Atmospheric electric fields at the Kennedy Space Center, 1997-2005:
no evidence for effects of global warming or modulation by galactic cosmic rays.

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Abstract:

Near surface, atmospheric voltage gradients [E_z] measured at 31 sites of the Kennedy Space Center [KSC], between Aug. 1997 and Dec. 2005, averaged 162.5 ± 3.5 V/m, positive upwards, with a standard deviation of 21.4 V/m and an apparent trend of +0.40 ± 1.04 %/yr. That is, no significant positive trend, predicted to be a consequence of global warming, yet rises above the noise. The correlation of E_z with a monthly index of galactic cosmic rays at Haleakala, Hawaii, was –0.07 ± 0.18, for periods between 2 and 25 months. That is, no significant short-period effect of solar-magnetically modulated cosmic-ray flux on E_z was observed at KSC, during this epoch.

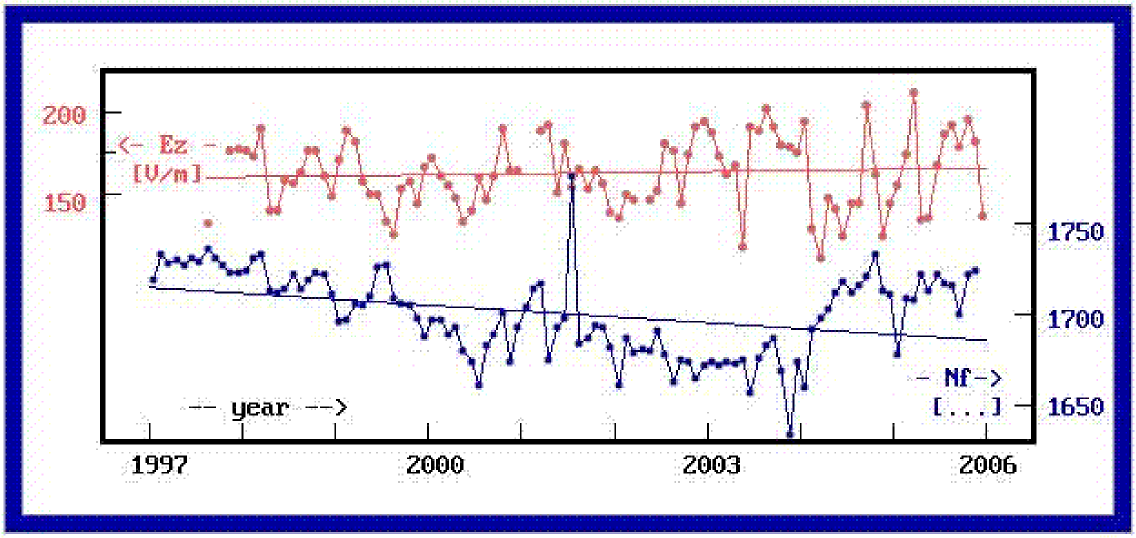

Figure 1:

Atmospheric voltage gradients, E_z V/m, positive upwards, at KSC, 1997-2005, and a galactic cosmic-ray index, N_f [neutron counts per hour at Haleakala, Hawaii, arbitrarily rescaled to match an earlier record at Huancayo, Peru].

I. Introduction:

This note explores KSC data to test E.R. Williams' suggestion that E_z should increase, owing to global warming [Williams, 2005], and R.G. Harrison's hypothesis that galactic cosmic rays modulate the near-surface electric-field [R.G. Harrison, 2003a][1]

A negative secular trend of E_z at the Eskdalemuir observatory in Scotland between 1911 and 1981 shows a remarkable 27% reduction between 1920 and 1950, ≈ -1%/yr [R.G. Harrison, 2003a]. Similar decreasing trends are reported over shorter intervals at Lerwick, Scotland, 1927-1937, [R.G. Harrison, 2003b], Davos, Switzerland, 1909-1926, [Israel, H., and H. Dolezalek, 1973], Sierra do Pilar, Portugal, 1967-1977 [F. Marcz and R.G. Harrison, 2005], and Nagycenk, Hungary [F. Marcz and R.G. Harrison, 2003]. The apparent trend at Nagycenk may be an artifact of local tree growth near to the detectors [Williams *et al*., 2005]. Williams further suggests that continentally scaled trends in aerosol concentrations may alternatively explain the apparent E_z trends in Europe [Williams, 2003]. R.G. Harrison replies that declining E_z more likely results from a multi-decadal weakening of the solar magnetic field, which otherwise partly shields the earth's atmosphere from a low energy fraction of ionizing galactic cosmic rays [R.G. Harrison, 2003b].

During the period of atmospheric weapons testing [1945-1963] E_z at Eskdalemuir dropped to half its values before and since, owing to the increased conductivity of the lower atmosphere that resulted from transient radioactivity. In the more recent epoch it may be that the atmosphere's conductivity and E_z is affected also by an upward trend in ^{85}Kr, a beta emitter with 11-year half-life that is released in the processing of nuclear fuel. As recently as 2004 atmospheric radioactivity from ^{85}Kr was increasing at about 2.5%/yr. [K. Smith *et al*., 2005. See also Harrison, R.G. and H.M. ApSimon, 1994].

Near-surface E_z is sensitive to continental radioactivity, corona from local power lines, salt spray, fog and rain, and to electrical activity in near-by clouds. E_z is further modulated by variations in boundary-layer turbulence and by the atmosphere's near-surface conductivity, which in turn is influenced by haze and aerosols. These complexities significantly frustrate efforts to use local data to derive meaningful geophysical insight about the global electric circuit, with the result that, with a few exceptions most long-term sites have been abandoned.

Chief among the exceptions is a network of 31 near-surface field mills at the Kennedy Space Center [KSC], maintained there since 1970, following a post-launch lightning strike and near tragedy of the Apollo 12 mission of 19 Nov. 1969. Field mills are both more stable and easier to calibrate than the electrometers commonly deployed before 1970. At KSC, 31 field mills operate within a few kilometers of one another, and most afternoons are refreshed by marine air.

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[1] E_z , the atmospheric voltage gradient, is <u>defined</u> here as positive upwards: $E_z = dE/dZ =$ [E(up) – E(down)]/[Z(up) – (down)] (Volts/meter). The standard convention defines 'electric field gradients, $d\varphi/dZ$, as positive in the direction that a small test charge would move in the applied electric field, φ. In the atmosphere, $d\varphi/dZ$ is positive downwards, and $E_z = - d\varphi/dZ$. [See H. Israel, 1973, chapter V,b: 'The sign problem', page 319.

II. Data:

Ez at KSC are recorded every 0.1 sec at 31 field mills, approximately 300 GBytes for the 9 years of this study. Samples of 0.1-sec data were plotted and examined visually to verify that high- and low-variance electric-field weather are distinguishable by their qualitative appearance, both individually and among the stations. To filter out effects of high-variance local weather, the 0.1-second data were vigorously processed by multi-step down-weighting of outliers, proportionally to the squared reciprocals of their deviations from the evolving robust means [Appendix A.].

As one test that this process substantially removes high-variance effects of local weather, hourly E_z data were sequentially regressed against their diurnal waves [yearly averaged as in Appendix A], then against hourly wind speeds and directions, pressure, temperature, and binary indices of cloud cover, fog, hail, thunder, rain, and snow reported at KTIX [Space Coast Regional Airport, Titusville, Florida: lat. 28.5167N, lng. 80.8000W, across the sound from the Kennedy Space Center]. None of the weather variables added significant correlant power that was not better attributed to the diurnal wave. Similarly, no significant correlations were discovered between daily averaged E_z with daily sunspot numbers and areas, x-ray fluxes, solar radio-frequency emissions, and hemispherically averaged solar insolation.

By visual inspection E_z at KSC did not correlate with either El Nino nor La Nina events between 1998 and 2005, though too few cycles of either occurred in that interval, to be significant. The annual wave of E_z at KSC, however, does show a marginally significant minimum during April and May, an observation that is not consistent with summer maxima reported by Adlerman and Williams [1996].

Field-mill data at KSC between 1994 and 1997 were not accessible for this study. Data before 1994 appear to have been erased.

A monthly index of cosmic-ray produced neutron flux [N_f] at Haleakala was obtained from the National Geophysical Data center [NOAA, 2005]. Further details of data access and processing are described in Appendix A of this note, and in a supplementary reconnaissance published as a web document [H. Harrison 2004].

III. Results:

Figure 1 displays monthly E_z and N_f data from Aug. 1997 through Dec. 2005. In this epoch E_z at KSC averaged 162.5 ± 3.5 V/m [positive upwards] with a standard deviation of 24.1 V/m. The apparent trend was +0.40 ± 1.04 %/yr, corrected for persistence. That is, no significant positive trend yet rises above the noise.

During the same 9-year epoch the index of galactic-ray modulated neutron flux [N_f] averaged 1707.9 ± 5.8 [x100], neutron counts per hour, arbitrarily rescaled to patch onto an earlier record at Huancayo, Peru. A significant downward trend of N_f [–0.21 ± 0.14 %/yr] was driven during the first part of this epoch by a negative phase of the 11-yr solar cycle, which reversed in 2004. The net correlation of E_z with N_f [$r = -0.07 \pm 0.18$, 2 to 25 months] does not support the suggestion that E_z is affected by solar-magnetic modulation of galactic cosmic rays [*R.G. Harrison, 2003a*].

IV. Discussion:

E_z is predicted to increase with global warming [Williams, 2005.] In a much simplified model, E_z is expected to vary approximately with the incidence of lightning, which in turn varies with partial pressures of atmospheric water vapor, $p_v(T)$, in the tropical regions where both lightning and surface water are most prevalent. During the last three decades the earth's mean temperature over land has increased ~0.6 K, or at 0.02 K/yr [NASA, 2004]. With the Clausius-Clapeyron equation, $100\ d[\ln(E_z)/dT] \approx 100\ d[\ln(p_v)/dT] \approx 100\ [L_v/(R_vT)]\ [(dT/dt)/T] \approx 100\ [17.6][0.02/300] \approx +0.12\ \%/\mathrm{yr}$[2]. The value observed in the present study was $+0.40 \pm 1.0\ \%/\mathrm{yr}$**;** that is, the standard error exceeded the derived value. However, a $+5^o$ K global warming associated with a future doubling of atmospheric CO_2 might by this simple model result in $dE_z/E_z \approx 30\%$, which is both not negligible and is comparable to presently observed latitude-dependent effects associated with 5^o K [NASA, 1999].

Negative trends in E_z are observed at several European sites, but no evidence appears in those records for an 11-year modulation by the solar cycle. Because ionization and its recovery in our atmosphere occur in times very much less than decadal, it seems useful to test for correlations at shorter intervals. This note tests the effects of cosmic rays [with N_f acting as a surrogate for the conductivity of the upper and middle atmosphere] at shorter periods by examining the correlation of E_z with N_f, the flux of atmospheric neutrons measured at Haleakala [3048 m ASL], which is an inverse measure of the solar magnetic field.

Note in figure 1 that both E_z and N_f may be approximated by straight lines, with opposite slopes. Were they perfectly straight one would expect a correlation, r, of –1.0, with infinite uncertainty. Spectral analysis of the products of E_z and N_f reveals that ~70% of the apparent gross correlation [$r = -0.10 \pm 0.16$, 2 to 105 months] is associated with periods between 2 and 25 months. As the standard errors of partial correlation coefficients, r(P), associated with periods P are approximately equal to $[\boldsymbol{df}(\mathbf{P}) - 4]^{-1/2}$ with ***df(P)*** in this special case approximately equal to the number of complete cycles at periods P, the components of the gross correlation associated with periods longer than 25 months [$\boldsymbol{df}(\mathbf{P}) \leq 4$] are not significant [Appendix A]. For periods between 2 and 25 months, the residual correlation between E_z and N_f is -0.07 ± 0.18, which again is not significant.

A readable introduction to the physics of atmospheric electric fields is presented by R.G. Harrison [2003a]. Briefly, positive charge is transferred upwards to the upper atmosphere [or negative charge downwards] from [or to] the tops of electrified cumulus towers, mostly tropical and mostly over moist continents. The ionospheric potential, V_i , quickly globalizes [minutes]; then current, I_i , leaks slowly [days to weeks] back to the surface through the very high impedance, R_u, of the upper atmosphere. A tiny fraction of the total potential drop may be measured across a resistance, R_z, of the lowest meter, z,

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[2] L_v, the latent head of vaporization of water at 300 K = 2.44×10^6 J/kg. R_v, the gas constant for water vapor = 461 J/deg/kg. $T \approx 300$ K.

above the surface. That voltage, $V_o = V_i R_z / (R_u+R_z) = I_i R_z$, infers a near surface $E_z = dV_o/dz \approx V_o / z$, positive upwards.

The implicit mechanism by which the solar magnetic field might modulate E_z begins with the assumption of more or less steady flux of galactic cosmic rays, mostly protons, that impinge upon the solar system [R.G. Harrison, 2004]. A fraction of these is deflected by the sun's varying magnetic field, which thus modulates the flux of ionizing particles, the conductivity of the earth's upper atmosphere, and the production of neutrons [N_f] by $p \rightarrow n$ interactions with nitrogen nuclei. Then if the charging mechanism of the ionosphere acts substantially as a constant voltage source, V_i remains approximately constant, and a *decrease* in the solar magnetic field would simultaneously *increase* N_f, *decrease* R_u [leaving R_z substantially unaffected], *increase* the apparent E_z, and produce a positive correlation between E_z and N_f. Conversely, if the charging mechanism of the ionosphere acts substantially as a constant current source, then $E_z \approx I_i R_z$ would be expected to be largely independent of the solar magnetic field and N_f, as appears to be the case.

V. Summary:

This study found no significant trend in E_z nor correlation between E_z and N_f. It therefore does not support the hypotheses that the atmospheric electric-field is increasing from global warming, nor modulated by the solar magnetic field, and it implies a charging mechanism for the ionosphere that acts more nearly as constant current than constant voltage.

V. Acknowledgement:

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Appendix A: Data Reduction

The task is to discriminate against the relatively rare but large-amplitude excursions of E_z that are associated with local weather, in files too verbose for manual inspection.

For every 0.1-sec data line reporting E_z at 31 stations, entries at sites 3, 22, 23, 24, and 31 were rejected owing to reported systematic difficulties of instrumentation or site location, as for example from contamination by salt spray or corona from near-by power lines. At the remaining 26 sites, measured E_z were rejected if zero or less, or greater than + 500 V/m, positive upwards. If 10 or more sites reported non-default E_z, their median was calculated and accepted as representing that 0.1-sec data line. Otherwise that line was rejected.

The surviving 0.1-sec data lines, among the maximum of 18,000 lines that may comprise one 30-minute segment, were fitted to a least-squares straight line $Y = A + BX$, with X set equal to the time index in the segment, from 1 to 18,000. The midpoint of the fitted line [$Y_{mid} = A + B\ 9{,}000$] was accepted as a 'best' single estimate of E_z in that 30-minute window, and it was tabulated together with the standard deviation and the fraction of non-default data lines in that window.

These 30-minute E_z were then robustly averaged into the monthly entries $<E_z>$ of figure 1 by an iterative process which repeatedly weighted each 30-minute E_z by

w = $F / \{SD^2 + [E_z - < E_z>]^2\}$, where
F = the fraction of non-default data lines. [Most F were 100% of 18,000.]
SD = the internal standard deviation within each 30-minute window, typically 5-10 V/m..

E_z = the mid-point value for the 30-minute atmospheric voltage gradients, from the previous step.
$<E_z>$ = the robustly average monthly gradient, V/m, initially set to 160 V/m, then iteratively updated. After 100 iterations the external root-mean-square of monthly averaged [$<E_z>_{n+1} - <E_z>_n$] was in all cases less than 0.05 V/m.

These steps were extremely laborious, requiring two or more weeks of continuous computer operations for every year parsed, plus numerous repeats for consistency and to correct errors. Years 1998 and 2003 were reduced completely by this recipe. In inelegant but project-saving economy, years 1997 and 1999-2002 were reduced for every other day with uniform random sampling of 3 to 13 [average = 8] 30-minute windows of each day, and years 2004 and 2005 were reduced for every third day, for every half hour.

The standard deviations cited in this note were computed conventionally as $SD = [<Y^2> - <Y>^2]^{1/2}$ with < > denoting simple averages over all non-default observations, $Y = E_z$, N_f , and each of the 48 half-hourly averages of the diurnal wave, which were averaged over all years. Standard errors of means and correlations were defined as $SE = SD / \sqrt{df}$ with ***df*** equal to the disposable degrees of freedom, corrected for persistence with the lag-one autocorrelation coefficients, r_1, as

$$\boldsymbol{df} \approx N_{obs}\,(1 - r_1) / (1 + r_1) - K$$

$N_{obs} = 95$, the number of monthly observations. K equals 1 for simple means of E_z or N_f , 2 for their trends, and 4 for their crossed correlation.

The standard errors of trends in E_z and N_f were computed as

$$SE = \{< [(Y_t - A - BX_t)^2\,(X_t - <X>)^2\,]>^{1/2}\,\} / [<X^2> - <X>^2]\} / \sqrt{\boldsymbol{df}}$$

with $Y_t = E_z$ or N_f at time X_t = Year + (month – ½) / 12. The coefficients A and B were determined by least-squares best fit to the straight-lines $Y_t = A + BX_t$.

In the limit of small r, the standard error of crossed correlation coefficients, SE(r) , is ≈ $1/\sqrt{\boldsymbol{df}}$.