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One-Year Electric Field Study at the North Slope of Alaska Field Campaign Report

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Acronyms and Abbreviations

AGU	American Geophysical Union
ARM	Atmospheric Radiation Measurement
DOE	U.S. Department of Energy
ENSO	El Nino Southern Oscillation
GEC	Global Electric Circuit
GSSOD	Global Surface Summary of the Day
KAZR	Ka-band ARM Zenith Radar
MPL	micropulse lidar
NSA	North Slope of Alaska
OYESNSA	One-Year Electric Field Study-North Slope of Alaska
UTC	Coordinated Universal Time

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1.0 Summary

The Global Electric Circuit (GEC) of the atmosphere provides a unique prospective of the changing climate around the Earth. Monitoring this global electrical signature provides details of the global nature of electrified clouds and thunderstorms that are occurring. Using this very inexpensive measurement system, we can obtain much-needed information about the vast electrical system that surrounds us, as well as gaining an understanding of how the electrical properties of global precipitation systems are changing over time.

Prior to the OYESNSA field campaign (http://atmos.tamucc.edu/oyesnsa/; https://www.arm.gov/research/campaigns/nsa2017oyesnsa/), much of the electric field data used to compare to the physical properties of electrified clouds were collected in the Antarctica. With the inclusion of this high-quality data set in the Arctic, it allows for the simultaneous observation of the electric field at both poles, as well as the subtropics (Corpus Christi, Texas). Preliminary results from the One-Year Electric Field Study-North Slope of Alaska (OYESNSA) field campaign in the last two years already show that the GEC appears to be indeed a truly global phenomenon, with very similar fair-weather observations being taken at both poles. This first year and a half of data has already been uploaded to the ARM Data Center, and preliminary results have been presented at the American Geophysical Union (AGU) 2017 meeting with very positive feedback (http://atmos.tamucc.edu/oyesnsa/AGU_2017_Poster.pdf).

The North Slope of Alaska provides a unique location for collecting these electric field measurements. Besides being at the opposite pole from many previous measurements, this site provides a rare opportunity to use the other instruments at the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility's Barrow, Alaska observatory, such as the Ka-band ARM Zenith Radar (KAZR), upward-facing lidar (micropulse lidar; MPL), vertical profile of meteorological measures, and other aerosol measurements. This allows for the unique chance to not only provide information about the global signature of the GEC, but also the physical inputs to the local electric field, by analyzing the physical properties of the simultaneous cloud, wind, and aerosol properties occurring with the vertical electric field. Barrow, Alaska is home to some unique cloud formations that undoubtedly influence the electric field. This field campaign allows for the quantification of the influence to the electric field of these cloud types, as well as other unique phenomenon such as blowing snow. Already, the first 18 months of data have shown correlations of the electric field to radar reflectivity properties, cloud types, and increased wind (blowing snow and aerosol). Providing an understanding of these inputs to the local electric field will improve modeling techniques of this system both locally and globally.

As well as being an exceptional location for collecting electric field data with supplementary instrumentation, the North Slope of Alaska also provides an opportunity to study the electrical nature of a rapidly warming region of the earth. A recent study observed that air temperatures in the Arctic have increased 2.7^{o} C (4.9^{o} F) over the past five decades (Box et al. 2019). This rapid warming has no doubt influenced the types of clouds and precipitation systems in the region. Figure 1 shows the thunder-day trends in Alaska, as well as other locations around the globe since 1975. An interesting finding is that Alaska (Figure 1a) observes a significant increasing trend in thunder days over the past 43 years. This is opposite to the rest of the Arctic (Figure 1c), which shows significant decreasing trends in thunder days. It appears that the Alaskan region exhibits more similarities to the thunder-day trends in the tropics (Figure

1b), and the rest of the Arctic show similarities to the Northern Hemispheric mid-latitudes (Figure 1d). A scientific focus moving forward would be to monitor the electrically active systems in the unique region of Alaska. Since 1975, on average Barrow, Alaska hears a thunderstorm less than once per year. During the first two full summer seasons (2018 and 2019) of the OYESNSA field campaign, the region has observed over 10 events each year with at least +2,000 V/m charge separation, which is considered to be electrically active. A longer-term measurement of the electric field is needed to better understand the region's response to such rapid warming. With electrified shower clouds typically preceding thunderstorm activity, the preliminary results show that the region could observe significantly more electrified clouds if the current trends continue.

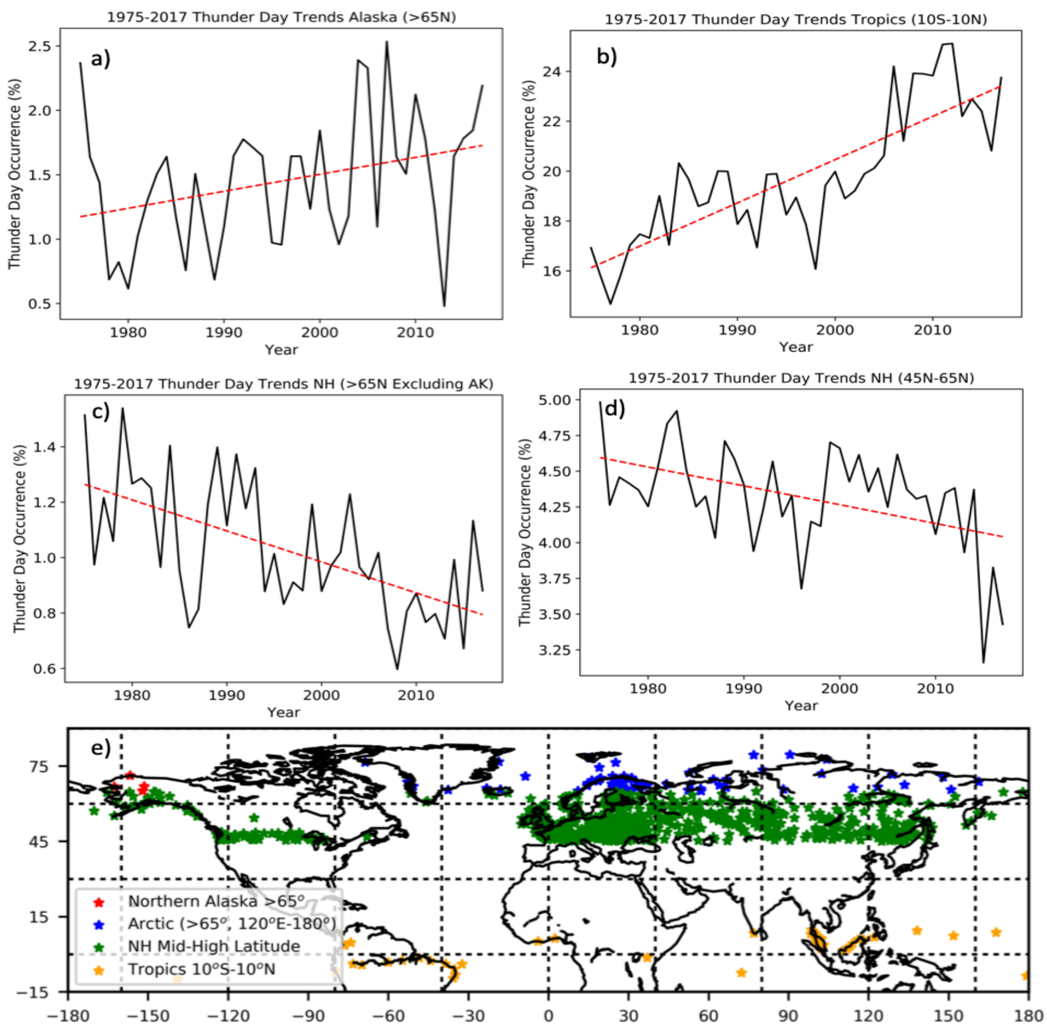

Figure 1. Thunder day trends in: a) Northern Alaska (>65°N), b) the tropics (10°S-10°N), c) the Arctic excluding Alaska (>65°N, 120°E-180°W), d) Northern Hemispheric mid-high latitudes (45°N-65°N), and e) geolocations of ground stations with long record of thunder days used for each global region. Red stars indicate Northern Alaskan stations, orange represents the tropics, green designate stations in the southern hemispheric mid-high latitudes, and blue represents the Arctic excluding Alaska. Thunder day occurrence (%) was calculated by dividing the summation of thunder days in each region by the summation of total sampled days from each region*100. Ground stations were used from the Global Surface Summary of the Day (GSSOD) data set.

Although the first two years of measurements from the OYESNSA field campaign have already provided insight into these important questions and goals, a longer-term, high-quality data set is needed to ultimately provide the critical climatology required to understand this truly global and ever-changing system. That is why we have requested a three-year extension to the OYESNSA field campaign to lengthen this data set. Fortunately, all the equipment has withstood the first 2.5 years of the field campaign, and no additional instrumentation or support resources are required. This extension would allow not only for the short-term, diurnal, and seasonal variations to be explored, but now also the interannual variability of the GEC, such as the El Nino Southern Oscillation (ENSO) cycle. This interannual variability is the measure that can truly shine some light on the variability of the climate and electrical properties of storms on a year-to-year basis.

Furthermore, electric field data began to be collected in the Southern Ocean in the early 1900s with the Carnegie Cruise, collecting high-quality measurements from 1909-1929 (Whipple 1929). Having globally representative measures of thunderstorm and electrified cloud activity approximately 100 years apart could allow for a unique opportunity to observe how the occurrence and distribution of these storms have changed under the changing climate on time scales that were previously not possible. Having a longer electric field record in this century, in a very valuable location, would be extremely useful in monitoring the changing Earth system

2.0 Results from Past Two Years of Measurements

In June 2017, a team of scientists, including Dr. Chuntao Liu and graduate student Thomas Lavigne, visited the ARM North Slope of Alaska (NSA) observatory at Barrow. With the help of the local ARM support team, two CS110 electric field meters and an anemometer were installed on a 20-foot tower as shown in Figure 1. Since then, the instruments have been successfully collecting observations and transferring them back to Texas A&M University at Corpus Christi in real time. In the summer of 2019, the team of scientists returned to the site to conduct routine maintenance on the equipment to ensure long-term, high-quality measurements.

Figure 2. Field campaign setup. Left panel shows the two CS110 electric field meters, and the RM-Young Alpine anemometer at the ARM Barrow site. Right panel shows internal components of the heated box, including the power, communication, and wiring setup.

In order to establish an “absolute” measure of the vertical electric field at NSA, rigorous calibration was conducted. To remove the influence of the metal mounting pole, as well as other nearby instrumentation setups, a ground-level, upward-facing measure of the vertical electric field was taken simultaneously to the downward-facing CS110s on the pole. The upward-facing measurement was taken far away from any metal or powerline influences, and provides the “true” undisturbed vertical electric field measure. The two operational CS110 instruments on the pole were then calibrated to match these values (shown below in Figure 3).

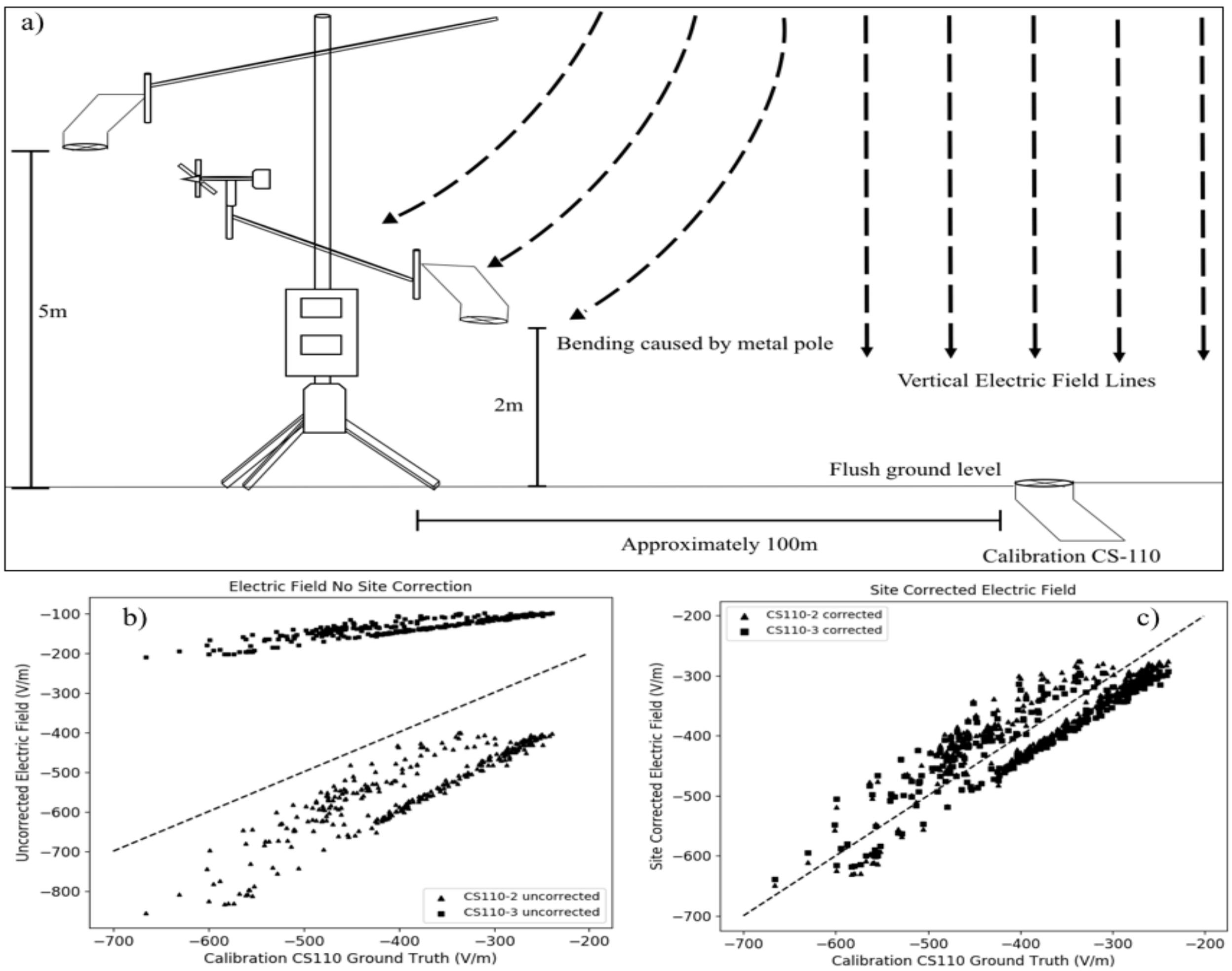

Figure 3. a) Schematic diagram of the vertical electric field calibration process, accounting for the influence of the metal setup and elevation. b) shows the simultaneous uncalibrated scatter between the CS110-2 (top) and CS110-3 (bottom) against the ground-truth electric field instrument. c) displays the site-corrected scatter of the 2 CS110s verses the simultaneous ground truth. The dashed line shows the perfect one-one correlation. The calibration factor for the CS110-2 is a slope of 0.823 and intercept of 54.9, while the factor for the CS110-3 is a slope of 3.121 and an intercept of 16.69.

The first validation of the fair-weather measurement is the diurnal variation in UTC time. As shown in Figure 4, the diurnal variation of the electric field in Barrow, Alaska, Corpus Christi, Texas, and Vostok Station, Antarctica are compared. Very similar patterns in both amplitude and phase are observed in all three sites. The peak diurnal electric field intensity for all three sites is shown to be approximately

18-19 UTC, while the minima in the electric field is between 3-5 UTC. Three distinct peak periods or "hotspots" in the diurnal cycle are present in all three locations, occurring at approximately 7-9 UTC, 12-14 UTC, and 17-20 UTC, primarily coming from thunderstorms and electrified shower clouds in the Maritime Continent, Africa, and the Americas, respectively. These three regions are commonly referred to as the "convective chimney" regions. This result provides further proof of the "global" nature of the fair-weather electric field, with stations at each pole, as well as a subtropical station all providing very similar variability and distribution on the diurnal time scale.

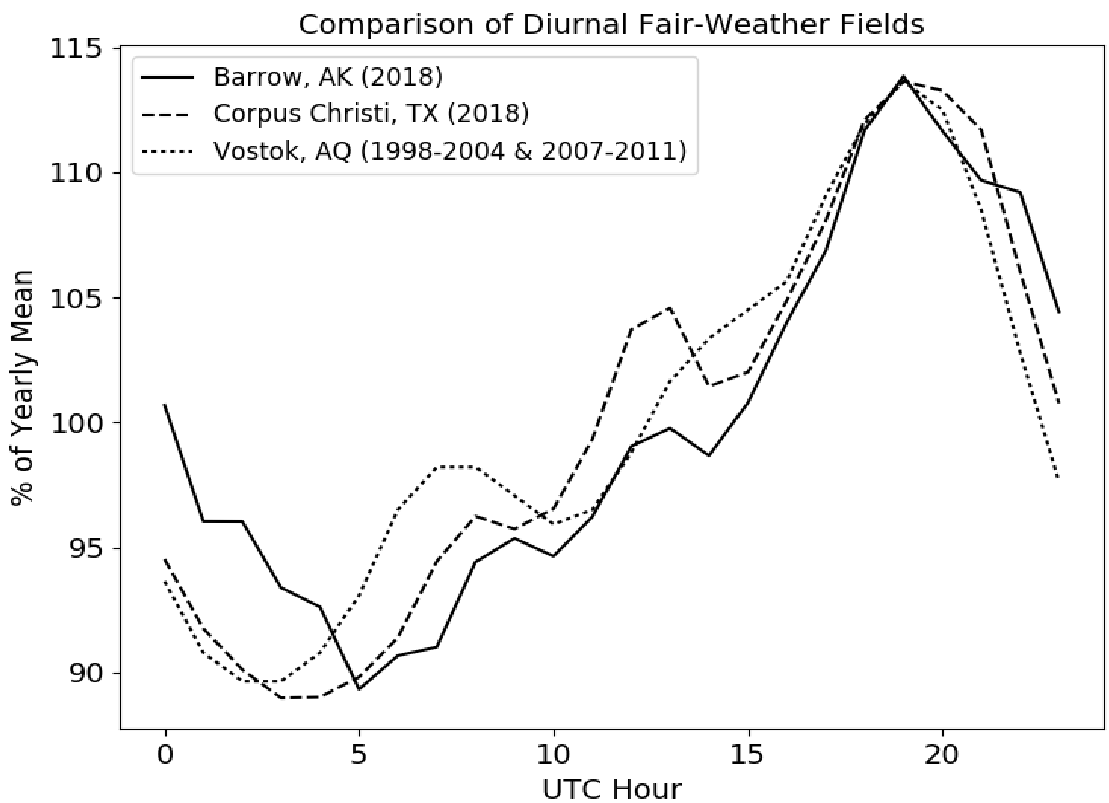

Figure 4. Diurnal variation observed in the fair-weather electric field at the North Slope of Alaska (solid), Vostok Station, Antarctica (dotted), and the Corpus Christi, Texas (dashed). Data from 2018 were used in the Barrow and Corpus Christi sites, whereas data from 1998-2004 and 2007-2011 were used at the Vostok site. All values are represented as a % deviation from the yearly mean at the given site.

One big advantage of collecting the electric field at the NSA is the abundant supplementary observations that can provide valuable environment information. For example, electrified clouds due to significant charge separation in summertime could lead to large local electric field changes. As shown in Figure 5, a rare strong electrified thunderstorm occurred on July 3, 2018 near Barrow and led to a large variation of the local electric field on the order of 10,000 V/m that was captured by the CS110. These intense electric field values occurred during the peak intensity of the event (>30 dbZ).

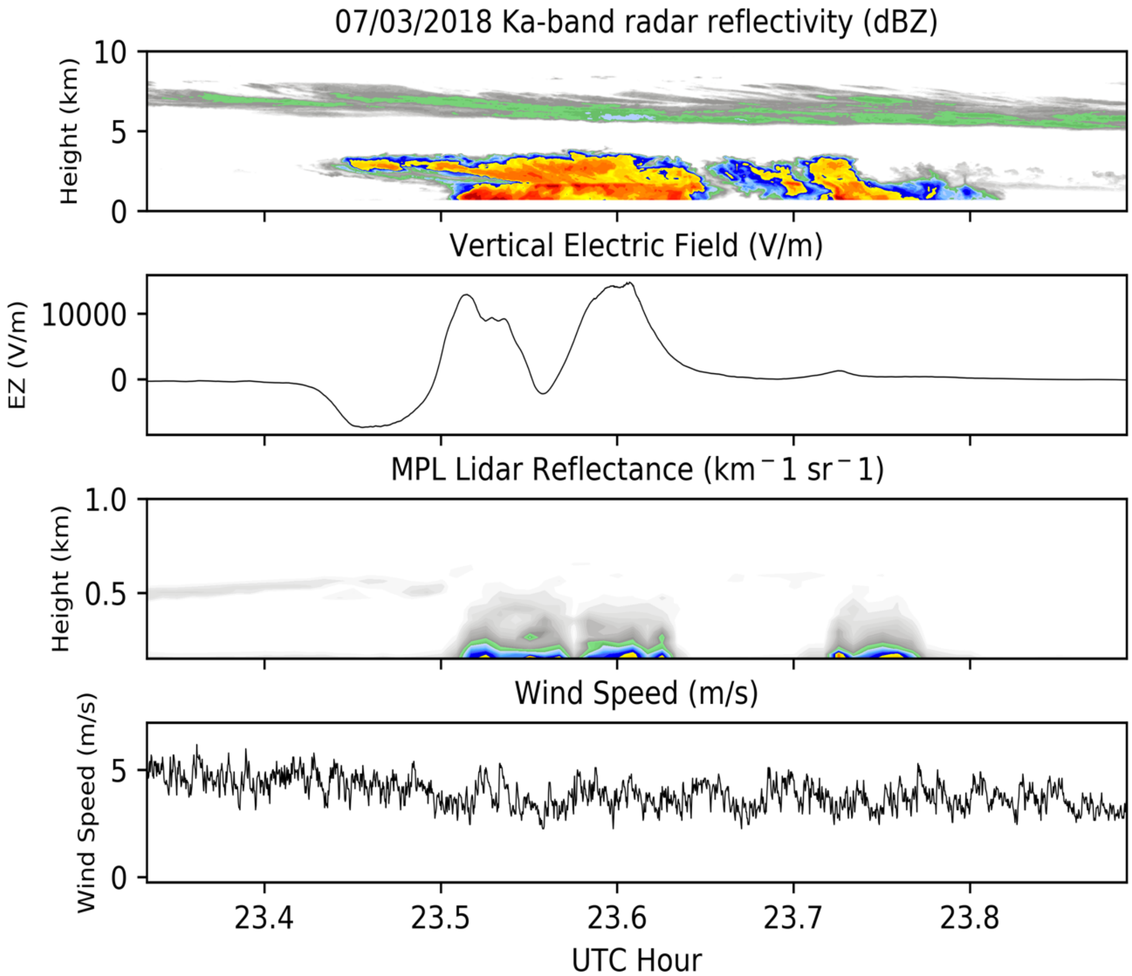

Figure 5. Case study of an intense storm electric field event in Barrow, Alaska on July 3, 2017. Panel a) displays the vertically pointing Ka-band radar reflectivity, b) the vertical electric field measurement at a sampling rate of 1 Hz, c) the vertically pointing micropulse lidar backscattering signature (km-1sr-1), and d) the wind speed (m/s) for the day measured at 1 Hz.

The Ka-band radar shows clearly the radar echo reaching above 30 dbZ, indicating significant electrification in the clouds (supported by Figure 6 below) that is also observed in the electric field. Much weaker influences can also be noticed from clouds with lower reflectivity values. By combining both Ka-band radar data and electric field data, we can visually separate non-fair-weather observations (Figure 6).

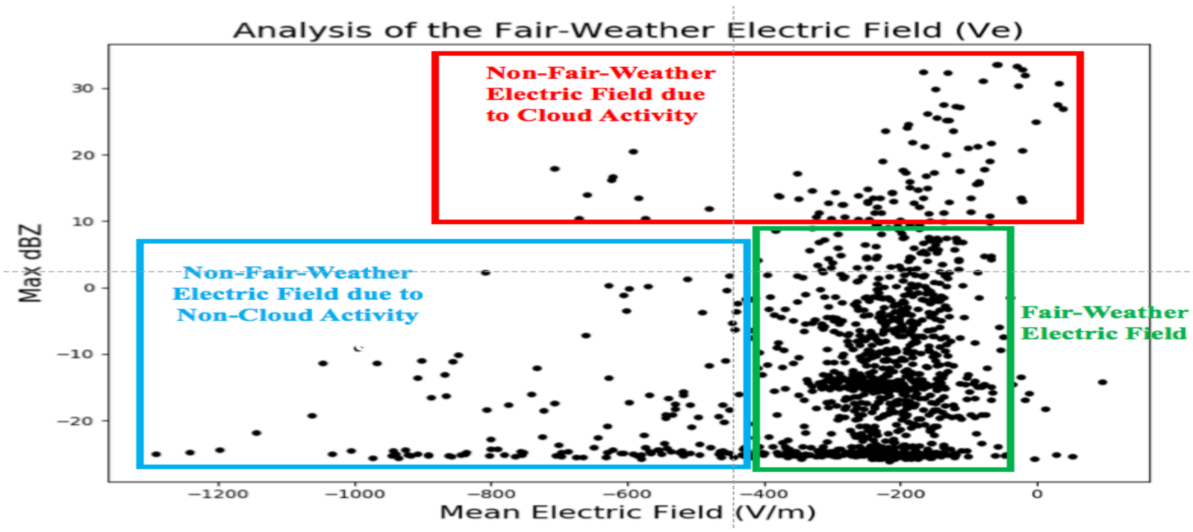

Figure 6. Breakdown of the 10-minute-averaged electric field values versus maximum reflectivity observed during the one-week calibration period. Three distinct regions of the electric field with associated cloud activity were observed.

We also found that local aerosol or blowing snow could influence the local electric field, which can be indicated by lidar and wind observations. Figure 7 shows how this further supplementary data is extremely useful. During this day, virtually no significant cloud activity was present according to the Ka-band radar. However, strong perturbations in the vertical electric field were still present. Using the MPL, it is apparent that the strong variability in the electric field occurs during periods of large MPL backscatter (increased aerosol activity).

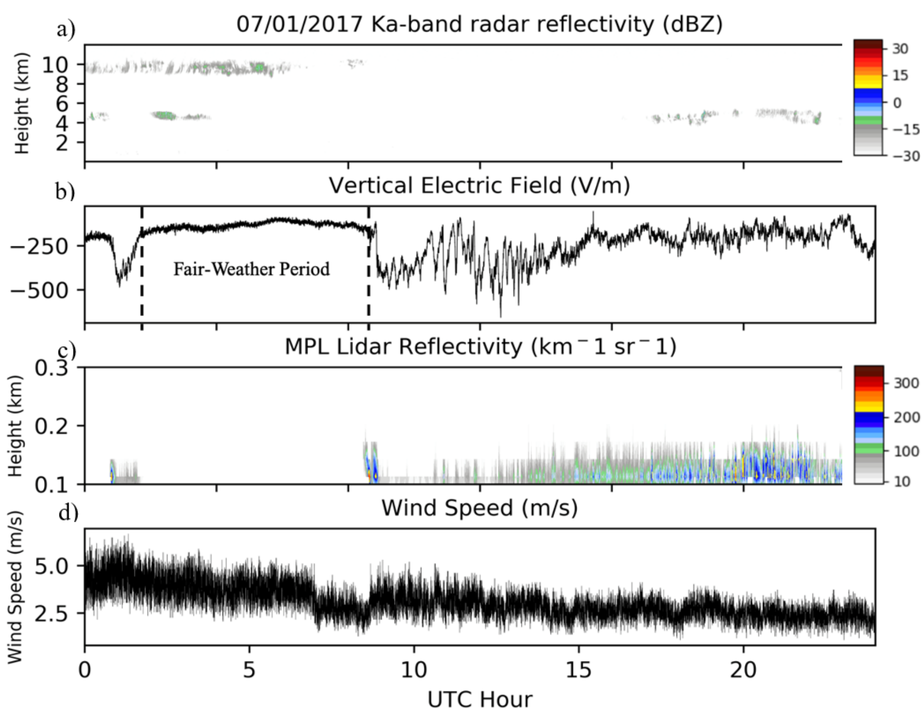

Figure 7. Same as Figure 5, except for a fair-weather period case study recorded on July 1, 2017.

A very stable electric field is observed during periods when there is no significant cloud or aerosol activity. During the first two years of data collection, this has been a consistent signature. This allows for the ability to use both the Ka-radar and MPL to distinguish between the fair-weather and locally influenced electric field.

Results show that during periods with no significant cloud activity as well as suppressed aerosols, the electric field is very stable (small standard deviation), as well as with absolute values in the known fair-weather range. Figure 8a shows a scatter of the electric field versus the standard deviation of the electric field on June 6, 2018. A very clear separation is present between 10-minute periods with a backscattering of less than 100 $km^{-1}sr^{-1}$. On this day, these values fall in the fair-weather range of approximately -50 to -125 V/m. Figure 8b shows the scatter between the MPL backscattering and the standard deviation of the 10-minute averaged electric field. Again, a clear separation is present with a backscattering of less than 100 $km^{-1}sr^{-1}$. On this day, periods with very little aerosol activity exhibited a stable electric field with standard deviations less than 20 V/m. Using the combination of these two relationships allows for the MPL supplementary data to define a known range of acceptable fair-weather electric field values with their associated standard deviations. This, in turn, allows for more robust and accurate simultaneous comparisons to other fair-weather electric field measurements around the globe, without the need for such extensive supplementary data as an MPL in the other regions.

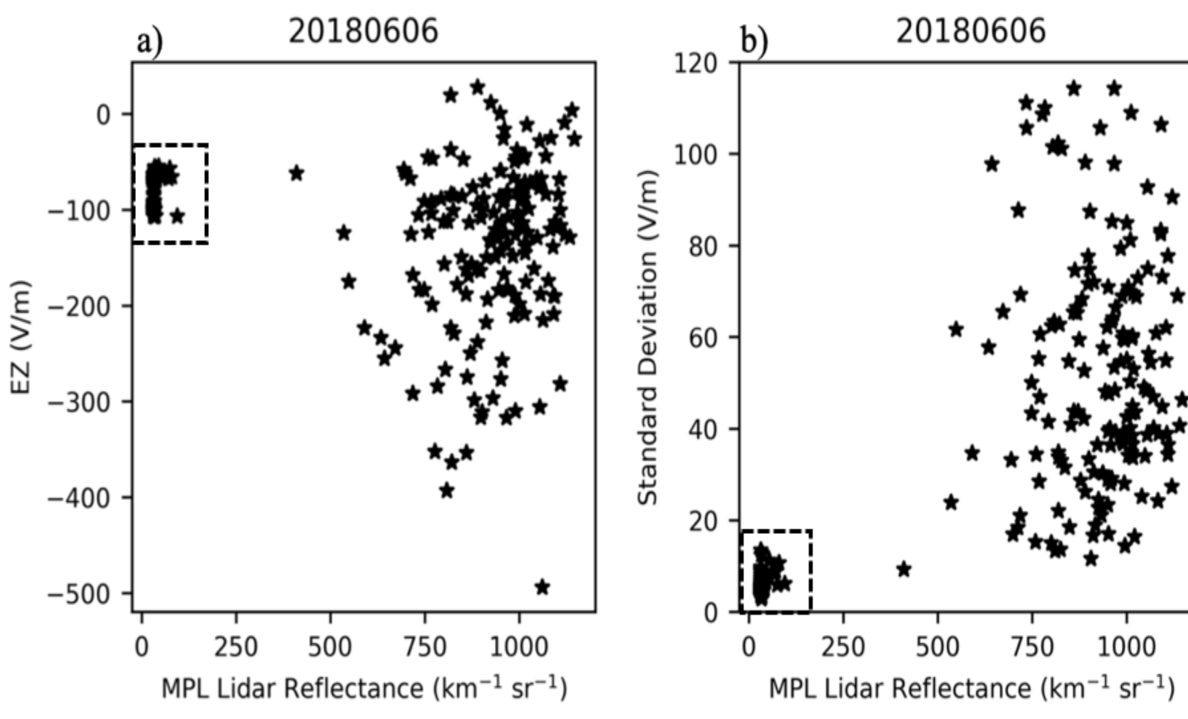

Figure 8. Example scatterplots of 5-minute mean electric-field (V/m) versus the simultaneous 5-minute maximum backscattering ($km^{-1}sr^{-1}$) overserved by the micropulse lidar (panel a), and the standard deviation of the 5-minute averaged electric-field (V/m) versus the simultaneous 5-minute maximum backscattering ($km^{-1}sr^{-1}$) overserved by the micropulse lidar (panel b).

Using the mathematically defined absolute value and standard deviation thresholds for fair-weather electric field periods, a simultaneous look at the very short time scale (minutes to hours) fair-weather electric field can be achieved at Barrow, Alaska and Corpus Christi, Texas. Figure 9 shows several case studies of this simultaneous variability. In many cases throughout the first several years of the field campaign, a very similar pattern of the electric field can be observed at both sites. Theoretically, this value represents the totality of all the global thunderstorms and electrified clouds occurring at each instant. This provides a very simple and inexpensive method of monitoring the occurrence and spatial distribution of global electrified clouds and precipitation. Probably the most exciting possibility from this research is to look at this occurrence and distribution from modern fair-weather electric field measurements, given continued measurements at Barrow in the years to come, and compare to the same measurements taken 90-100 years ago. This would allow for at least a cursory look into the changing electrical nature of the earth under a changing climate.

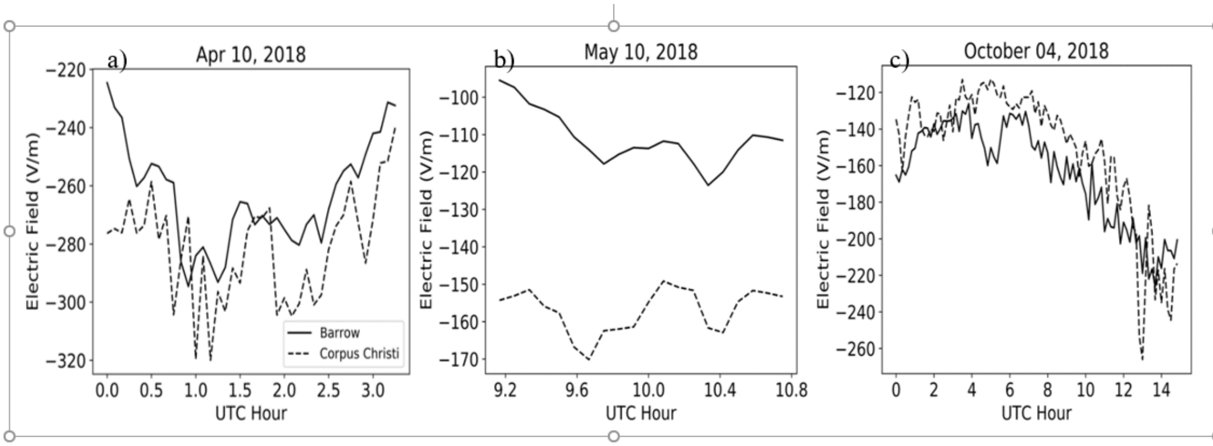

Figure 9. Comparison of simultaneous mathematically selected fair-weather from Corpus Christi (dashed) and Barrow (solid). All panels use a 5-minute averaged electric field. All data from Barrow are displayed using the top instrument (CS110-2).

2.1 Key Results

Some key results are summarized below:

- OYESNSA field campaign establishes much-needed electric field measurements in the Northern Hemisphere at a latitude of 71^{o}N.
- Preliminary results show remarkable similarities between the diurnal variations of fair-weather electric field at the North and South Poles, as well as the subtropics, indicating a truly global system.
- With the use of the calibration techniques, absolute electric field measurements are available. These absolute measurements can be compared to various other data sets such as cloud radar reflectivity, aerosol, and wind to understand the factors related to the local variation of electric field.
- Using the MP, a method for separating fair-weather from locally influenced electric field periods was created. Very similar inter-timestep variability was observed on the order of minutes to hours at the Barrow, Alaska and Corpus Christi, Texas sites. This further emphasizes the global nature of the system, and possibly allows for future real-time global cloud analysis.

2.2 Lessons Learned that Motivate Longer-Term Observations at NSA

- Because the fair-weather electric field is an indicator of the global electric circuit system, it may be used to monitor global thunderstorm activity. To make this a valuable measure, long-term consistent measurement is required. Based on the first 24 months of operation, we believe that it is possible to maintain relatively cheap CS110 measurements at the NSA station, and collect reliable long-term data continuously with slight effort. This is an important step toward establishing a reliable way to monitor the change of electric systems both locally in the Arctic, and globally from the GEC.
- Compared to the simultaneous electric field measurements at Corpus Christi, Texas, we have found cases showing consistent variations between two stations. This is a very encouraging result that may verify the unity of the global electric circuit, which has been a challenge to prove at the instantaneous perspective. Though further analysis is still needed to validate this result, this is already the most exciting result. Because of various local effects, there are only a handful of cases when fair-weather electric fields are obtained in the past two years. More samples from continued observations at the NSA site are needed to robustly build the relationship between two sites.
- Though two CS110s provided valuable measurements of the electric field at NSA most of the time, there were some complications during the first 24 months of the field campaign. For example, during spring and fall season, freezing rain has caused some problems to the instruments, and some data are not collected or have bad values during these periods. All these events could lead to sensitivity change of the instrument. Therefore, maintenance/calibration of the instruments are required every year or two.

3.0 Publications and References

3.1 Peer-Reviewed Journal Articles

Lavigne, T, C Liu, W Deierling, and D Mach. 2017. “Relationship between the global electric circuit and electrified cloud parameters at diurnal, seasonal and interannual timescales.” *Journal of Geophysical Research – Atmospheres* 122(16): 8525–8542, https://doi.org/10.1002/2016JD026442

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Lavigne, T, C Liu, J Hill, and E Bruning. 2020. “Observations from the One-Year Electric Field Study-North Slope of Alaska (OYES-NSA) field campaign, and their implications for observing the distribution of global electrified cloud activity.” *Bulletin of the American Meteorological Society*, in preparation.

3.2 Conference Presentations

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Lavigne, T, and C Liu. 2019. Observations from the One-Year Electric Field Study-North Slope of Alaska (OYES-NSA) field campaign, and their implications for observing the distribution of global electrified cloud activity.” Presented at the American Geophysical Union Fall Meeting. San Francisco, California.

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