Twentieth century secular decrease in the atmospheric potential gradient


It is advisable to refer to the publisher’s version if you intend to cite from the work. See Guidance on citing. Published version at: http://dx.doi.org/10.1029/2002GL014878
To link to this article DOI: http://dx.doi.org/10.1029/2002GL014878

Publisher: American Geophysical Union

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the End User Agreement.

www.reading.ac.uk/centaur
CentAUR
Central Archive at the University of Reading
Reading’s research outputs online
Twentieth century secular decrease in the atmospheric potential gradient

Giles Harrison
Department of Meteorology, The University of Reading, UK

Received 7 February 2002; revised 8 April 2002; accepted 23 May 2002; published 16 July 2002.

[1] Current flowing in the global atmospheric electrical circuit (AEC) substantially decreased during the twentieth century. Fair-weather potential gradient (PG) observations in Scotland and Shetland show a previously unreported annual decline from 1920 to 1980, when the measurements ceased. A 25% reduction in PG occurred in Scotland 1920–50, with the maximum decline during the winter months. This is quantitatively explained by a decrease in cosmic rays (CR) increasing the thunderstorm-electrosphere coupling resistance, reducing the ionospheric potential $V_I$, independent measurements of $V_I$ also suggest a reduction of 27% from 1920–50. The secular decrease will influence fair weather atmospheric electrical parameters, including ion concentrations and aerosol electrification. Between 1920–50, the PG showed a negative correlation with global temperature, despite the positive correlation found recently between surface temperature and $V_I$. The 1980s stabilisation in $V_I$ may arise from compensation of the continuing CR-induced decline by increases in global temperature and convective electrification. INDEX TERMS: 3304 Meteorology and Atmospheric Dynamics: Atmospheric electricity; 2104 Interplanetary Physics: Cosmic rays; 2427 Ionosphere: Ionosphere/atmosphere interactions (0335); 1650 Global Change: Solar variability

1. Introduction

[2] Current in the atmospheric electrical circuit (AEC) arises from charge-separation in thunderstorms [MacGorman and Rust, 1998], causing a vertical potential gradient (PG) in non-thunderstorm (fair weather) zones. The lower conducting layer of the ionosphere, the electrosphere, establishes a global equipotential region, Figure 1. The surface PG in fair weather conditions represents a fraction of the ionospheric potential $V_I$, and is a measure of the electrical activity of global thunderstorms. In fair weather with no local effects, the diurnal cycles in surface PG and ionospheric potential $V_I$ are similar, resulting from the diurnal cycle in global thunderstorm activity [Whipple, 1929]. The diurnal variation was identified in oceanic PG measurements during voyages of the research vessel Carnegie in the 1920s; it is a characteristic global signature in atmospheric electrical measurements. Kelvin established surface PG measurements in 1861 at Kew Observatory, London [Everett, 1868], and permanent observatories were remote from sources of pollution and regularly showed the Carnegie variation, with rigorous criteria consistently applied to identify the fair weather periods [Harrison, 2002]. Hourly measurements of PG ceased at Eskdalemuir and Lerwick in 1981 and 1983 respectively.

2. Prolonged Decrease in Potential Gradient

[3] A remarkable feature of both observatories’ measurements [Dobson, 1914; HMSO, 1912; Watson, 1928; HMSO, 1965; UKMO, 1983] is the previously unreported and prolonged downward trend in the PG from 1920 to 1980, although the 1951–70 data was affected by nuclear weapons testing [Pierce, 1972]. Removing the 1951–70 data, the two observatories’ annual fair weather PG averages 1927–1981 have a correlation coefficient $r = 0.48$, with a probability $P$ of chance correlation $< 2 \times 10^{-5}$. This suggests a common origin to the decline. A downward trend at Lerwick is particularly surprising, as wind directions from northern Europe frequently [Hamilton, 1965] increased the Lerwick PG. Any common origin for the long-term decrease would have to dominate such local effects.

Figure 1. Simplified global atmospheric electric circuit. Thunderstorms separate electric charge, generating a current flowing through an upper atmosphere coupling resistance $R_{\text{FT}}$ to the lower ionospheric conductive region, the electrosphere. The ionospheric potential $V_I$ drives a vertical current in the fair weather region of the circuit, through the electrical resistances of the free troposphere $R_{\text{FT}}$ and the boundary layer $R_{\text{BL}}$. The measured surface potential gradient (PG) arises from the potential developed across the near-surface resistance, $R_s$. 

Copyright 2002 by the American Geophysical Union.
0094-8276/02/2002GL014878S05.00
Figure 2a shows the longer Eskdalemuir fair weather PG time series, from 1911 to 1981. For the period 1920–50 before the weapons testing data gap, the Eskdalemuir PG decreases at 2.2 Vm$^{-1}$ yr$^{-1}$, with a total PG decrease 1920–50 of 25%. The decrease occurs in all months, but the decline is greatest during the seasonal PG maximum [Israel, 1973], averaging 4.0 Vm$^{-1}$ yr$^{-1}$ in February. Between 1920 and 1950, the annual average numbers of fair weather days selected were 84 ± 3 (Lerwick) and 97 ± 16 (Eskdalemuir). Eskdalemuir showed little seasonal variability in its number of fair weather days, but Lerwick had the majority of its fair weather days (33) in the summer months (June, July and August). The summer data at Lerwick shows a decline of 1.4 Vm$^{-1}$ yr$^{-1}$ (17%) from 1920–50.

3. Possible Causes of the Potential Gradient Decrease

There are several possible causes for the decline in surface PG including (1) calibration drift in the instruments, (2) local effects causing changes in PG and (3) global changes in the AEC. (1) is most unlikely because of careful standardisation [Anon, 1955]. Site and instrument changes were comprehensively reported in the official Observatory Year Books, published annually 1922–1965 [HMSO, 1965]. Other than identifying the nuclear weapons period, no systematic effects were found and no land use changes are apparent. (2) could arise from aerosol or ionisation changes. Air conductivity is increased by ionisation and decreased by cloud or aerosol particles, changing the near-surface resistance $R_s$: surface PG therefore varies inversely with the local air conductivity. Substantial increases in atmospheric ionisation from weapons testing and the nuclear industry only began after 1950 [Harrison and ApSimon, 1994], so are not responsible. If the PG decrease arose from aerosol changes, a decrease in aerosol concentration would be required. There is, however, good evidence of an increase in boundary layer particle number concentration. Synoptic meteorological data from Eskdalemuir independently show a decrease in the frequency of days with good visibility [HMSO, 1950] and air conductivity measurements in northern hemisphere marine air from 1910–1968 decrease by 32%, 1920–1950 [Cobb and Wells, 1970]. A steady local increase in air conductivity is therefore unlikely.
HARRISON: SECULAR ATMOSPHERIC ELECTRICITY DECLINE

4. Secular Cosmic Ray Decrease and the Atmospheric Electrical Circuit

A globally-induced change in electrification (3) would result from a decline in current flowing in the AEC. This could arise from either a decrease in charge generation from tropical convective thunderstorms, or a reduction in the thunderstorms’ electrical output associated with a change in the thunderstorm-electrosphere resistance $R_c$ [Markson, 1981]. A measure of global electrification is the ionospheric potential $V_I$. Studies of recent changes in surface temperature [Price, 1993] show a considerable sensitivity of $V_I$ to global temperature (20% increase in $V_I$ for a 3K change in global temperature); global temperature anomalies using land stations [Peterson and Vose, 1997] are plotted for comparison in Figure 2b. There is a negative correlation between the Eskdalemuir PG and global surface temperature anomalies for 1920–50 ($r = -0.55, P < 0.002$). It indicates that the PG decreased as the global temperature increased. This is surprising, given the usual assumption of increased thunderstorm activity associated with global warming. Surface temperature changes alone therefore cannot explain the long-term decrease in atmospheric electrification.

5. Discussion

It is clear that there has been a reduction in the atmospheric PG 1920–1970, which is quantitatively asso-
ciated with a reduction in cosmic rays. The long-term reduction in current in the AEC will have influenced fair weather atmospheric electricity parameters and the atmospheric processes linked to ions and charged aerosol [Harrison, 2000].

The decline in the PG continued until the mid-1970s, soon after which the PG data ceased to be recorded. At about the same time, however, $V_I$ became relatively constant, despite a continued reduction in CR. The reduction in $V_I$ would have been expected to continue. An explanation for this may lie in the positive response between $V_I$ and surface temperature, at a time of an increase in global temperature. Temperature-induced increases in convection, increasing $V_I$, may have compensated for the continued reduction from cosmic rays.

Acknowledgments. I am grateful to J. Beer for provision of the ice core data and to St John’s College, Oxford for a Visiting Scholarship. The UK Met Office obtained the Lerwick and Eskdalemuir atmospheric electrical data.

References


Everett, J. D., Results of observations of atmospheric electricity at Kew Observatory, and at Kings College, Windsor, Nova Scotia, Phil Trans, 158, 347–361, 1868.


Whipple, F. J. W., On the association of the diurnal variation of electric potential on fine weather with the distribution of thunderstorms over the globe, Quart J. Roy Meteor Soc., 55, 1–17, 1929.

R. G. Harrison, Department of Meteorology, The University of Reading, P.O. Box 243, Earley Gate, Reading RG6 6BB, UK. (r.g.harrison@reading.ac.uk)