Low-cost dropsonde development for multi-point measurement of thunderstorm electric fields

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Abstract

Thunderstorms are often described as consisting of three charge layers: upper positive, central negative, and lower positive. This simple charge structure is inferred from balloon-borne electric field measurements, however, they typically only provide information from a single moving point. Realistic charge structures in thunderclouds are expected to be more complicated than this tripole description for a variety of reasons, including non-trivial updraft geometry, turbulence, and charge deposition by lightning. In order to more fully measure such charge structures, we herein describe the development of an experiment composed of multiple low-cost electric field dropsondes. Each dropsonde consists of two pairs of electrodes where each pair has the electrodes on opposing sides of the device and connected to a differential charge amplifier. The enclosures for the dropsondes are designed so that they spin as they fall which induces charge motion and allows us to measure electric field strength. This electric field data will be transmitted to a ground station in real time along with GPS coordinates. By keeping instrument and recovery costs low, we aim to launch a single balloon payload carrying several of these instruments to drop at intervals to provide a multi-point map of electric field and infer associated charge structures inside a thunderstorm.

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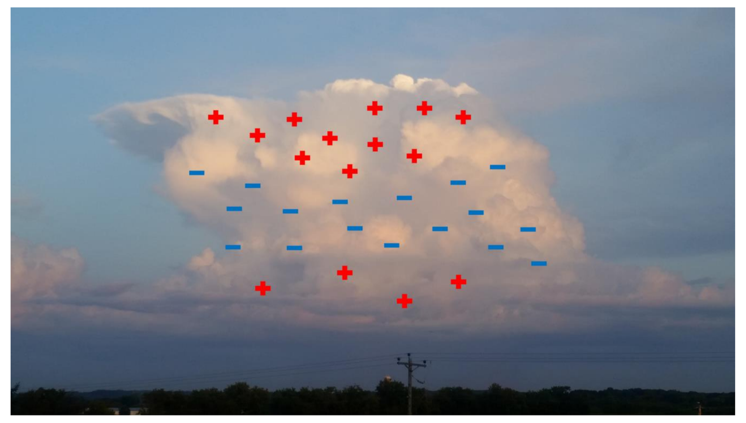
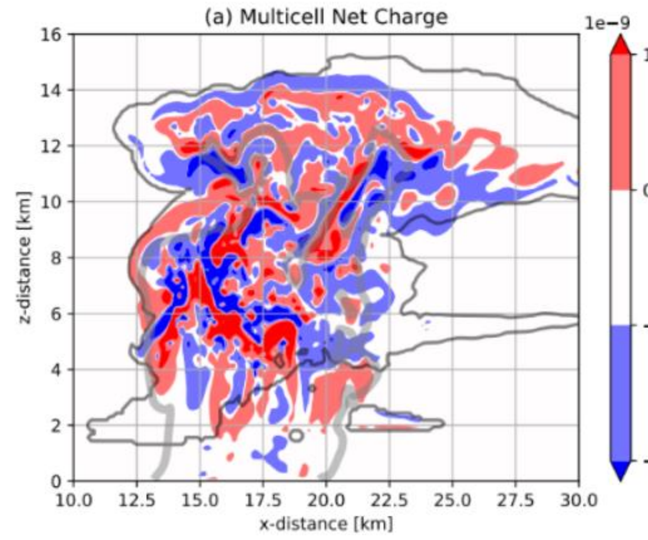
Introduction

The current understanding of the charge distribution inside thunderstorms is rather rudimentary. Single moving-point measurements, like that of balloon-borne electric field sensors, show that there are three typical charge layers: upper positive, central negative, and lower positive. However, this picture relies on the assumption that field changes are due to motion of the instrument, rather than time-variability of the charge structure. Realistic charge structures in thunderclouds are expected to be more complicated than this tripole description for a variety of reasons including non-trivial updraft geometry, turbulence, and charge deposition by lightning. The goal here is to go beyond single moving-point measurements by reducing costs and simplifying logistics to enable the launch of multiple instruments to map fields at multiple points as they evolve with time, thereby separating spatial structure and time evolution.

Depiction of a simplified charge distribution inside a thundercloud.



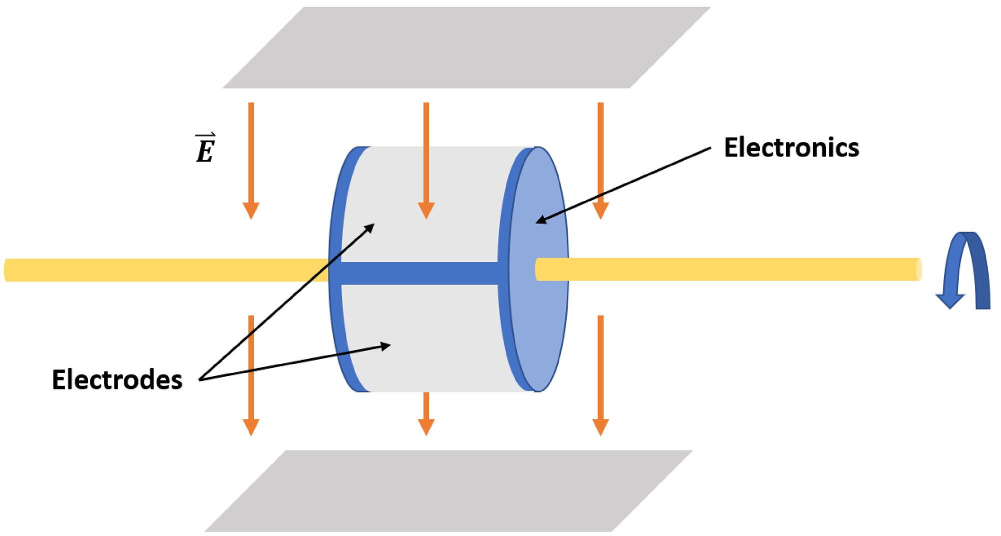
Vertical cross section of net charge density in thunderstorm simulation. (Figure 4a from Brothers et al., 2018)



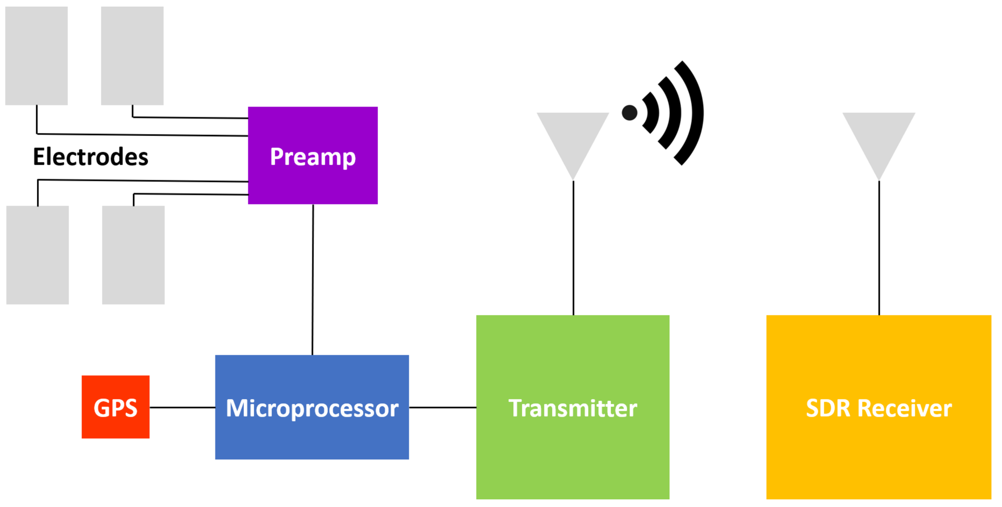
Dropsonde Concept

The instrument we are developing for multipoint soundings is a field mill dropsonde. Each dropsonde must consist of two pairs of electrodes, two differential charge amplifiers, a microprocessor, a GPS, an efficient telemetry system, and an enclosure that spins with its axis parallel to Earth's surface as it falls. The overall price of the instrument is less than $100.

Spinning measurement concept.



Electric field dropsonde functional block diagram.



Instrument Development

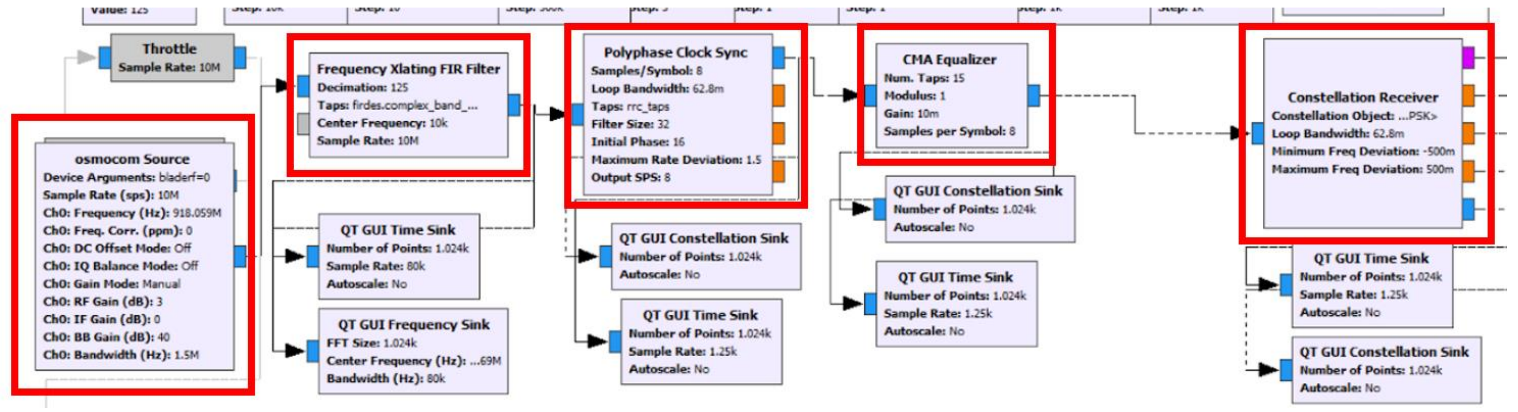
Transmission system details:

- BPSK modulation of 915 MHz ISM band carrier frequency
- Hamming (7,4) correction code
- Packet contents: GPS coordinates, time, maximum and minimum analog to digital converter (ADC) readings, mean, variance, and a few individual samples
- Main loop: check GPS for valid NMEA strings, fill packet with measurements, check GPS again, fill packet with GPS coordinates and time, transmit packet
- Preliminary range testing at ground level showed plenty leftover SNR at 3 km

The first order of business for the summer was developing the telemetry system to a functional level so that we can actually see the data that is collected. This meant creating a software defined radio receiver that could minimize packet error rate. This was done using GNU Radio Companion. Being amateur electrical engineers, we followed tutorials in order to create the receiver flowgraph below. It accomplished the following objectives:

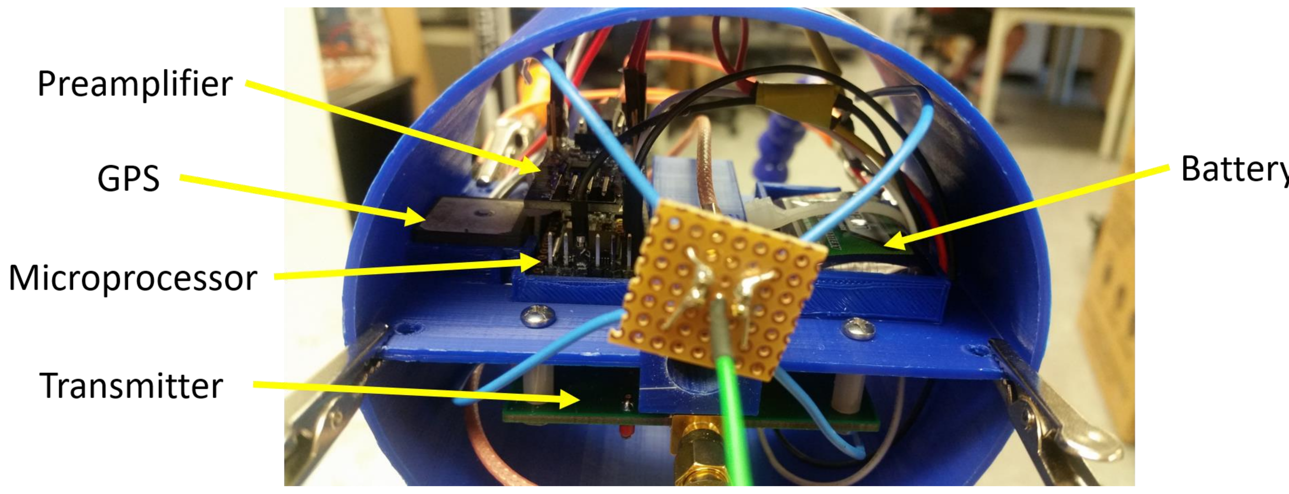
- Minimize inter-symbol interference
- Recover timing, frequency, and phase
- Demodulate the BPSK transmitted signal

Main blocks of receiver flowgraph.

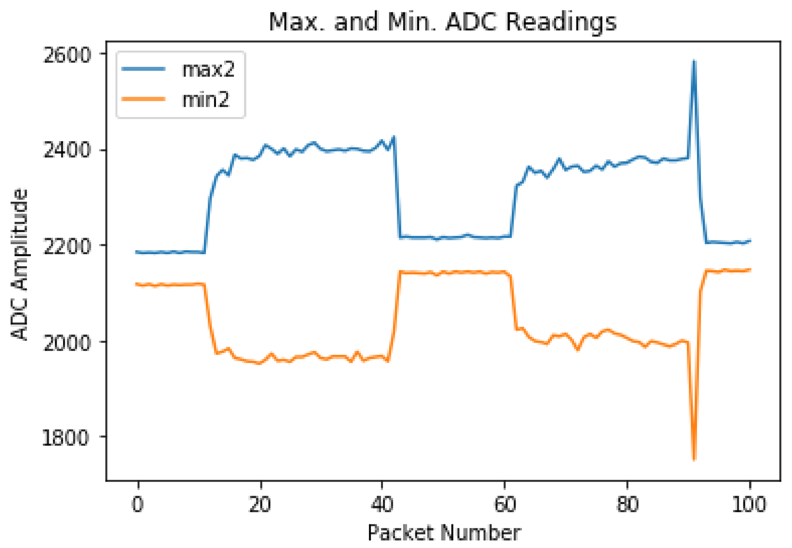


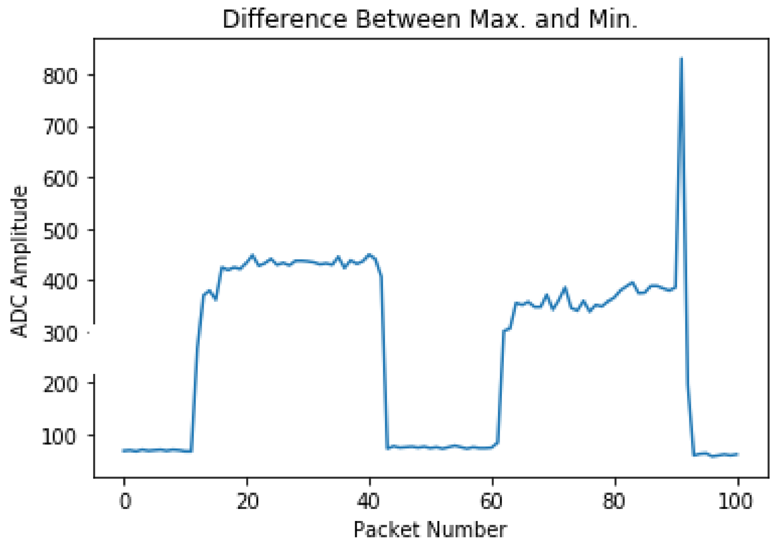
The blue 3D printed mount in the figure below is a spinnable prototype created to house the electronics while testing. It was designed so that the mass of the components was distributed as evenly as possible and electrodes could be mounted to the outside of the device. With working data acquisition and telemetry systems, as well as a mount that could spin, we were able to finally gather data which exhibited expected behavior.

Electric field dropsonde spin test prototype.



First sensible spin test data.

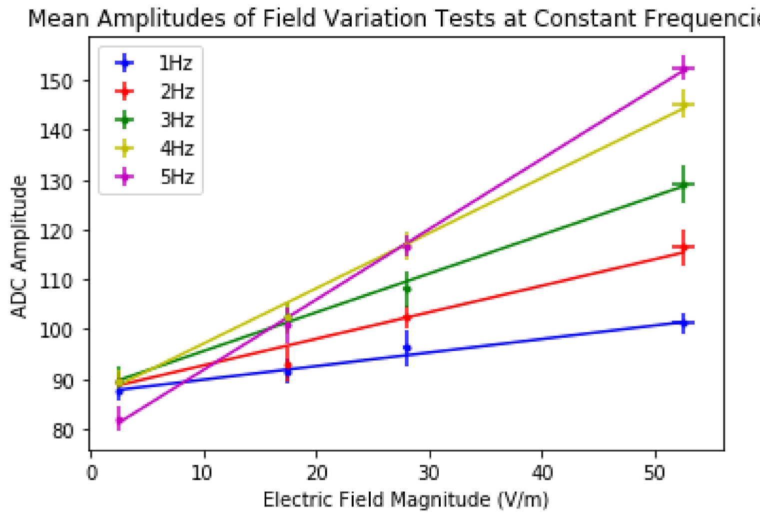


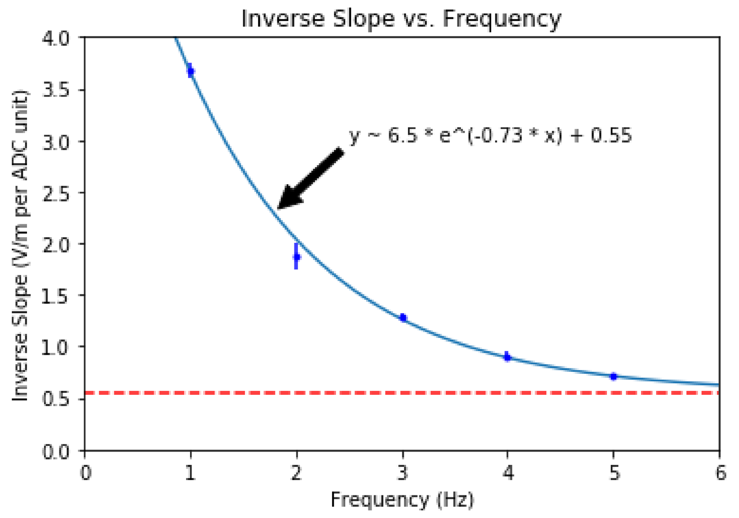


Preliminary Calibration

- 12 bit ADC (2^12 values)
- Parallel plate calibration set-up
- AC electric field instead of spinning (controlled frequency)
- Vary frequency and amplitude
- Record and analyze results

The plot on the left is of average differences between maximum and minimum ADC values sampled during four different E-field magnitudes for each constant frequency test. The plot to the right is of the inverse slopes of the linear fits from plot on the left versus frequency. The results indicate that the conversion factor varies more strongly with frequency at lower frequencies. We would like to keep the frequency variation as minimal as possible to reduce uncertainty in measured E-field values, but we expect the dropsondes to be spinning upwards of 3 Hz.

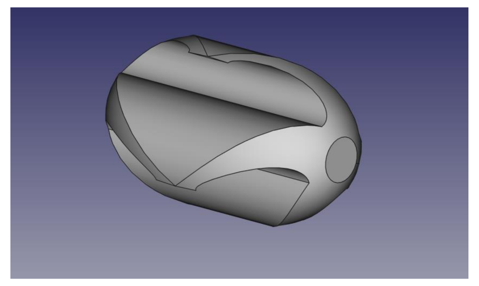




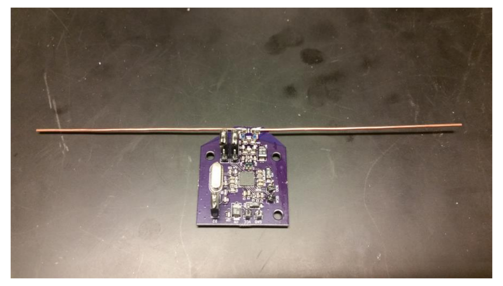
On-going Development

- Improve transmitter
- Self-contained enclosure design and fabrication; integration and balancing
- Spin/drop testing
- Temperature range testing
- Telemetry range testing
- More complete calibration with revised calibration set-up
- Multiple instrument telemetry testing
- Balloon payload design and fabrication

Drop test enclosure design.



Miniaturized and modified transmitter.



Conclusion

Creating low-cost dropsondes for multipoint measurement of electric field is a feasible and new experimental approach to data gathering in thunderstorm electrification research.

Acknowledgements

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References:

Brothers, Matthew D., Eric C. Bruning, and Edward R. Mansell. "Investigating the Relative Contributions of Charge Deposition and Turbulence in Organizing Charge within a Thunderstorm." *Journal of the Atmospheric Sciences* 2018 (2018).