The Global Atmospheric Circuit from Antarctic Plateau Electric Field Measurements at Vostok and Concordia

G.B. Burns[1], A.V. Frank-Kamenetsky[2], B.A. Tinsley[3], W.J.R. French[1], P. Grigioni[4], G. Camporeale[5], E.A. Bering[6]

[1]Australian Antarctic Division, Climate Processes and Change, Kingston, Australia.
[2]Arctic and Antarctic Research Institute, Geomagnetism, St Petersburg, Russia.
[3]University of Texas at Dallas, Physics, Richardson, USA.
[4]ENEA, Centro Ricerche Casaccia, Rome, Italy.
[5]ENEA, Centro Ricerche Brindisi, Brindisi, Italy.
[6]University of Houston, Physics, Houston, USA.

The Global Atmospheric Circuit from Antarctic Plateau Electric Field Measurements at Vostok and Concordia

A brief review of earlier results and a discussion of new, unpublished Antarctic Plateau Ez results containing 3 years of overlapping and simultaneous observations

Surface pressure is shown to vary with overhead ionospheric potential changes. The potential changes are driven by both solar wind and internal atmospheric generators.

Monthly-average Ez diurnal variations reflect the seasonally changing output of the thunderstorms and electrified cloud generators at low latitudes.

The Antarctic Ez data are sorted according to several sets of criteria for rejecting local variability to examine a local summer-noon convection influence, and to improve estimates of the global signal.

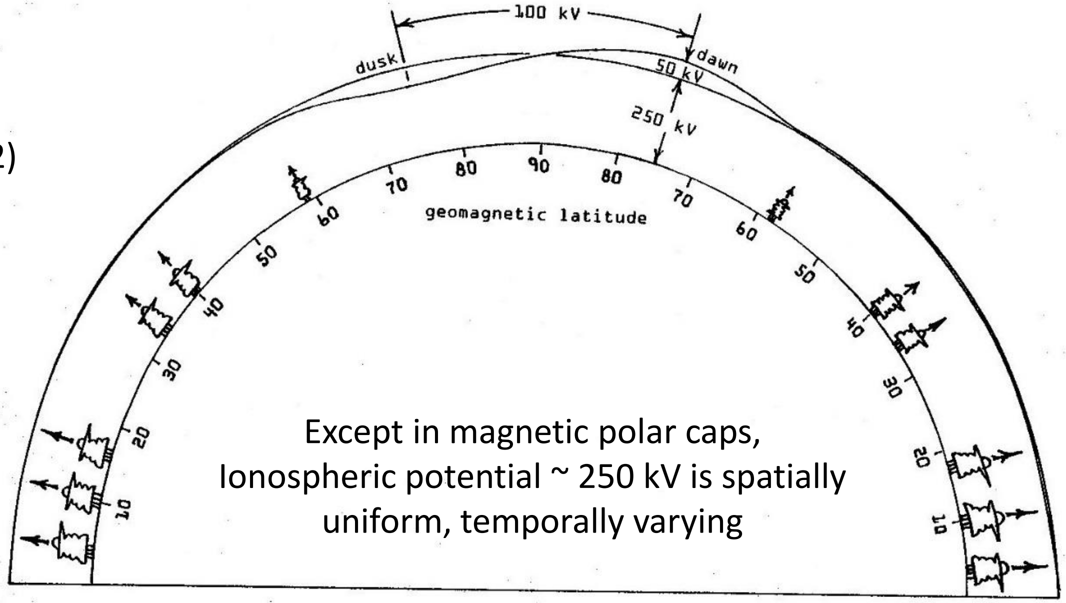
The relatively small contribution to ionospheric potential and surface electric field of the solar wind influence is evaluated and removed to obtain the global signal.

Atmospheric electric field measurements from Concordia station on the Antarctic Plateau are compared with those from Vostok (560 km away) for the period of overlap (2009-2011), to reliably demonstrate the day-to-day variability of the global ionospheric potential variations.

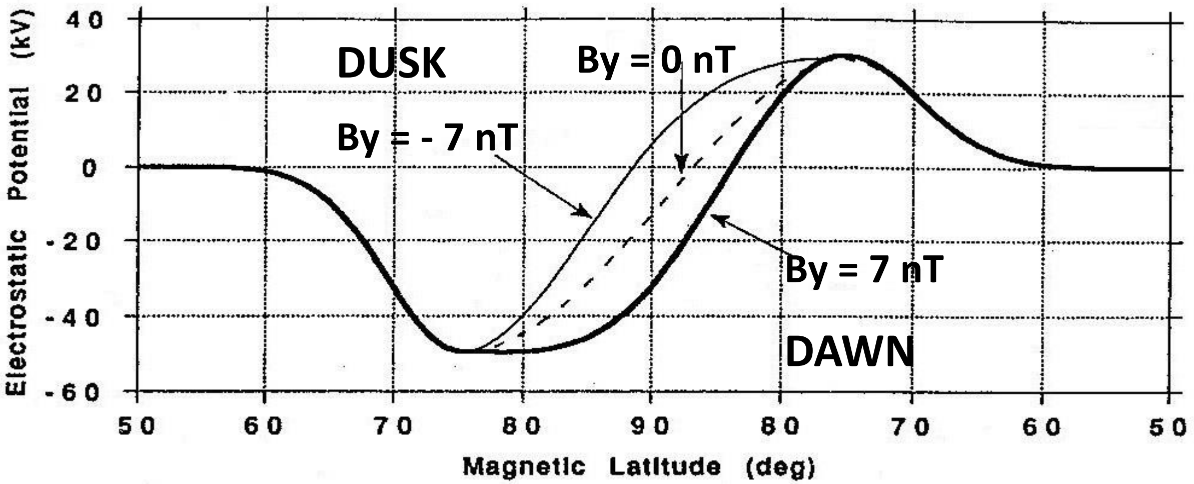
The Carnegie (1915-1929) diurnal variations are reconstructed with error bars, and compared with the new measurements

POLAR CAP IONOSPHERE POTENTIALS from SOLAR WIND VxB FIELDS

Arctic
(Markson, 1982)



Arctic
(Tinsley and
Heelis, 1993)

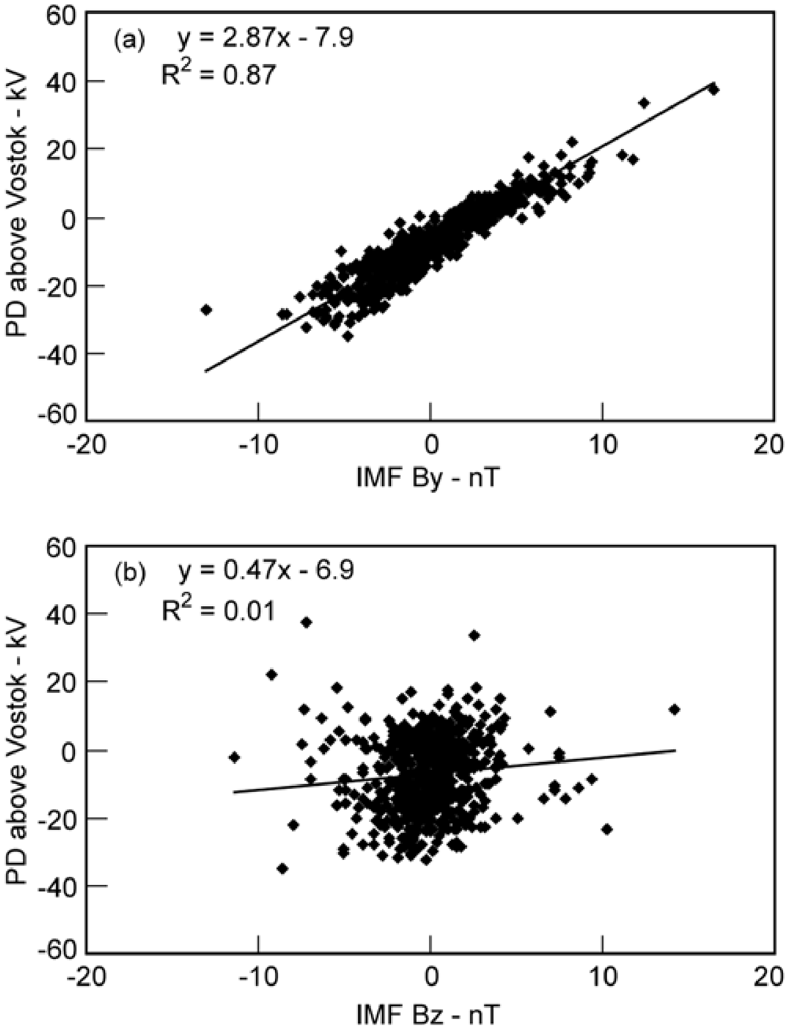


Within 30^0 of magnetic poles solar wind (**V**x**B**) electric fields generate potentials superimposed on the thunderstorm generated ionospheric potential.

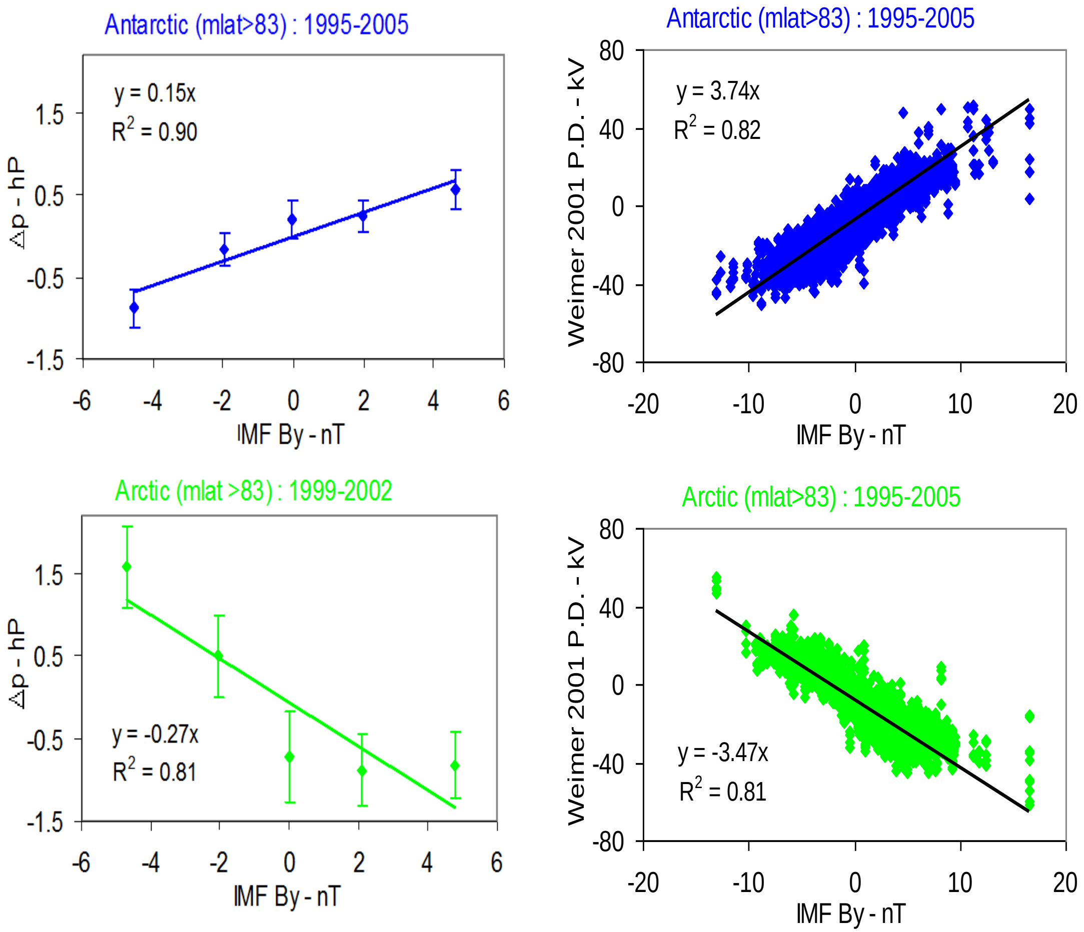
The $\mathbf{B_z}$ component gives dawn and dusk potential excursions, maximizing 15^o from the magnetic poles.

The $\mathbf{B_y}$ component maximizes at the magnetic poles.

Weimer IMF **By** Ionospheric Potential change, and Polar surface pressure change, in Antarctic & Arctic



IMF By, not IMF Bz, dominantly controlled the daily-average solar wind influence on the ionospheric potential above Vostok (magnetic latitude 83 S°). (Burns et al. 2007, using Weimer model,)

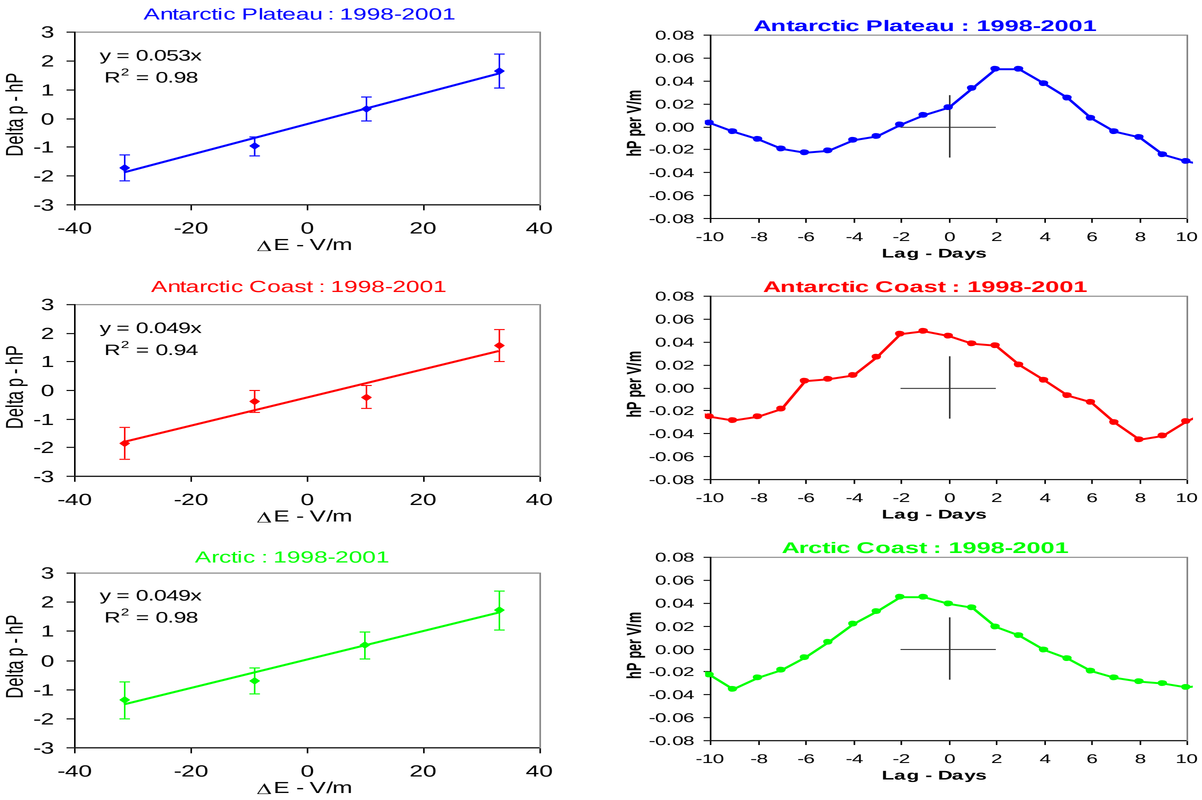


'Mansurov effect' confirmed as IMF By influences ground-level pressure at high SH mag. lats. Opposite Arctic pressure response, as expected from solar wind influence on local atmospheric circuit. (Burns et al 2008).

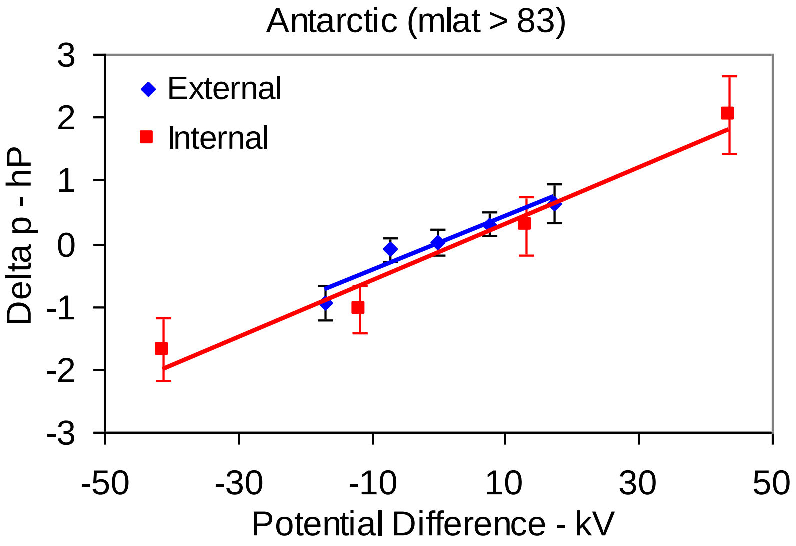
Polar Surface Pressure and the Global Ionospheric Potential

If IMF By (external generator) is influencing ground-level pressure via the atmospheric circuit, then a larger pressure variation would occur via the dominant meteorological generators (thunderstorms & strongly electrified clouds; internal generator) and this internal generator influence would be positive at high magnetic latitudes in both hemispheres.

Daily average Vostok Ez measurements, corrected for the solar wind influence, are a proxy for the day-to-day variability of the meteorological generators of ionospheric potential

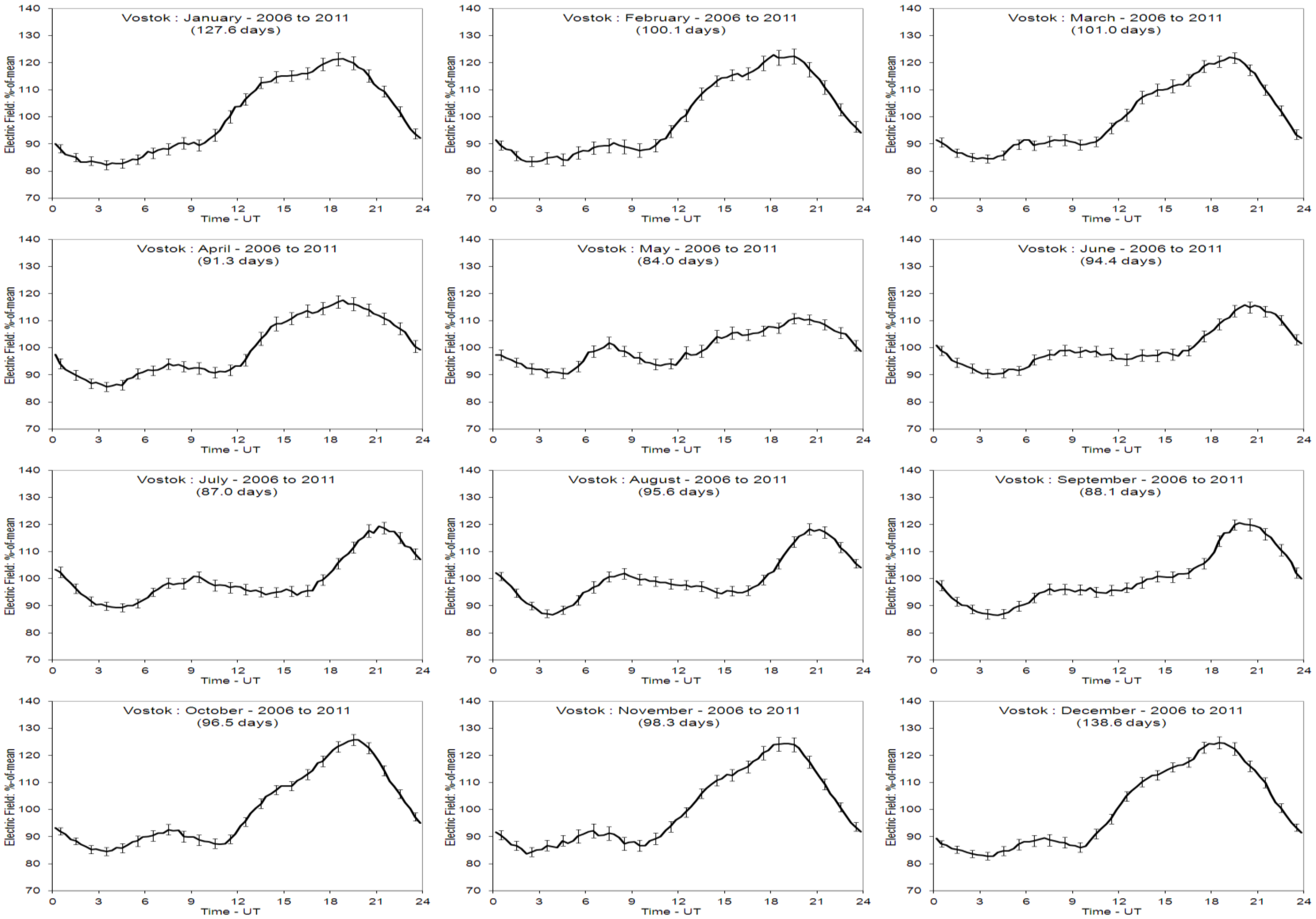


There is a positive pressure association between electric field (from the meteorological generator) and surface pressure on the Antarctic Plateau (4 sites), Antarctic Coast (7 sites) and Arctic (7 sites); but a different lag response for the Antarctic Plateau. (Burns et al, 2008)



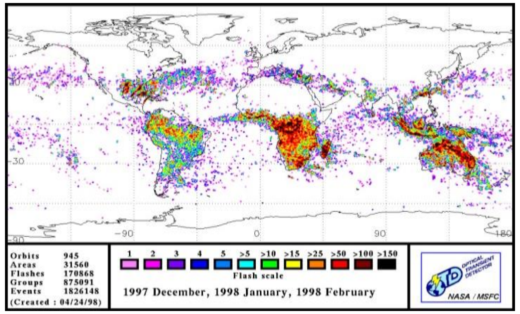
The Antarctic Plateau ground-level pressure response to the internal (meteorological) and external (IMF By) generators is similar when compared via their respective influence on the Atmospheric Electric Circuit (Burns et al 2008)

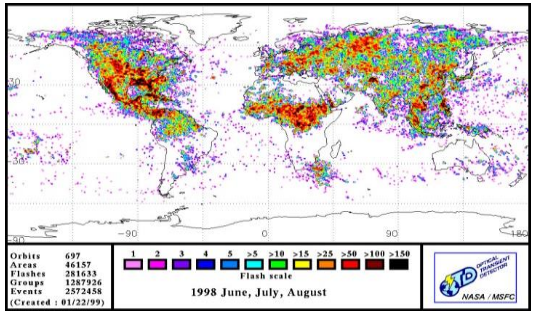
Vostok (2006-to-2011) Monthly Diurnal Averages : %-of-mean



Monthly diurnal-averages for Vostok (2006-11) with at least 84 days sampling-for-each-month. These curves are corrected for diurnal temperature variations derived using a multi-variate analysis in doi: 10.1175/JAS-D-11-0212.1 (JAS-2012). The seasonal shift in the diurnal peak and range-as-%-of-mean (see plot to right) is more readily apparent. Errors are ±1 standard error.

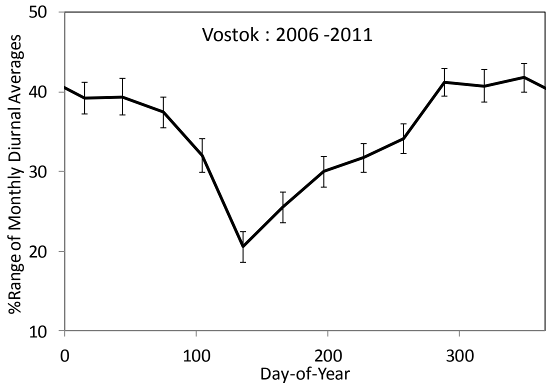
Monthly variations in the global chimneys are apparent, using the Vostok data set.



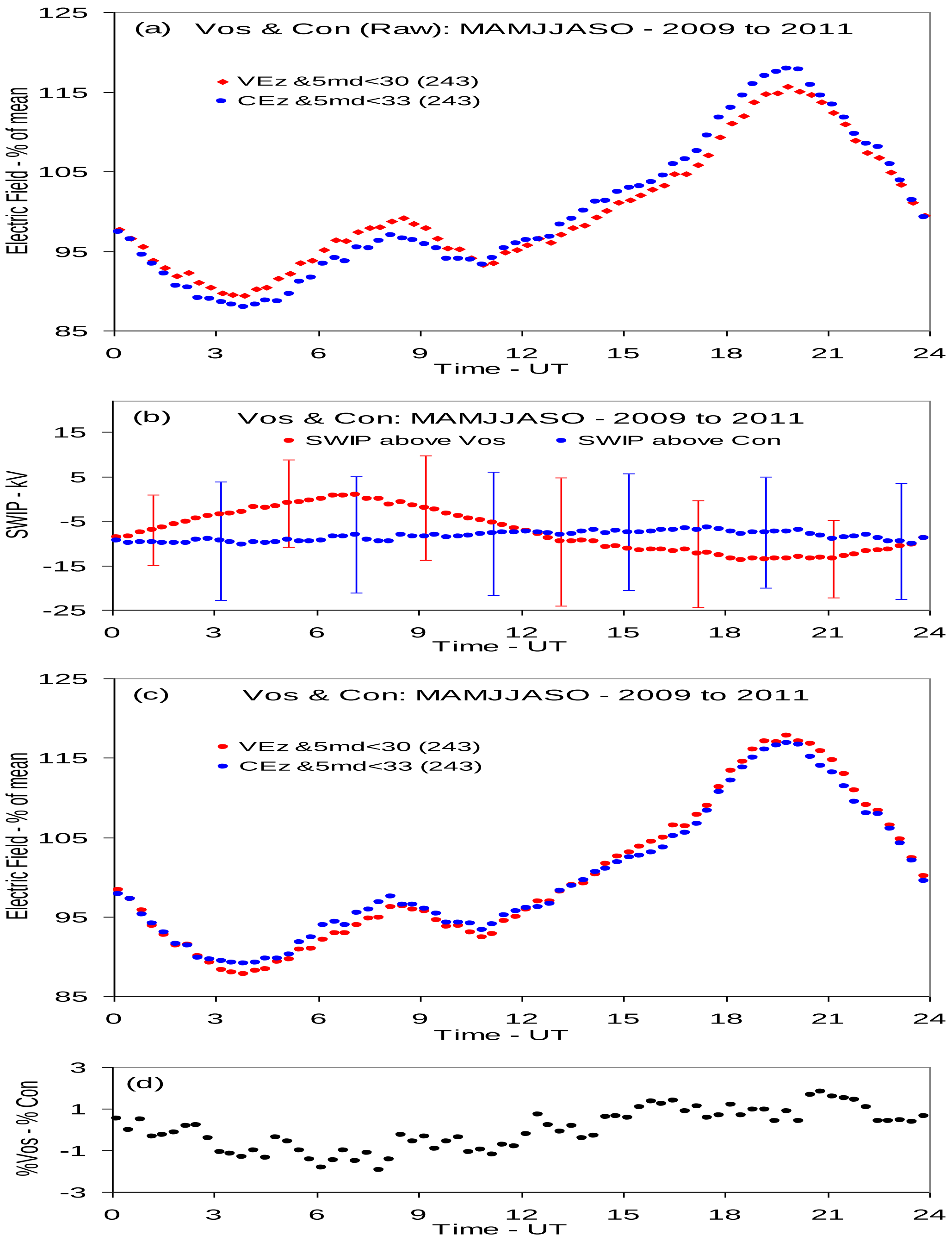


(http://thunder.msfc.nasa.gov/data/OTDsummaries)

Above plots show the seasonal variation of global lightning . The North & South America longitude difference drives the seasonal shift in Ez diurnal peak. The larger SH Pacific gap influences the seasonal shift in the range-as-%-of-mean . (Note: both thunderstorms & strongly electrified clouds contribute to the AEC).



Solar wind influence in simultaneous Vostok & Concordia average diurnal Ez variations (MAMJJASO)



The average solar-wind influence on the ground-level Ez is small but apparent .

We make an initial Vostok & Concordia comparison across the best months (=MAMJJASO), using the best data (='Strictest' 5-min variation rejection).

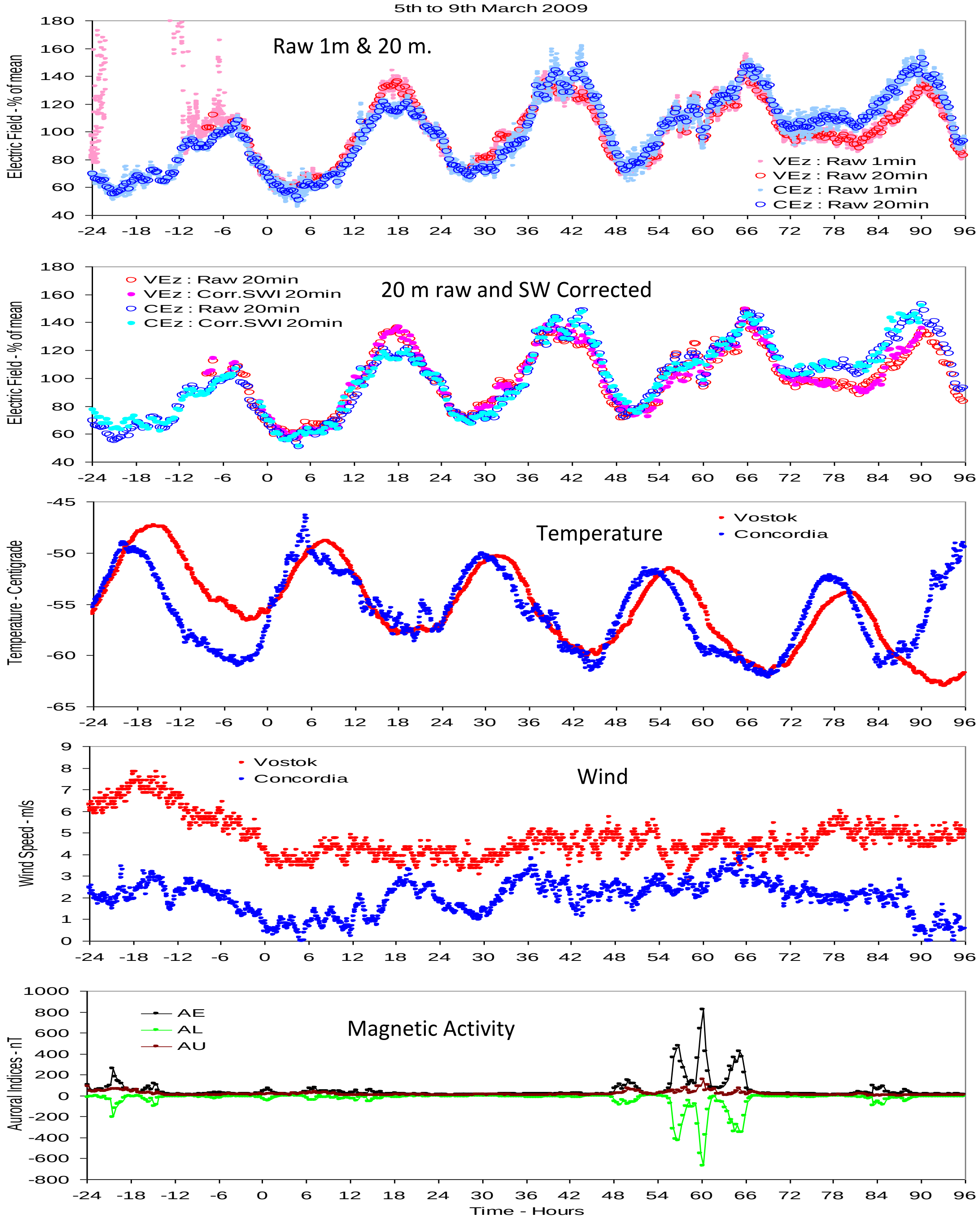
(a) The upper plot separately shows the Vostok and Concordia MAMJJASO raw Ez, simultaneous data, diurnal-averages for the strictest selection criteria, presented as 'percentage-of-the-mean'.

(b) Average solar-wind-imposed potential (SWIP) above the sites, with indicative variability (±1 standard deviation). The Vostok (mag. lat. 83.6°) diurnal average shows a broad dawn-to-dusk variability about local magnetic noon (~13.2UT). The diurnal average of the near-magnetic-pole Concordia (mag. lat. 89.0°) SWIP is broadly flat, but the day-to-day variability is similar to Vostok (mainly IMF By influences at both sites).

(c) Diurnal averages with the solar wind ionospheric potential (SWIP) influence removed. The match between the Vostok & Concordia diurnal averages is visually improved. The diurnal root-mean-square (rms) difference for the SWIP-corrected curves is 0.95%. For the less restrictive '5-minute variability' comparisons the rms values are 1.02% and 1.12% respectively. Again demonstrating the higher quality of the Strictest data set.

(d) Differences between the corrected Vostok and Concordia diurnal curves. This is broadly a sinusoid, asymmetrical about ~13UT (near local magnetic noon for Vostok) suggesting incomplete correction using the model-calculated SWIP.

Five Consecutive Days of Vostok & Concordia Ez



Stacked plots of electric field measurements (raw data then corrected for SWIP), temperatures and wind speeds at Vostok and Concordia, and AL, AU and AE auroral indices, for five consecutive days in March 2009.

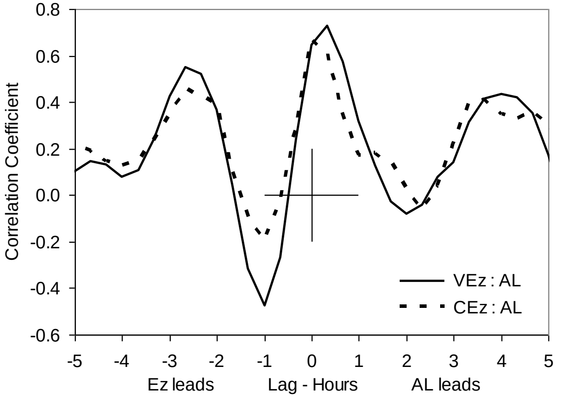
The shape of the diurnal variations changes from day-to-day, in a manner broadly consistent between the sites. The covariance for the middle 3 days is 92%.

These five days show an upward trend in Ez and a downward trend in temperature, at both sites. A statistically significant, inverse temperature average association with Vostok Ez has been reported using a multi-variate analysis in doi: 10.1175/JAS-D-11-0212.1 (JAS-2012).

Local meteorological influences are also apparent. Comparing the Vostok raw 1-minute electric field values with the wind speed for the earliest day show how small variations in average wind speed can dramatically alter the electric field. This is a common Ez observation in Antarctica and is likely due to lifted snow modifying the local space charge or conductivity (e.g. JASTP, 57,1783-1797, 1995).

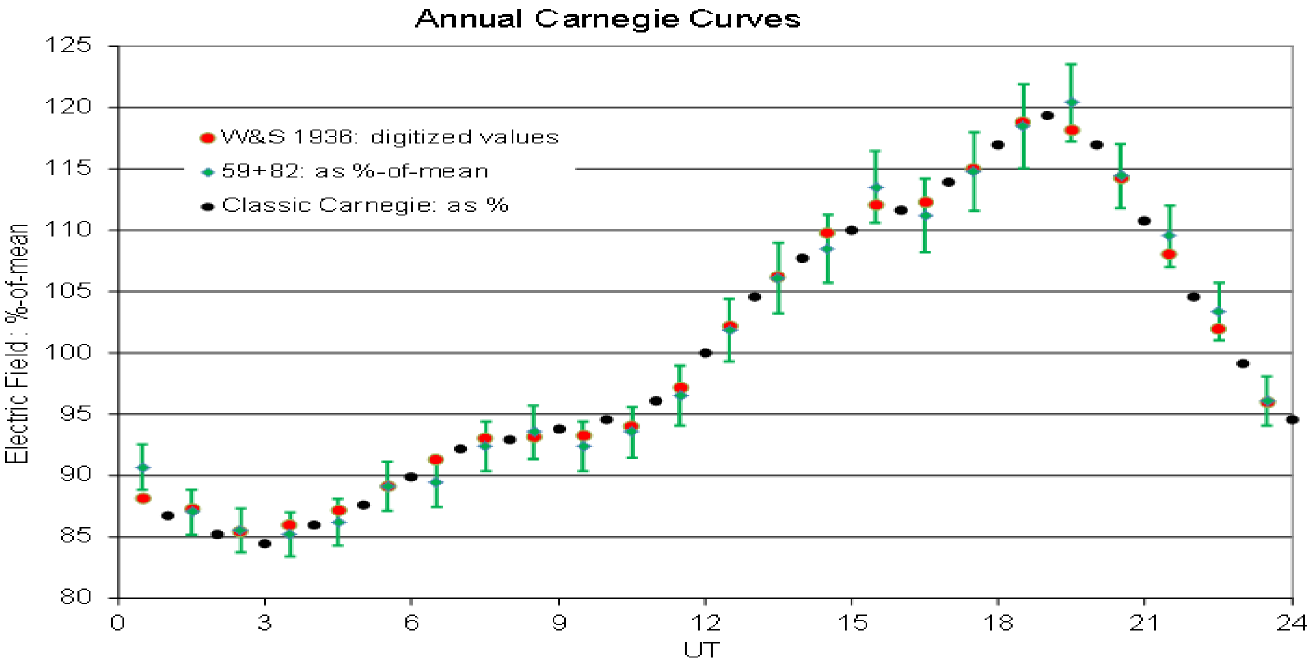
Near the commencement of the fifth day (around 72 hours) there is a separation of the Vostok and Concordia electric field measurements. For the major portion of the day some difference in the ratio of column to near-ground-level conductivity, or space charge, between the sites has resulted in a difference between the Ez measurements at the sites.

An example of auroral substorm influence is apparent around 60 hours. *AL* and *AU* broadly measure the intensity of the evening and morning auroral electrojets respectively. *AE* is a general auroral activity index, calculated as *AU – AL*. To the right, lead-lag regression coefficient plots of VEz : *AL* and CEz : *AL* are shown. For the 6-hour interval compared, the regression coefficient peaks at greater than 0.65 for both stations, at an interpolated Ez lag of between 0 and 20 minutes.

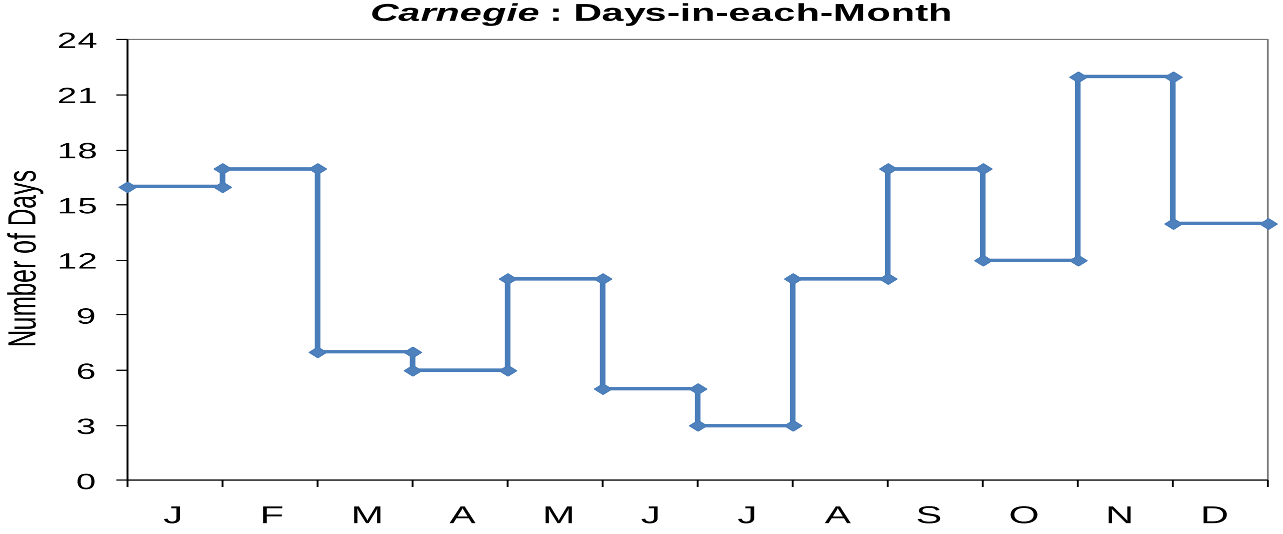


The Carnegie Curve

Plotted (to the right) are the Classic Carnegie Curve (black dots) (Israel, 1973) and '59+82' Carnegie fair-weather days (from 1926-Carnegie-report by Ault & Mauchly and the 1946-Carnegie- report by Torreson, Parkinson, Gish & Wait; green diamonds with +/-1 error-in-the-mean bars), both scaled to '%-in-the-mean' to allow comparison with a digitisation of the Whipple and Scrase (1936) Carnegie curve (red dots).

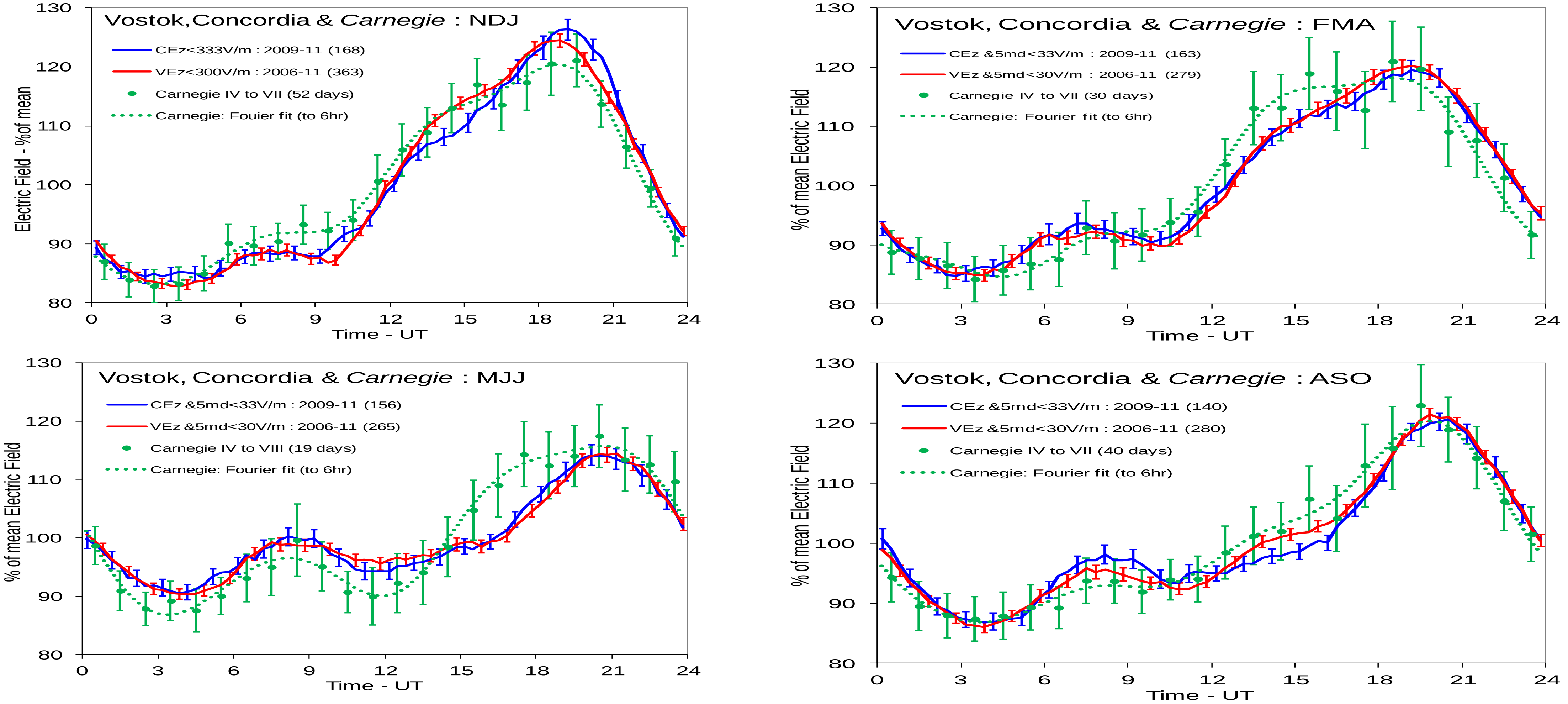


Plotted (to the right) are the number of days in each month comprising the Classic Carnegie Curve.



The Classic Carnegie Curve has variable coverage of individual months and a poor seasonal balance.

Vostok, Concordia & *Carnegie* : Comparison of Seasonal Averages



Vostok (2006-2011), Concordia (2009-2011) & *Carnegie* (1915-1929) diurnal-average seasonal plots.

There are no significant differences between the curves within each season; but there is an apparent seasonal shift in the diurnal peak (NDJ = earliest, MJJ = latest) and range-as-%-of-mean (NDJ = largest, MJJ = least).

There is a stronger Europe-Africa influence in the MJJ & FMA *Carnegie* curves (not statistically significant), but these are the least-well sampled *Carnegie* seasons [MJJ = 19 days (May=11, Jun=5, Jul=3); FMA = 30 days].

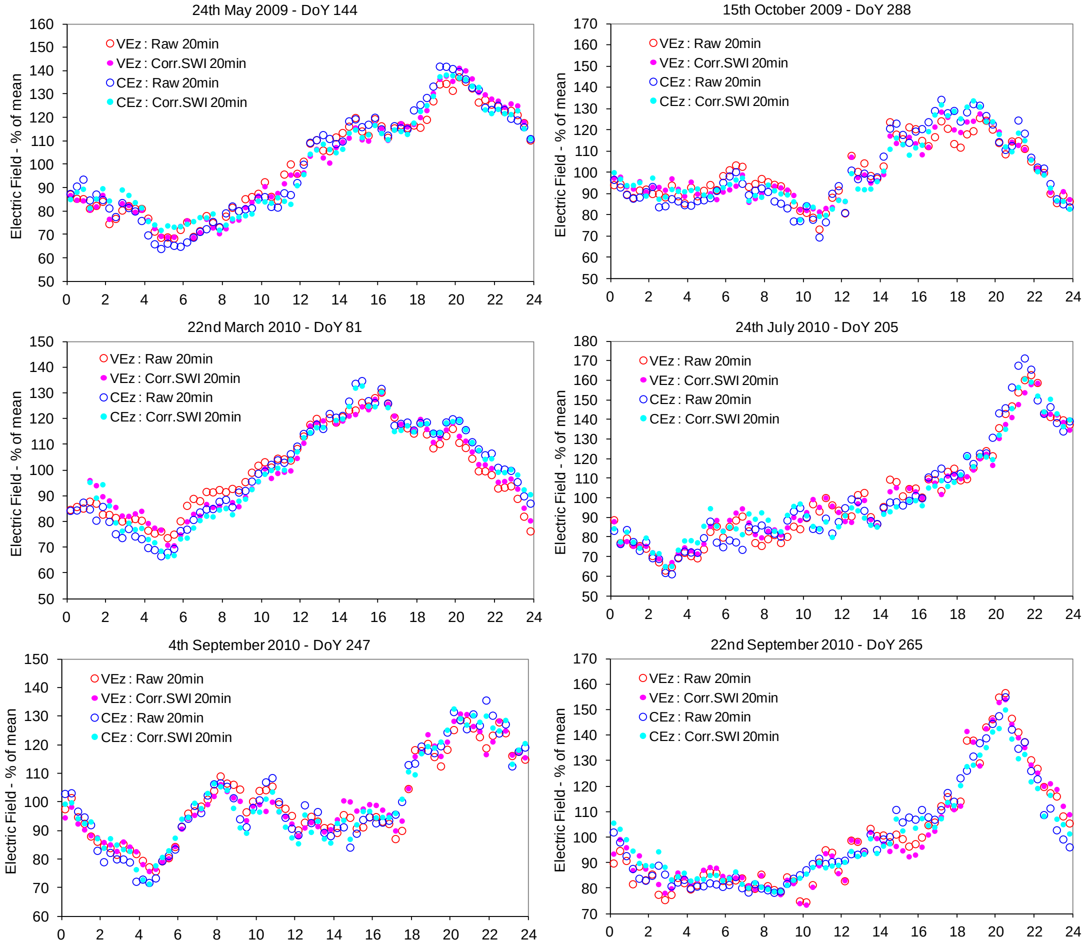
The standard errors demonstrate the increased resolution of the modern data sets.

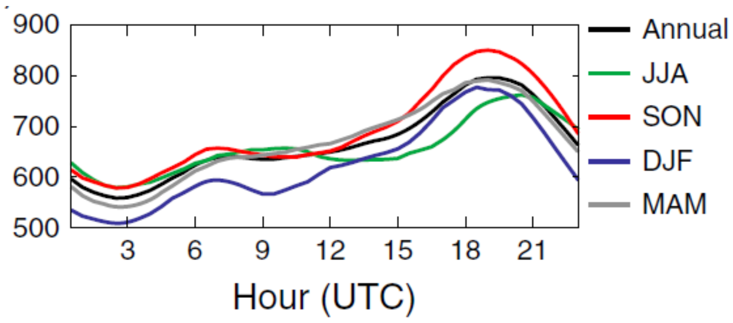
Better Data for Investigating the Meteorological Drivers of the AEC

While Ez measurements depend strongly on local conditions, the similarity of individual Vostok and Concordia days (see plots below-left) suggest substantial differences in the day-to-day contributions of the meteorological chimneys to the AEC. These days provide opportunities for matching Ez with global meteorological convection to investigate the AEC contribution from thunderstorms and strongly electrified clouds.

Similarly, the improved monthly-diurnal averages (presented earlier – slide 6) provide new opportunities for statistical comparisons with global meteorological electrical-convective activity.

The World Wide Lightning Location Network (WWLLN), for example, provides the resolution for both daily and monthly comparisons; and has published some encouraging insights (below-right).





Above is from a published analysis of WWLLN data. Hutchins et al., (2014) doi:10.1002/2013JA019593.

The seasonal diurnal-averaged 'thunderstorm counts' (above; their figure 5c) show a seasonal variation in the diurnal maximum and range-as-%-of-mean similar to the Vostok (2006-11) Ez data.

The conversion from lightning measurements to global current is problematic (discussed and approximated in the referenced publication).

This approach shows promise.

Conclusion and the Future

Conclusion:

Modern Ez data far exceed the resolution of the Carnegie data ...it is time we moved on.

Future Plans:
Publish results from Vostok and Concordia overlapping and simultaneous Ez comparison.

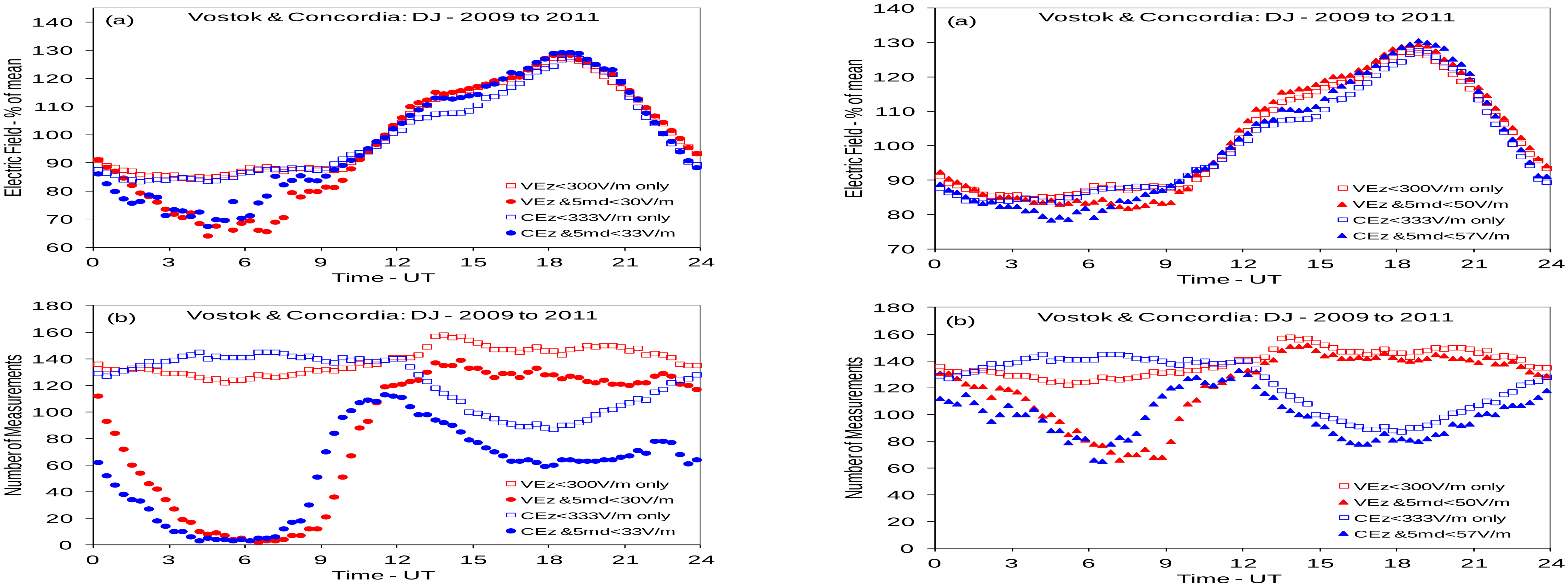
Prepare AEC proxies from Vostok (2006-11) and Concordia (2009-11) Ez for further investigation of AEC influences on weather and climate.

Use the Vostok & Concordia Ez measurements to improve understanding of the meteorological generators of the Atmospheric Electric Circuit.

Fut**ure needs:**
It would be good if someone resolved the ‘Particle Precipitation’ effects that add to ionospheric potential effects on Ez.

Arctic Ez measurements of similar quality, time-span and overlap as Vostok and Concordia are desirable.

December-January Ez average diurnal variations at Vostok & Concordia



Vostok and Concordia are separated by only 560km. Local noon is 4.9UT and 3.8UT respectively.
The most restrictive and no '5-min variability' rejection criteria are compared in the left-side plots. Almost no measurements pass the most-restrictive criteria around local noon (left lower plot). A displacement of about an hour in the reduction and recovery of the number of measurements at Vostok and Concordia is apparent, with Concordia leading . A similar displacement is apparent in the respective diurnal averages (upper left plot). These offsets confirm the local time influence on the summer-noon electric field variability at both sites. The least restrictive Vostok and Concordia selection criteria show less separation and smoother variations around local noon.

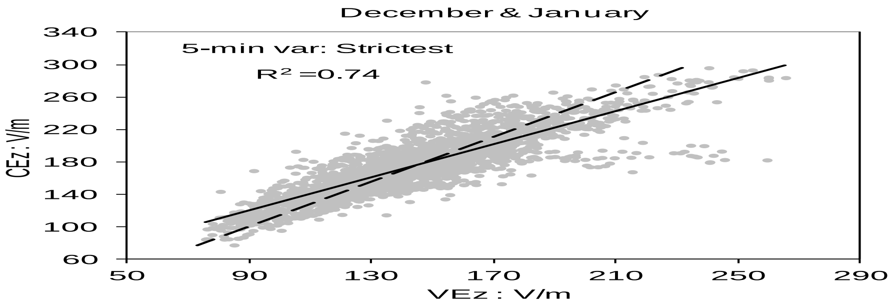
Similar differences are apparent for 'reduced' and 'no' 5-min variability rejection criteria (right-side plots).

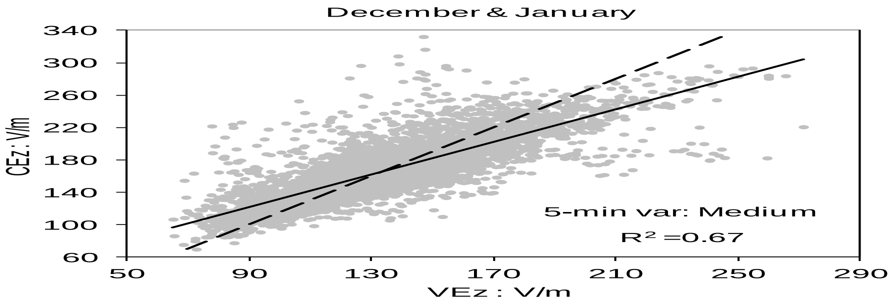
During the summer noon convection, our '5-minute variability' is preferentially selecting low Ez values.
The best match of December-January Ez Vostok and Concordia diurnal-averages is obtained without a 5-min variability rejection criteria.

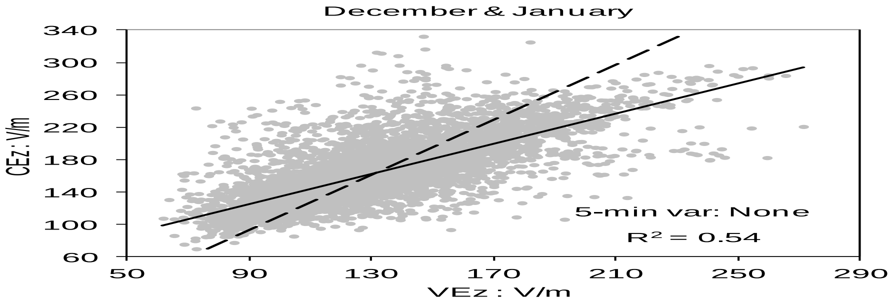
The Strictest ‘5-min Variability’ Data Selection for Comparison of Stations & to the SWIP.

Selections based on three different 5-minute variability rejection criteria
No variability rejection = ‘CEz<333V/m only’;
Medium = ‘CEz &5md<57V/m’;
Strictest = ‘CEz &5md<33V/m’).

The inter-station covariance reduces as the ‘less restrictive’ 5-min variability criteria are applied to the Dec-Jan data (74%, 67%, 54%). This relativity holds for all seasons. **The strictest ‘5-min variability’ data selection matches best between the stations.**







We can test how well the three ‘5-min variability’ data selections respond to the Solar Wind Imposed Potential (SWIP).

This for Vostok data (2006-2011)
Strictest: ΔE_z [Vm^{-1}] = 0.67 [Vm^{-1} per kV] * ΔV_s [kV] ; 14.8 t-stat.
Medium: ΔE_z [Vm^{-1}] = 0.64 [Vm^{-1} per kV] * ΔV_s [kV] ; 14.3 t-stat.
None: ΔE_z [Vm^{-1}] = 0.62 [Vm^{-1} per kV] * ΔV_s [kV] ; 13.9 t-stat.

The reduction in the t-statistic values as the 5-min variability criterion is relaxed and removed shows that the less restrictive data sets are less well linked to the SWIP.

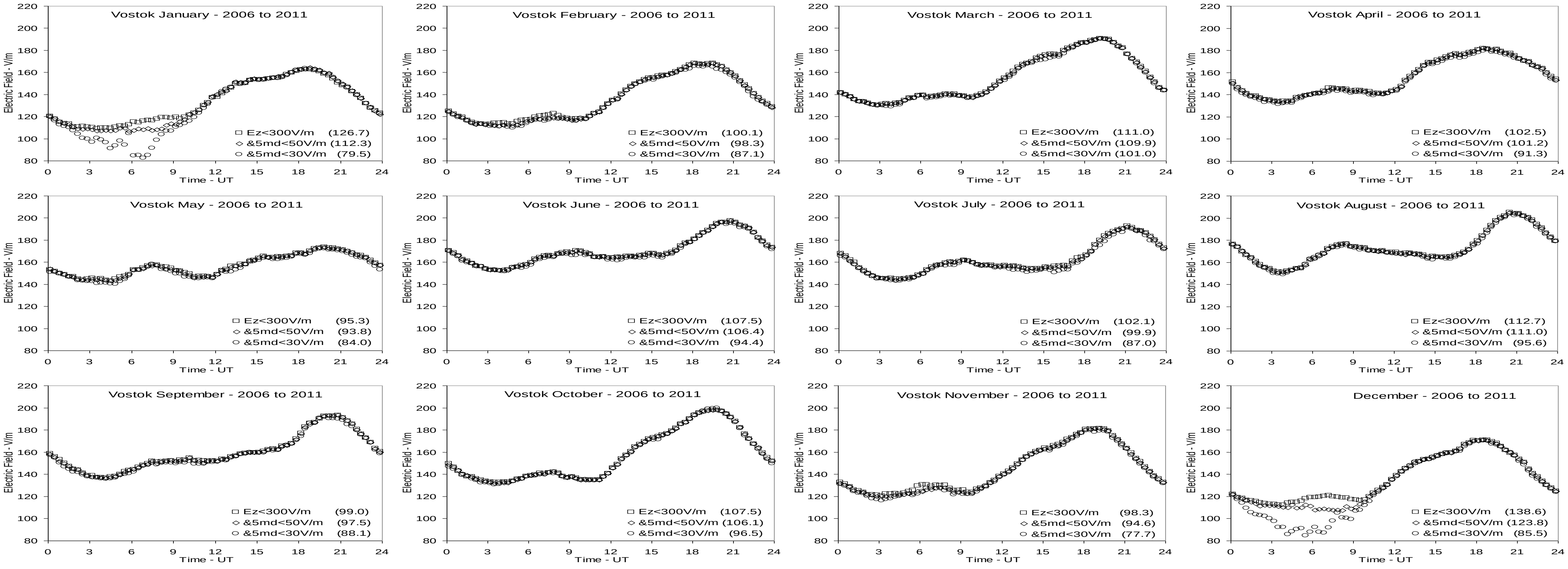
This for Vostok data (2006-2011)
Passes Medium but not Strictest:
ΔE_z [Vm^{-1}] = 0.55 [Vm^{-1} per kV] * ΔV_s [kV] ; 10.9 t-stat.

Passes None but not Medium
ΔE_z [Vm^{-1}] = 0.34 [Vm^{-1} per kV] * ΔV_s [kV] ; 5.1 t-stat.

The additional data of the less restrictive data sets still respond to the SWIP, but are less well linked.

Similar results are obtained for the Concordia data.

Diurnal variations in Vostok Monthly Ez Data (2006-2011) ...different variability rejection



The time-constant of the Atmospheric Circuit (~15 minutes), implies that short-term variations must be of local origin.
A 5-minute variability rejection criterion is useful to reduce local influences.

Our 'Strictest' 5-minute variability rejection criterion (Ez &5md<30V/m) is matched to our earlier era Ez data (Vostok 1998-2001). 'Medium' (Ez &5md<50V/m) and 'No' 5-minute variability rejection (Ez<300V/m) data sets are added to investigate an austral summer, local-noon influence on the December & January monthly diurnal averages. **Local solar noon is ~05UT.** Equivalent days of contributing data are indicated in brackets.

Around local noon, in the austral summer (particularly December & January) the Ez averages are more variable, likely associated with local meteorological convection.

Comparing ‘5-min Variability’ Data Selection with Concordia Power House Pollution

We can demonstrate that a 5-minute variability rejection criterion is useful to reduce local influences, with our Concordia (2009-2011) Ez measurements.

Our Concordia ‘Strictest’ 5-minute variability rejection criterion matches our earlier era Ez data (Vostok 1998-2001). ‘Medium’ and ‘No’ 5-minute variability rejection data sets are added.

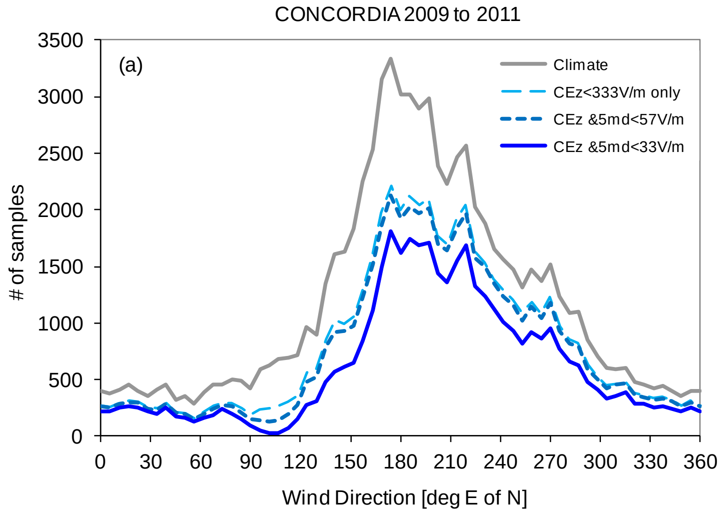
We show (right, top plot) the number of samples with wind from particular directions for all our meteorological data across 2009-2011 at Concordia (= ‘Climate’); and separately for data selections based on three different 5-minute variability rejection criteria (No variability rejection = ‘CEZ<333V/m only’; Medium = ‘CEZ &5md<57V/m’; Strictest = ‘CEz &5md<33V/m’).

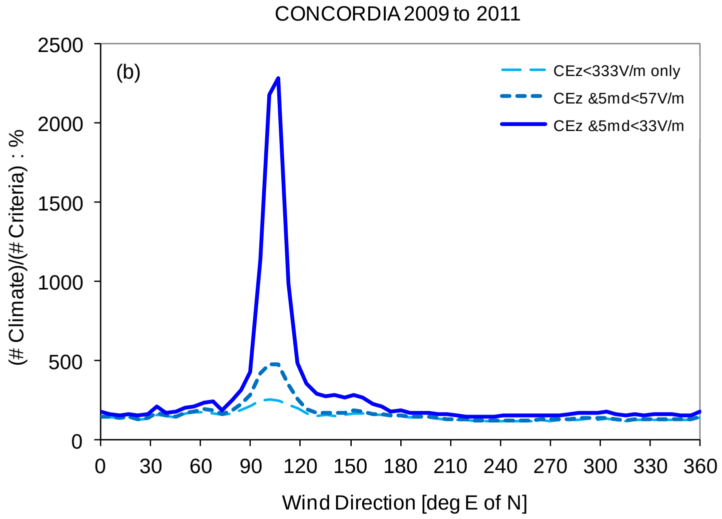
The Concordia power house is located ~900m in a direction 104°E of the EFM.

The ‘Strictest’ data selection demonstrates strong rejection of data from the direction of the power-house (right, lower plot).

The power-house is a local source of aerosol emissions that may influence electric field measurements by altering the atmospheric conductivity or space charge.

Our ‘Strictest’ 5-minute variability rejection criterion strongly rejects data from a know local source of pollution, better than the other data selections.



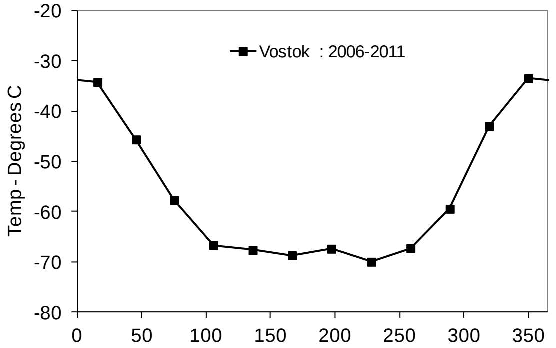


Vostok Month-to-Month Variations : %-of-mean of middle month

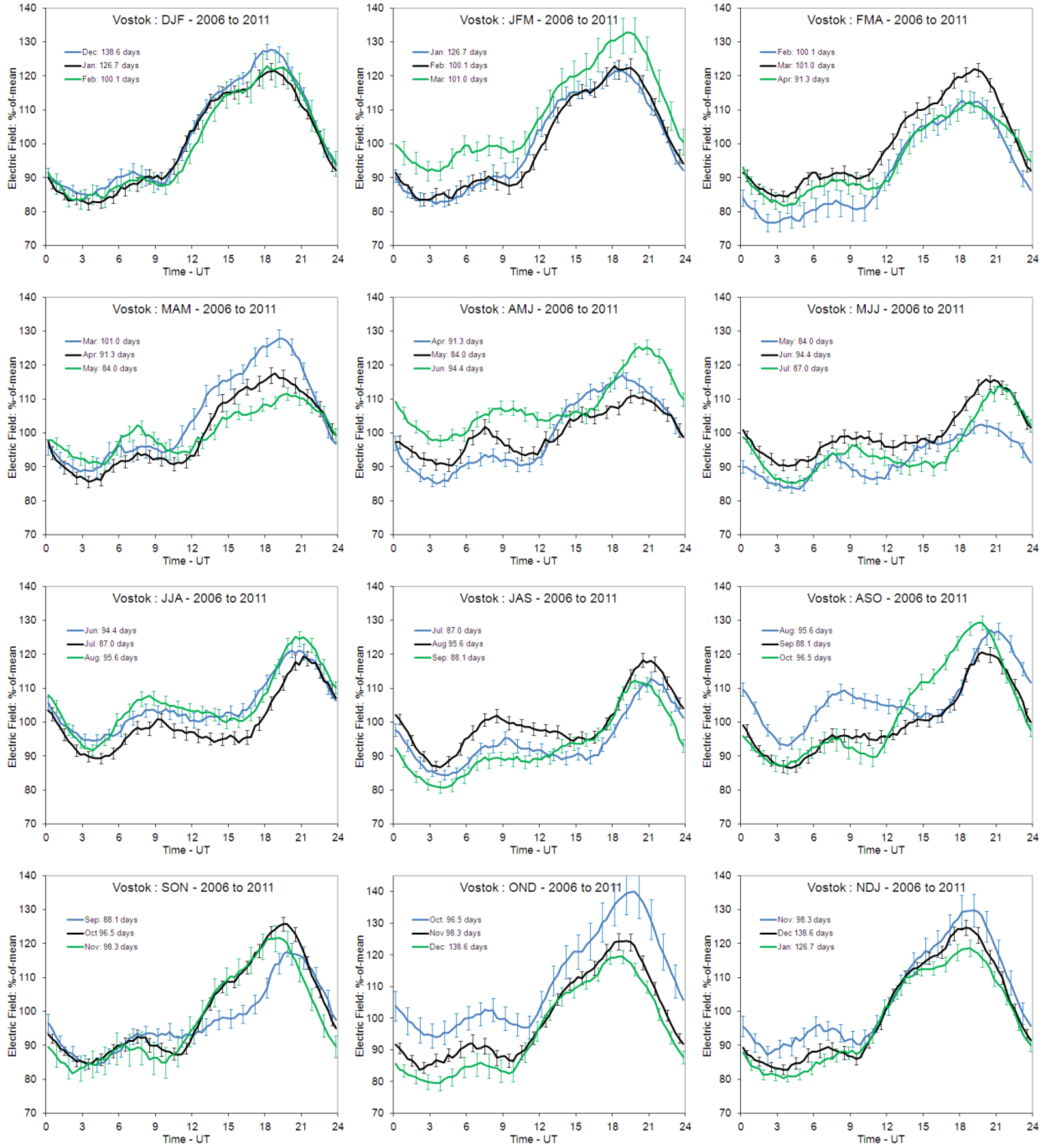
Using a multi-variate analysis reported in doi: 10.1175/JAS-D-11-0212.1 (JAS-2012) local temperature & wind-speed influences on Vostok Ez were determined. Only temperature variations have a noticeable influence on monthly-diurnal averages (for J,F,M & O,N,D). Month-to-month variations are shown at right, each month balanced to the mean temperature of the middle month. Large temperature shifts between months (see plot below) influence the errors (±1 standard deviation) via uncertainty in the temperature dependence.

Least Variable from Month-to-Month:
Dec-Jan-Feb & Jun-Jul-Aug (solstices and after)

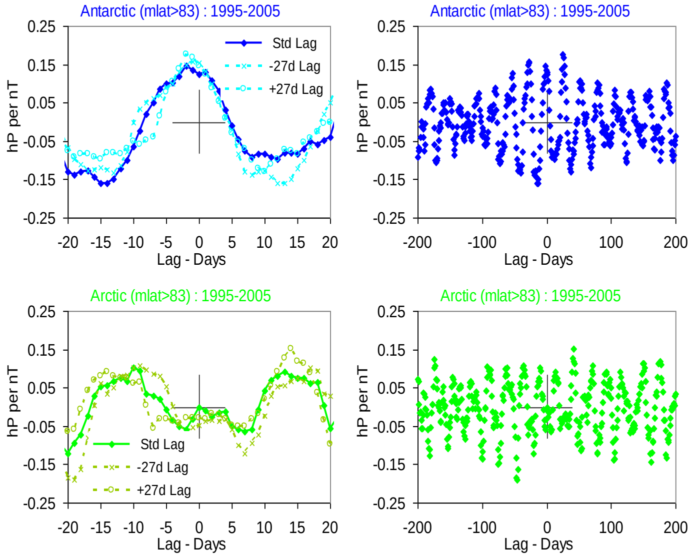
Most Variable from Month-to-Month:
Apr-May-Jun & Aug-Sep-Oct



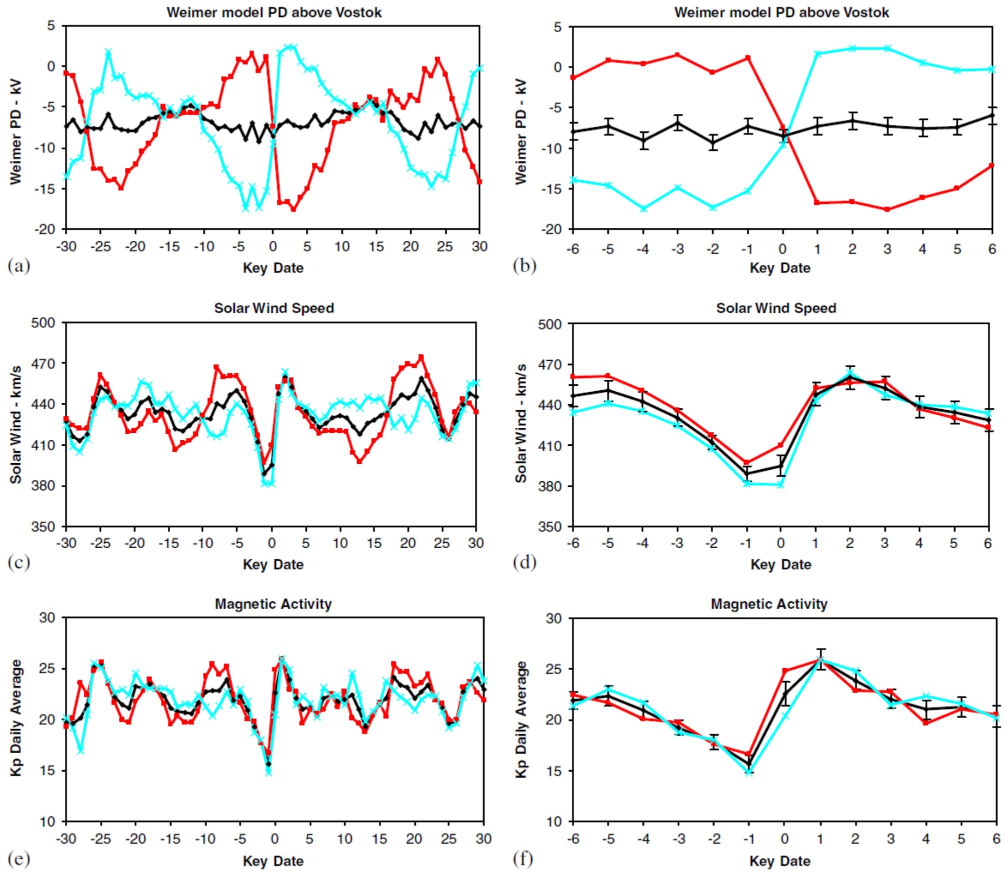
The large annual temperature variation coupled with the uncertainty of the temperature influence, precludes statistical significance between summer and winter Ez magnitudes.



Relevance to: M03 Weather and the Global Atmospheric Electric Circuit



There is a suggestion of a higher frequency variation in the NH correlation around zero lag.
(doi:10.1029/2007JD009618)

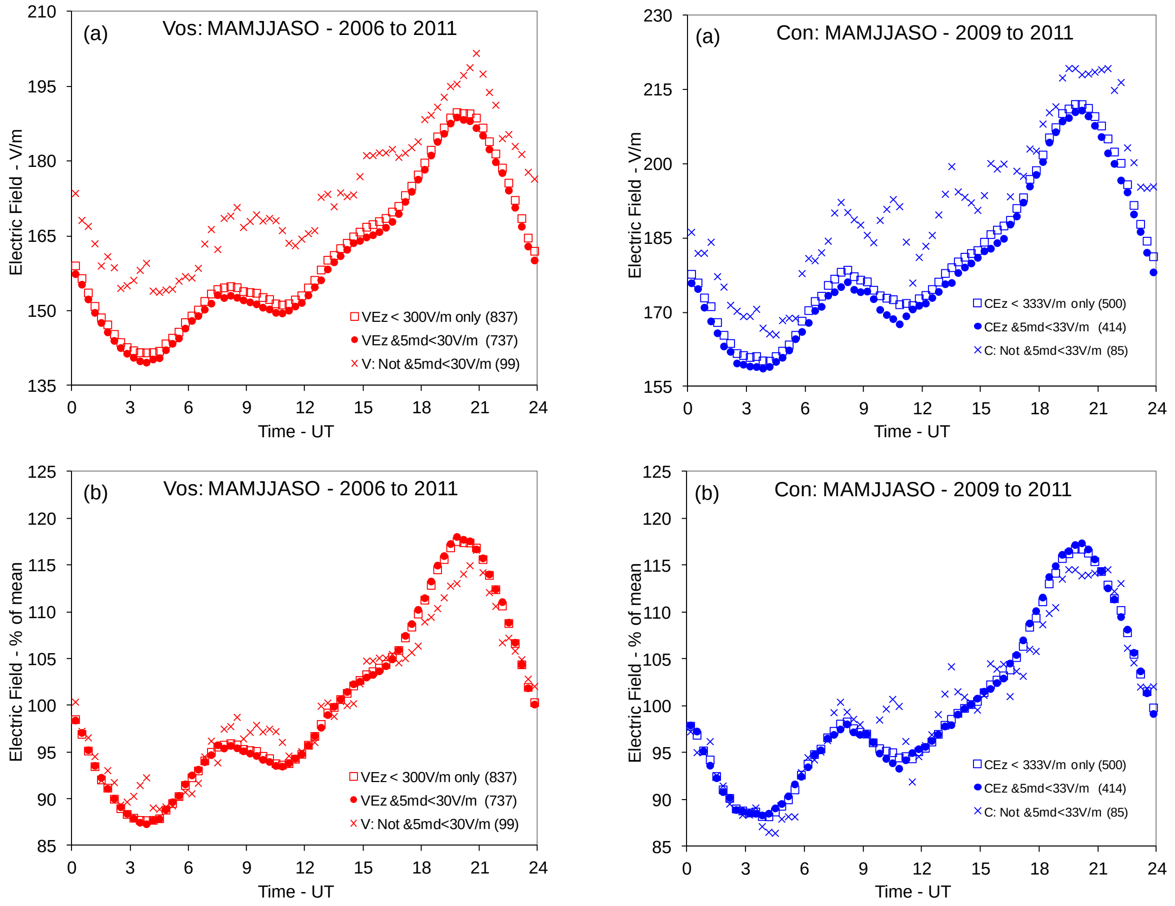


Alignment with Heliocentric Current Sheet Crossings

Particle precipitation (Kp as proxy) has a component that correlates with IMF By, but at twice the frequency.
(JASTP 68, 639-654, 2006)

Particle precipitation may be a higher frequency influence in NH

The ‘no’ 5-minute variability rejection data contain a Global Signal



The left-most plots show diurnal averages of the Vostok ‘Strictest’ and ‘No’ 5-minute variability rejection, data selections across the months which do not have any summer-noon influence (March-through-October: MAMJJASO). Separately averaged and displayed are data exclusive to the least restrictive data set. The left-upper plot shows absolute values (Vm^{-1}) and the left-lower plot is ‘percentage-of-the-mean’ values. The equivalent number of days of data contributing to each diurnal curve is indicated in brackets.

The right-most plots show similar averages for Concordia.

The diurnal mean exclusive to the least restrictive data selection is greater than for the most restrictive selection.
However, broadly similar diurnal curves appear when expressed as percentage-of-the-mean.

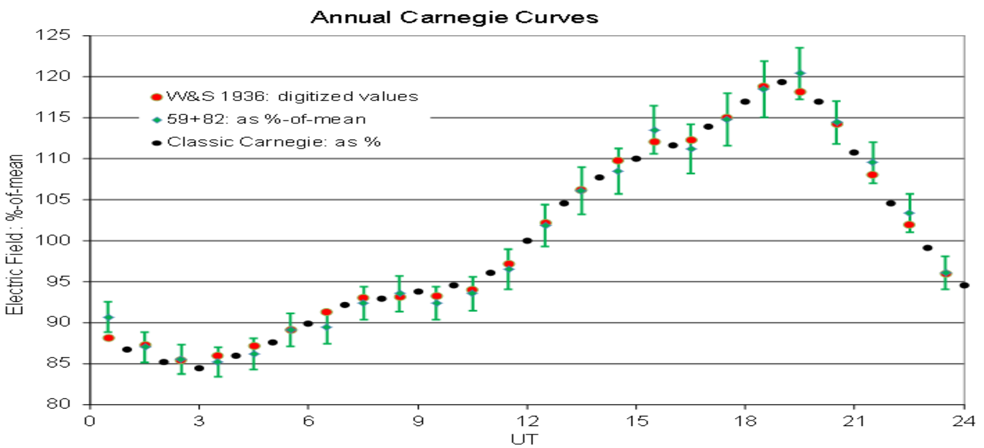
The Carnegie Curve

Israel (Vol. 2, 1973, Table XIX, page 647; reproduced to the right) attributes the ‘Classic Carnegie Curve’ to Whipple & Scrase (1936).

Whipple & Scrase (their Figure 9a; reproduced right) plot the Carnegie data ‘on-the-half-hour’ while the Israel Table XIX values are listed ‘on-the-hour’. The Carnegie measurements are also attributed ‘on-the-half-hour’ (1926-report & 1946-report). The Whipple & Scrase Carnegie Curve is presented as ‘Percentage-of-Mean’ while Israel Table XIX lists absolute values (V/m). Whipple & Scrase provide no reference to the source of their Carnegie data.

The 1926-report lists 59 selected fair-weather days from Cruises IV,V&VI : mean of 124 V/m.
The 1946-report lists 82 selected fair-weather days from Cruise VII : mean of 132 V/m.
The appropriately weighted mean of these 141 fair-weather days is 129 V/m.
This matches the ‘Classic Carnegie Curve’ mean listed by Israel (1973, reproduced right).

The most likely method by which the ‘Classic Carnegie’ values are listed ‘on-the-hour’ while the Carnegie measurements are ‘on-the-half-hour’, is via Fourier fitting and reconstitution.



Plotted (to the left) are the Classic Carnegie Curve (black dots) and ‘59+82’ Carnegie fair-weather days (green diamonds with +/-1 error-in-the-mean bars), both scaled to ‘%-in-the-mean’ to allow comparison with a digitisation of the Whipple and Scrase (1936) Carnegie curve (red dots).

The ‘Classic Carnegie Curve’ most likely results from a Fourier Fit (down to 4 hour period) to the 141 fair-weather days listed in the 1926-report (59 days) and the 1946-report (82 days).

Knowing the hourly values allows errors-in-the-mean of the averages to be calculated.
This is important when comparing averages and evaluating the importance of differences.

P.S. Happy Century! The earliest daily record in the Classic Carnegie Curve is the 8th July 1915.

TABLE XIX. Universal-time period of the potential gradient and global thunderstorm activity, I: mean diurnal variation of the potential gradient above the ocean on "undisturbed days" (taken from Whipple and Scrase /I, 800/).

Time of day GMT	Potential gradient in V/m[1]	Potential gradient in % of mean	Fourier analysis in percentage representation b^2
1	112	87	— 10.95
2	110	86	— 13.75
3	109	85	— 14.78
4	111	86	— 14.27
5	113	88	— 12.70
6	116	90	— 10.59
7	119	92	— 8.48
8	120	93	— 6.65
9	121	94	— 5.09
10	122	95	— 4.03
11	124	96	— 2.48
12	129	100	— 0.52
13	135	105	+ 2.17
14	139	108	5.61
15	142	110	9.42
16	144	112	13.19
17	147	114	16.16
18	151	117	17.65
19	154	120	17.26
20	151	117	14.79
21	143	111	10.55
22	135	105	5.11
23	128	99	— 0.98
24	122	95	— 6.54

[1] Mean: 129 V/m.

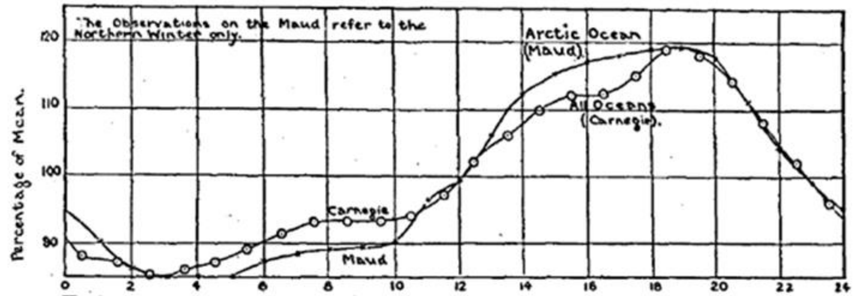


Fig 9a-The Diurnal Variation of Potential Gradient over the Oceans.

The 1926-report is: 'Researches of the Department of Terrestrial Magnetism Volume V' 'Ocean Magnetic and Electric Field Observations, 1915-1921'. Atmospheric-electric results by J.P.Ault and S.J.Mauchly. Published by Carnegie Institution of Washington, January 1926. (ftp://ftp.ngdc.noaa.gov/wdc/geomagnetism/docs/publications/1926/Ault_1926_22.pdf)

The 1946-report is: 'Scientific Results of Cruise VII of the CARNEGIE during 1928-1929 under the Command of Captain J.P. Ault'. Oceanography – III. Ocean Atmospheric-Electric Results. Carnegie Institution of Washington Publication 568, Washington, D.C., 1946, by O.W. Torreson, W.C. Parkinson, O.H. Gish & G.R. Wait.