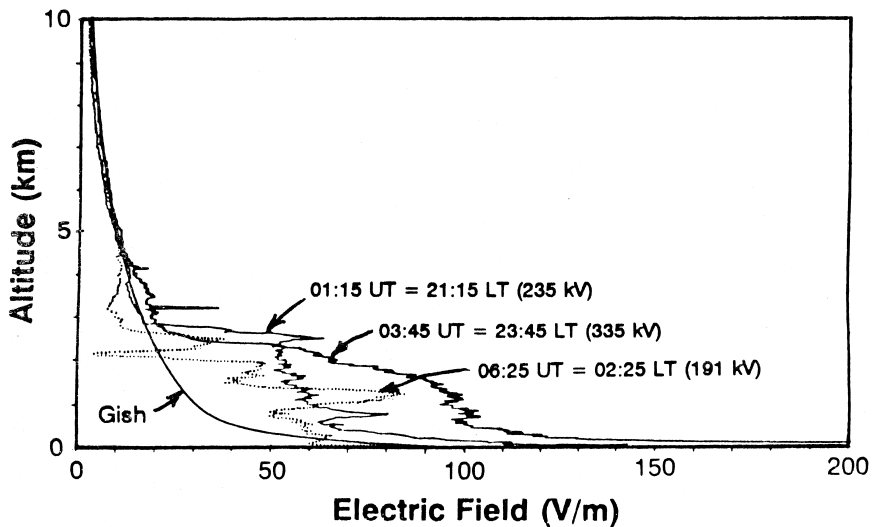


Fig. 3. E-field variation in exchange layer for consecutive soundings leading to apparent change in  $V_1$  measurements.

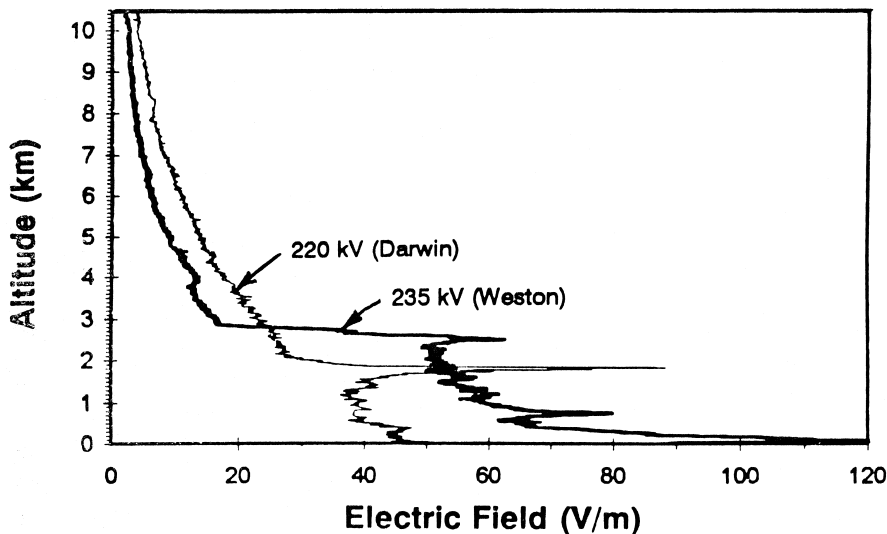


Fig. 4. Compensation of E-field leading to about the same  $V_1$  values from dissimilar profiles in widely separated locations.

Previous aircraft measurements have reported close matches between remote locations (Markson, 1985) and diurnal variations quite similar to the Carnegie Curve (Markson, 1976, 1986). Our aircraft soundings have been made to avoid air mass sampling problems by spiraling up and down in a 2 km diameter circle. Balloons typically are blown farther horizontally by the wind than their vertical rise. Aircraft also can obtain profiles over the ocean in relatively clean air with large scale horizontally stratified layers of aerosol so proper compensation will occur.

From the above investigation, the following guidelines have been defined and will be used in the future to obtain the most reliable  $V_1$  balloon soundings over land.

(1) Avoid air masses with enhanced electric fields in the mixed layer. This can be recognized best from a preliminary profile or more easily from larger than normal electric fields at ground level.

(2) Avoid times when the balloon would pass through or near clouds.

(3) Sufficiently dry air in the boundary layer will prevent the growth of aerosols causing the enhanced electric fields below the inversion. Soundings made by the Weather Bureau can provide this information.

We conclude that differences between simultaneous  $V_1$  measurements are due to atmospheric and instrumental factors, and that with good conditions, a single  $V_1$  measurement at sub-auroral latitudes would be globally representative.

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