2016 24th International Lightning Detection Conference &
6th International Lightning Meteorology Conference
18 - 21 April | San Diego, California, USA

Variability of surface electric fields

Greg Lucas, Wiebke Deierling, Jeffrey Thayer
Aerospace Engineering Dept.
University of Colorado
Boulder, Colorado, USA
greg.m.lucas@gmail.com

***Abstract*—The diurnal variation in universal time of the fair-weather surface electric field is a global phenomenon. In this study, variations in surface electric field strength in relation to meteorological parameters are investigated. Surface electric field measurements from an electric field mill array at the Kennedy Space Center (KSC) have been collected for 18 years. For fair-weather conditions, wind direction and cloudiness are shown to modify the surface electric field measurements by as much as 100 V/m. The coast line at KSC generates land and sea breezes that are evident within the electric field mill data. The field mill array at KSC is able to identify the horizontal structure of these events as well as other predominant wind patterns and boundary passages that a single field mill is unable to capture. Each field mill has a unique signature in the climatological data that is dependent on the meteorological conditions around KSC.**

***Keywords*—field mill array; meteorology; fair-weather**

I. Introduction

Electric fields are present in the atmosphere even without the presence of nearby electrified clouds. These fields are maintained through the global electric circuit (GEC) where electrified clouds maintain a potential difference between the ground and ionosphere of around 250 kV [Williams and Mareev 2014]. This potential difference produces a very small fair-weather current of 2 pA/m^2 that leads to electric fields of 100-200 V/m near ground level. This surface electric field has been measured for many years in different locations, and when viewed in universal time this fair-weather electric field correlates to the global distribution of thunderstorms and other elecrified clouds. Fig. 1 shows the diurnal variation of the electric field divided by its daily mean, which is referred to as the Carnegie curve in the literature due to the Carnegie vessel that measured this effect [Harrison 2013].

The Carnegie curve is a manifestation of long-term averages of measured surface electric fields. Individual days will not represent this exact diurnal variation due to a myriad of factors including: varying global electrified cloud distributions, local meteorology, and total global resistance. Recent modeling efforts for the GEC have been undertaken within community climate models to determine how the electric field varies with time at different locations across the globe [Baumgaertner, et. al. 2013, Baumgaertner et. al. 2014, Lucas et. al. 2015]. Lucas et al. [2015] specifically focused on the analyzis of the global distribution of modeled surface electric fields by incorporating conductivity calculations that include radon, galactic cosmic rays, clouds and aerosols, and has shown good correspondence between observed and surface electric fields. This new model capability provides a means of analyzing long-term and large spatial distributions of conductivity. However, looking at the large variability seen on individual field mills within the surface electric field datasets from Kennedy Space Center (KSC) indicates that there must be more localized influences occurring than are captured with the global modeling approach. The work presented below focuses on a localized analysis of the electric field mill array data from KSC with respect to various meteorological parameters.

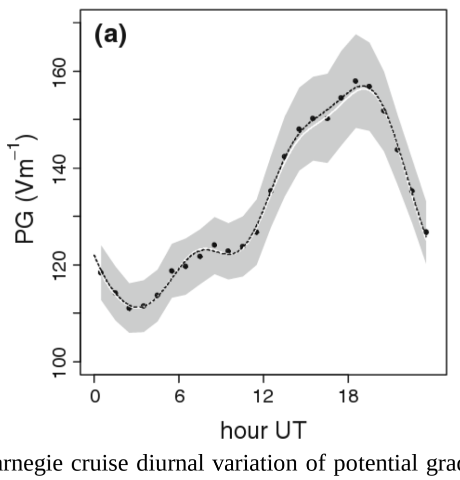

Fig. 1: Carnegie cruise diurnal variation of potential gradient (from Harrison 2013).

II. Data Analysis

In this work an array of multiple electric field mills at KSC covering 18 years is utilized to analyze different meteorological conditions and their influence on the surface

This work was supported by NSF Award AGS-1135446 to the University of Colorado under the Frontiers in Earth System Dynamics Program (FESD).

electric fields. An array of electric field mills provides the ability to spatially and temporally differentiate the electric fields present in the local environment. Fig. 2 shows the locations of the electric field mills utilized in this work. Meteorological data including temperature, dew point, relative humidity and wind speed/direction are obtained from the local weather towers around KSC at 5 minute intervals over the entire 18-year dataset. Cloud cover was obtained every 1 hour from Meteorological Terminal Aviation Routine (METAR) reports from the space shuttle landing strip (KTTS).

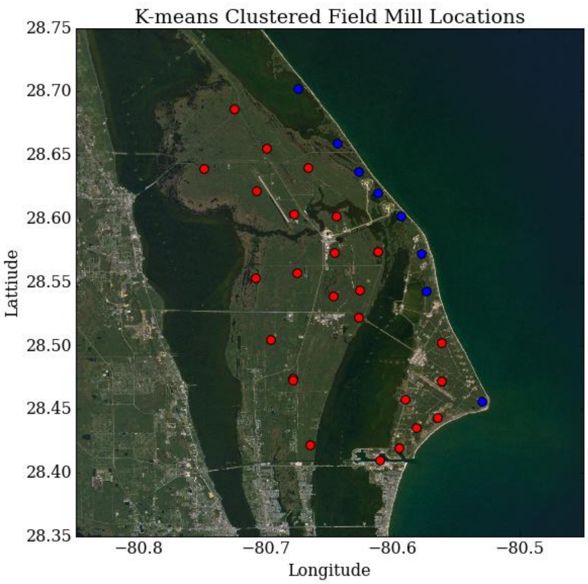

Fig. 2: Locations of electric field mills at KSC colored based on categorization as inland (red) or coastal (blue).

The field mills are located in a unique coastal environment where some are along or near coastlines (blue dots in Fig 2), and others are further inland (red dots in Fig. 2).

III. Results

To investigate diurnal variations of the electric field for individual field mills, Fig. 3 shows the median diurnal variation for each of the mills. The diurnal curves are classified into two categories, inland (red) and coastal (blue). Separating the field mills into two distinct categories allows for characterization of coastal influences on the electric field.

Fig. 4 shows the mean diurnal variation of the two categories of field mills. As can be seen in Fig. 4, there are distinct differences between the coastal and inland field mills electric field data. The absolute magnitude of the potential gradient is distinctively larger for the coastal field mills than the inland mills. To determine the cause of this deviation an analysis of the wind direction has been performed. Fig. 5 shows that when the wind is from the East (wind coming from the ocean) there is a large difference in the values seen between the coastal and inland field mills, whereas when the wind is from the West there is very little difference between the field magnitude measured by all of the field mills. This implies that the wind direction is accompanied by a 100 V/m change in the local electric field magnitude. However this affect is localized as it is not seen at the further inland field mills, which are only several kilometers more inland than the coastal mills - even under high wind conditions.

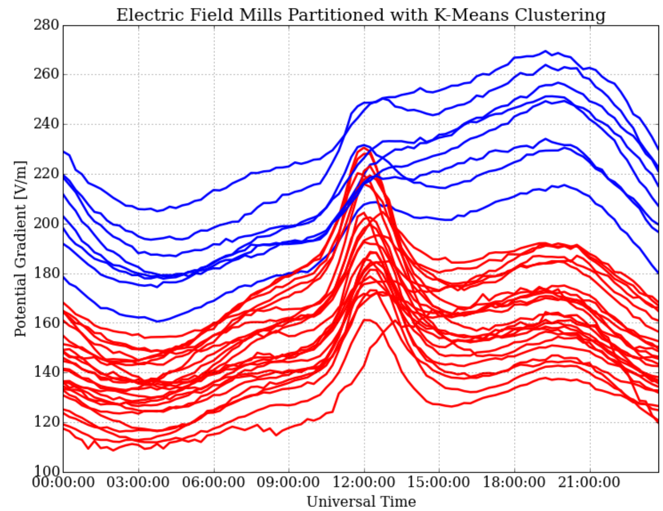

Fig. 3: Diurnal variation of the electric field for every field mill at KSC categorized as inland (red) or coastal (blue).

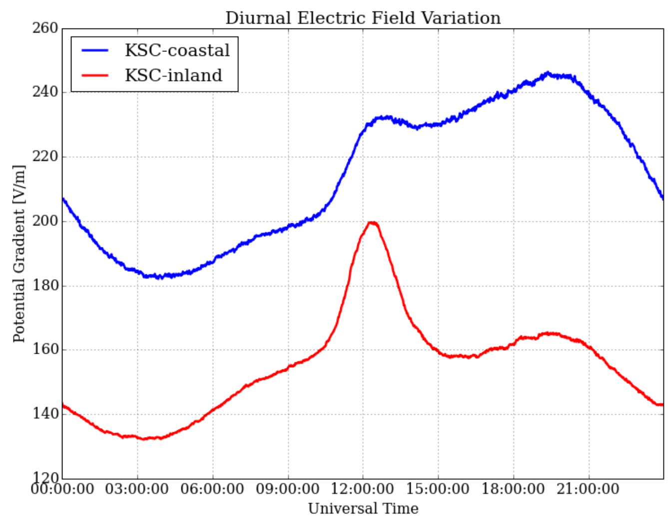

Fig. 4: Differences in the coastal versus inland field mills at KSC are seen in the diurnal variation of the electric field.

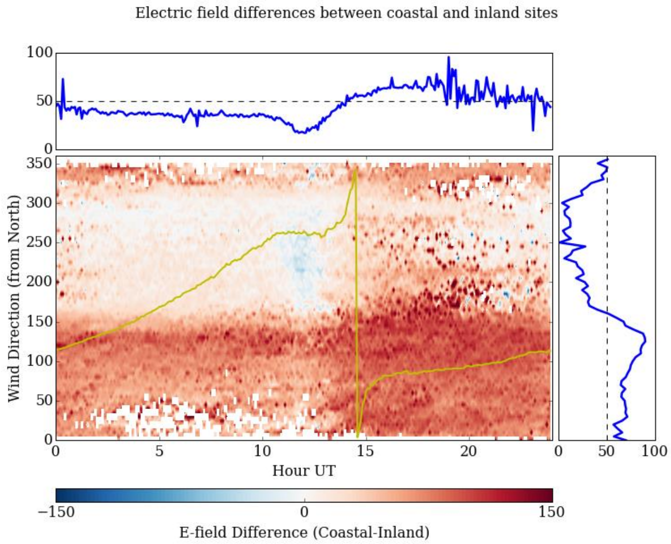

Fig. 5: Electric field differences between coastal and inland mills versus time of day and wind direction. The gold line is the prevailing wind direction for the given time of day. Eastward winds produce a stronger deviation between the two categories.

Baumgaertner et al. [2014] modeled the influence that clouds can have on column resistance within the GEC and therefore their influence on the local electric field. They showed that the extent of the clouds determine how much current can converge/diverge around the clouds. Small radius clouds have little influence on the column resistance while large radius clouds effectively act as a resistor within the column. Fig. 6 shows the electric field difference between different fair-weather cloud environments overhead as reported by the local METAR reports. Cloud cover in the METAR reports are defined based on eighths of sky covered: Clear=no clouds, Partly Cloudy=1/8-2/8, Scattered Clouds=3/8-5/8, Mostly Cloudy=6/8-7/8, Overcast=8/8. Partly cloudy days show little influence on the local electric field, while overcast days show a marked reduction in the magnitude of electric field, which corresponds well with the analysis by Baumgaertner et. al [2014]. When fog is present, the potential gradient is larger - opposite to the effect of overhead clouds where the potential gradient is decreased. This can be explained through the modification of local conductivity rather than the conductivity throughout the column. If the local conductivity is decreased due to ion attachment to water droplets which effectively reduces the mobility of ions in the air, then to maintain current continuity within the atmospheric column the electric field must be enhanced. This analysis shows that cloud cover overhead can contribute a 30 V/m deviation in local electric field, while fog events modifying the local conductivity can increase the potential gradient by over 150 V/m.

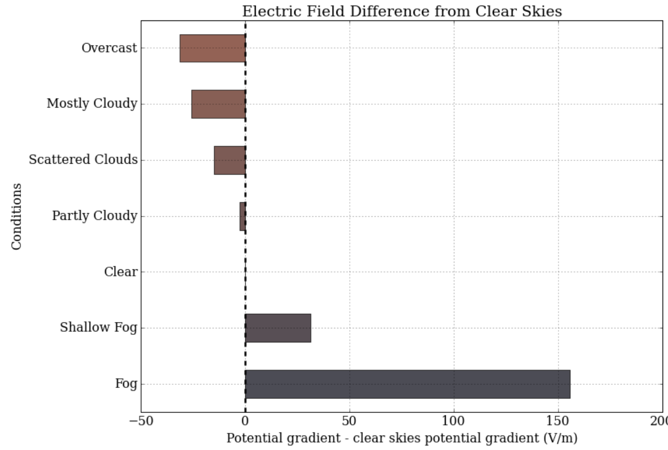

Fig. 6: Potential gradient deviations from clear skies for various weather conditions. Increasing cloud cover decreases the potential gradient, while fogs increase the potential gradient.

The same analysis can be undertaken for rain and thunderstorm events. Fig. 7 shows that large thunderstorms, unsurprisingly, yield large electric fields on the surface. In this case surface electric fields are influenced by the electric field of the electrified clouds overhead. To conclude, a clear distinction between the electric fields of thunderstorms, raining clouds, non-precipitating clouds and fog can be observed in the dataset.

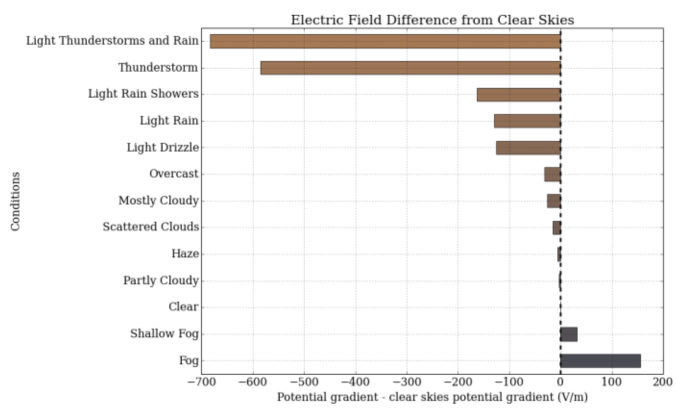

Fig. 7: Potential gradient deviations from clear skies for various weather conditions, including thunderstorms and rain.

IV. SUMMARY

Kennedy Space Center is a well instrumented site with many meteorological observations coincident with electric field mills. This unique dataset of a field mill array spanning 18 years has been utilized to provide new insights into the variability of electric fields due to meteorological processes. The wind direction has been observed to cause a deviation of up to 100 V/m between coastal and inland KSC field mills. In addition, investigating the cloud cover, assuming fair weather clouds, shows that the level of cloudiness overhead increases the column resistance (decreasing potential gradient), while fog modifies the local conductivity and therefore increases the potential gradient to maintain the current density within the column. The local meteorological conditions can have a significant impact on the surface electric field variability, and a single field mill is unable to differentiate the causes and strengths of these spatial and temporal changes.

ACKNOWLEDGMENTS

Electric field mill data and weather tower data obtained from NASA's weather archive website: kscwxarchive.nasa.gov.

REFERENCES

Baumgaertner, A.J.G., et. al. "Toward a comprehensive global electric circuit model: Atmospheric conductivity and its variability in cesm1(waccm) model simulations" J. Geophys. Res., vol. 118, no. 16, pp. 9221-9232, 2013. doi:10.1002/jgrd.50725

Baumgaertner, A. J., et. al. "On the role of clouds in the fair weather part of the Global Electric Circuit, Atmos. Chem. Phys., 14, 8599-8610, 2014. doi:10.5194/acp-14-8599-2014

Harrison, R. G. (2013), The carnegie curve, Surveys in Geophysics, 34 (2), 209{232, doi:10.1007/s10712-012-9210-2

Lucas, G. M., et. al. "A global electric circuit model within a community climate model", Journal of Geophysical Research - Atmospheres, 2015. doi:10.1002/2015JD023562

Williams, E., and E. Mareev (2014), Recent progress on the global electrical circuit, Atmospheric Research, 135-136, 208-227, doi:10.1016/j.atmosres.2013.05.015.